Infiltration

Introduction

Infiltration may be defined as the process by which water enters the ground and flows through the soil underneath. Infiltrated water first meets the soil moisture deficiency and then moves downwards to reach the groundwater table.

During precipitation, part of the rainfall reaching the ground surface enters the soil through infiltration. This process reduces the amount of water available as surface runoff. Hence, from surface water resources view point, infiltration is termed as a loss. However, for groundwater resources, infiltration is the main input.

- Infiltration rate: The *existing* rate at which water flows through a given soil at a given time is termed as infiltration rate, f , in cm/h.
- Infiltration Capacity: The *maximum* rate at which a given soil at a given time can absorb water is defined as infiltration capacity, f_c, in cm/h.

Relationship

Relation between rainfall intensity i, infiltration capacity f_c and infiltration rate f

If the rainfall intensity is less than the infiltration capacity, then the entire amount of rainfall will be absorbed by the soil. Hence the infiltration rate will be equal to the rainfall intensity. No water will be available for surface runoff.

However, if the rainfall intensity is more than the infiltration capacity, then the soil will absorb water at the maximum rate and the remaining amount will flow as surface runoff. Hence the infiltration rate will be equal to the infiltration capacity. In other words,

$f = i$	when $i < f_c$	No surface runoff
$f = f_c$	when $i \geq f_c$	$i - f_c$ = surface runoff

Factors Affecting

Infiltration capacity of a soil is affected by a number of factors.

- Soil characteristics
- Compaction
- Surface cover
- Soil moisture
- Depth of surface detention
- Thickness of saturated layer
- Temperature
- Water quality

Measurement of Infiltration

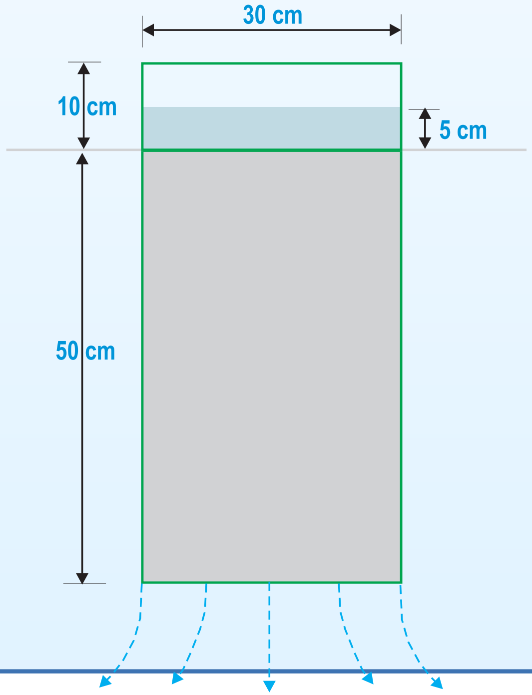
Instrument used to measure infiltration is known as infiltrometer. These are of two types

1. Flooding type infiltrometer
2. Rainfall simulator

Flooding type infiltrometer

1. Simple Infiltrometer of Tube Infiltrometer

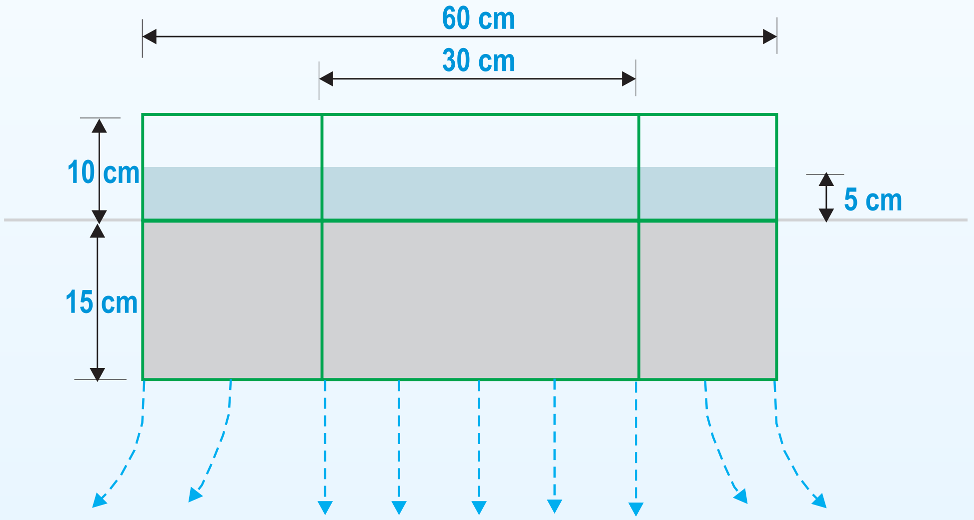
This instrument consists of a metal cylider, 30 cm diameter and 60 cm long, open at both ends. It is driven into the ground to a depth of 50 cm. The surface of the soil inside the ring is protected by a covering it with a perforated metal dish. Water is poured from the top to a depth of 5 cm over the soil surface. A pointer is set inside the ring to mark the water level. As infiltration proceeds, water level decreases Water is quickly added to maintain the water level at the marker. Knowing the volume of water added at different time intervals, the plot of infiltration capacity vs time is obtained. The observations are continued till a uniform infiltration rate is obtained. It may take 2 to 6 hours depending on the soil type.



Flooding type infiltrometer

2. Double Ring Infiltrometer

A Major drawback of the simple infiltrometer is that the infiltrated water spreads at the outlet from the tube. Hence, the tube area is not the true representative of area through which infiltration takes place. To avoid this problem *double ring infiltrometer* is used.



Double ring infiltrometer consists of two concentric metal cylinders driven into the soil upto a depth of 15 cm. Water is poured in both the rings from the top. Water is maintained at the same level in both the rings. Outer ring prevents the spreading out of the infiltering water of the inner tube. Measurements of water volume applied are done for the inner ring only.

Example 1

An infiltration test on a ring with 30 cm diameter yielded the following data.

Time from start (min)	0	2	5	10	20	30	60	90	150	210
Vol. of water added (cm^3)	0	278	658	1173	1924	2500	3345	3875	4595	5315

a) Determine the infiltration capacity rates for the times intervals in the experiment. b) What is the final infiltration capacity? c) What is the average infiltration capacity for the first 10 minutes and for the first 30 minutes of the experiment?

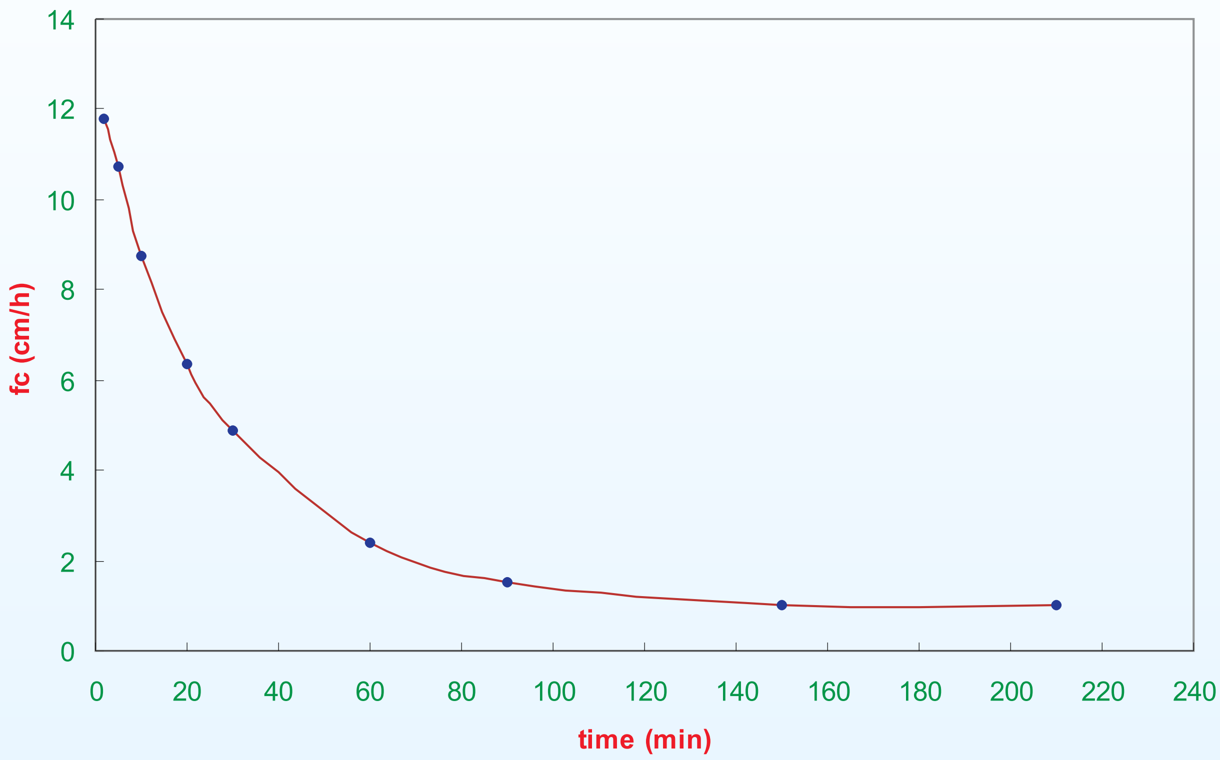
Solution:

Area of the ring, $A = \pi D^2/4 = \pi \times 30^2/4 = 706.859$ cm^2

i) Calculate Δt ; ii) Calulate ΔV ; iii) Calculate $\Delta F = \Delta V/A$; iv) Calculate $f_c = \Delta F/\Delta t$

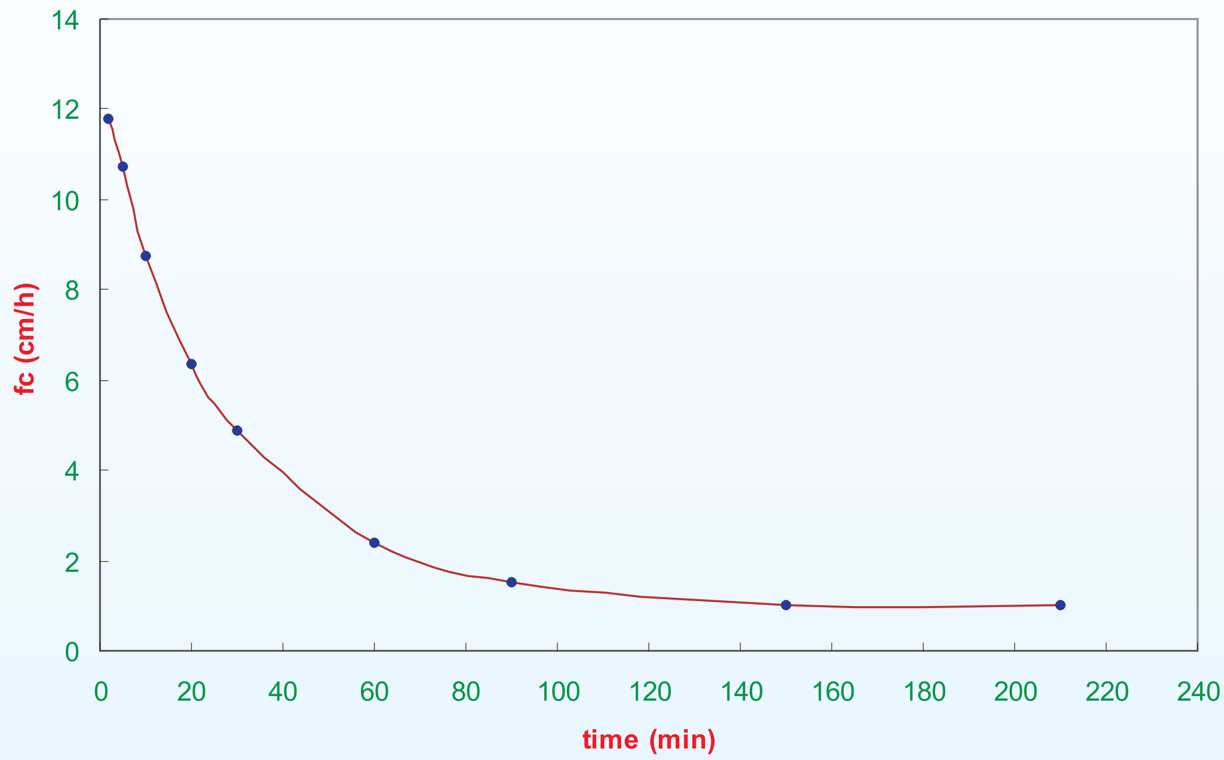
Time from start (min)	0	2	5	10	20	30	60	90	150	210
Vol. of water (cm^3)	0	278	658	1173	1924	2500	3345	3875	4595	5315
Δt(h)	-	0.033	0.05	0.083	0.167			0.50		1.0
ΔV (cm^3)	-	278	380	515	751				720	
ΔF (cm)	-	0.393				0.815				1.019
f_c(cm/h)	-		10.75		6.375				1.019	

Solution



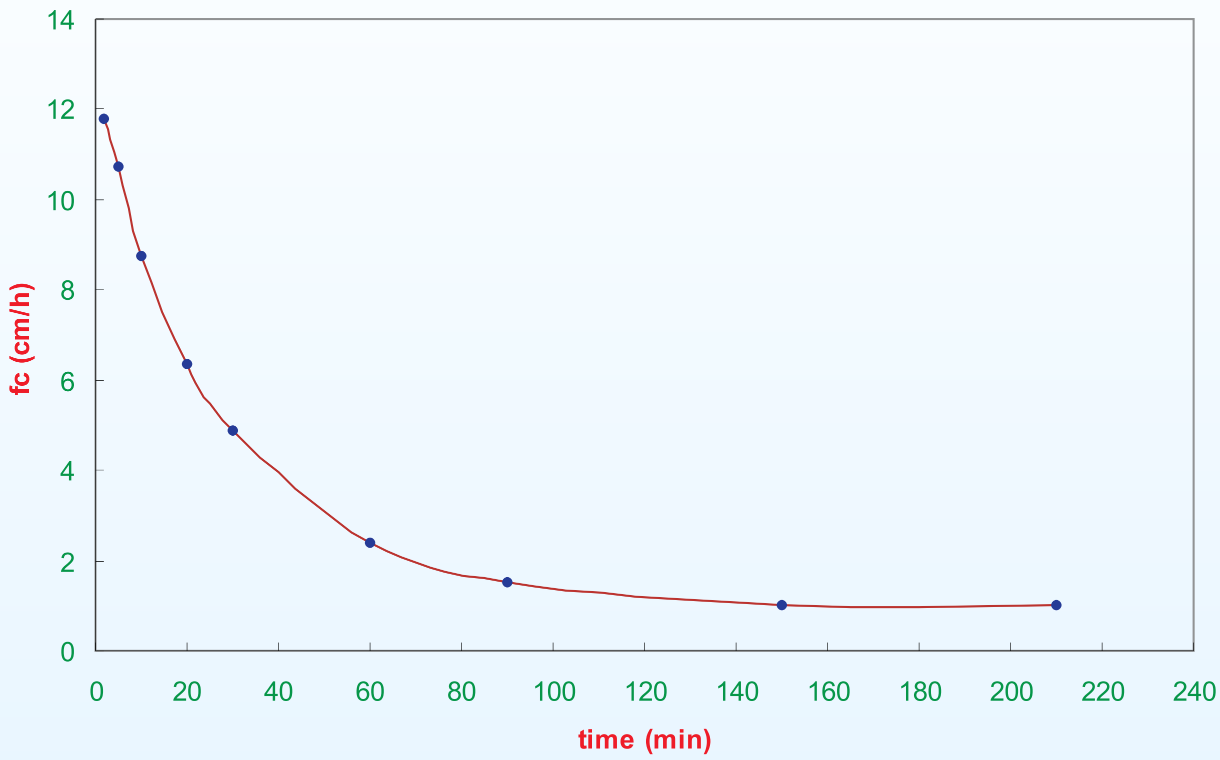
Final infiltration capacity =

Solution



Final infiltration capacity = 1.019 cm/h

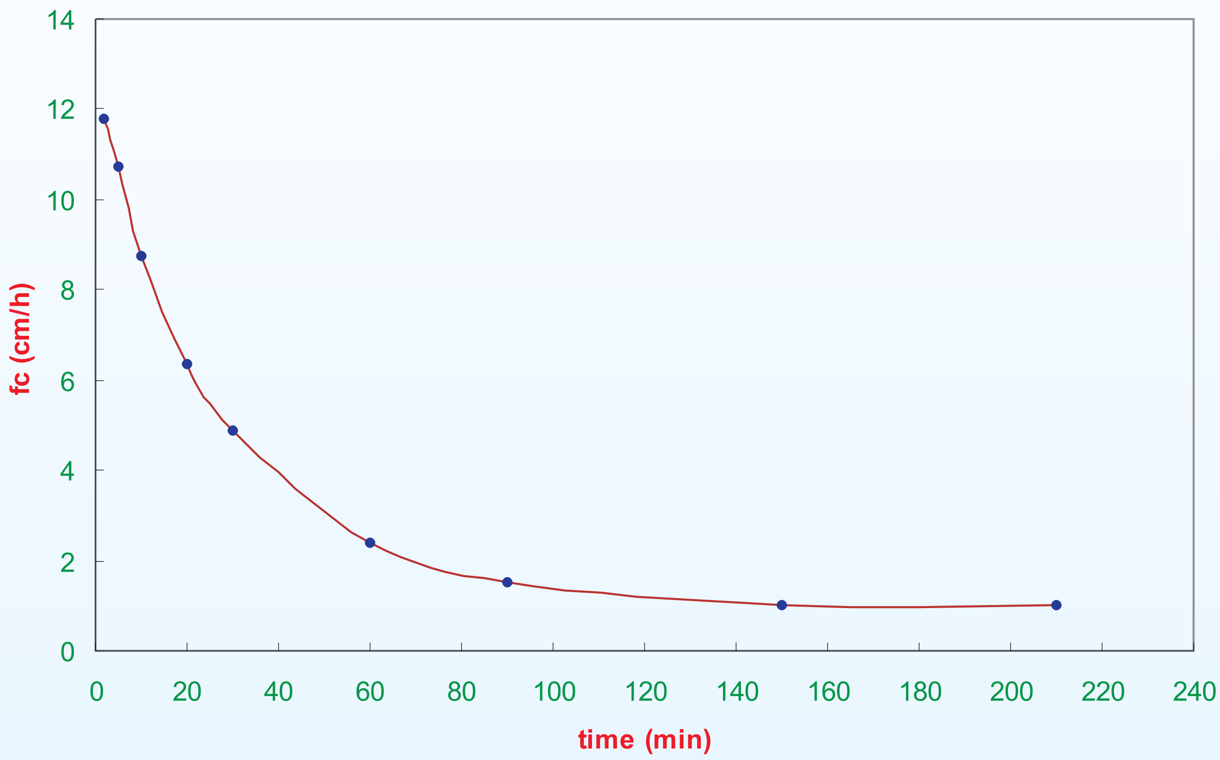
Solution



Final infiltration capacity = 1.019 cm/h

Average infiltration rate for the first 10 minutes =

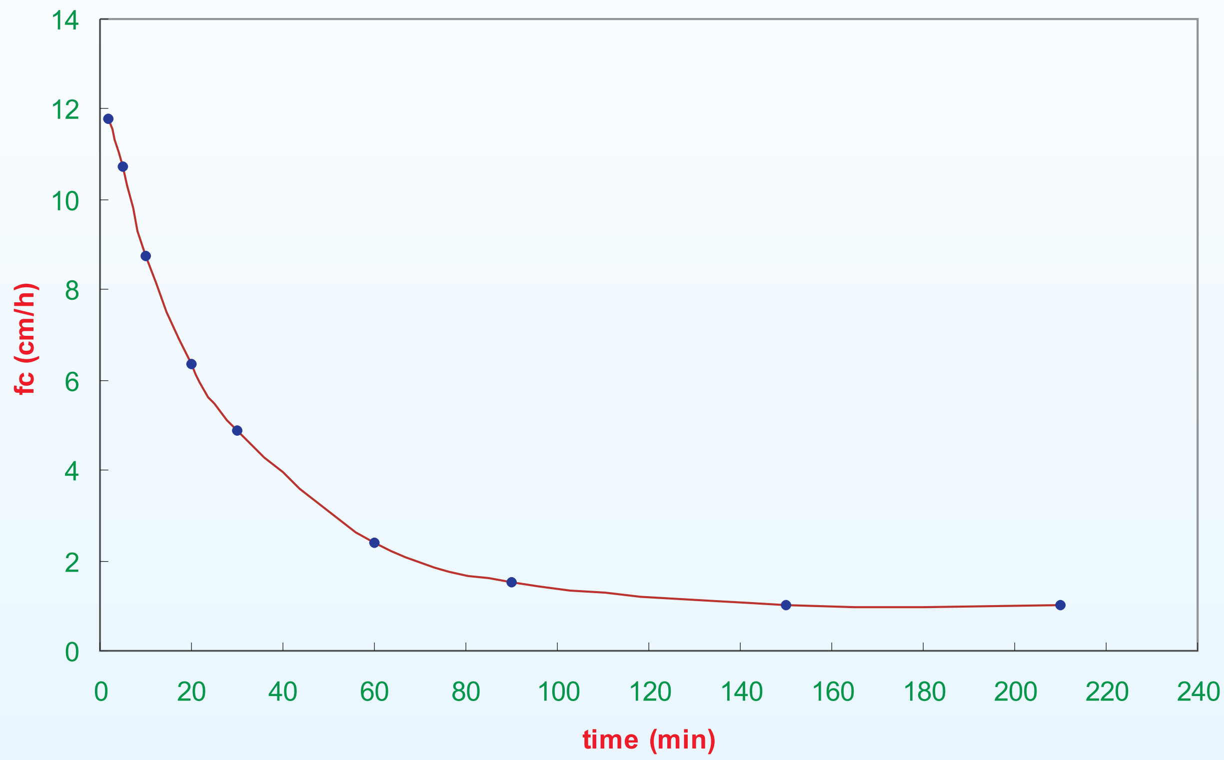
Solution



Final infiltration capacity = 1.019 cm/h

Average infiltration rate for the first 10 minutes = [(1173 - 0) / A] / (10/60) =

Solution



Final infiltration capacity = 1.019 cm/h

Average infiltration rate for the first 10 minutes = [(1173 - 0) / A] / (10/60) = 9.956 cm/h

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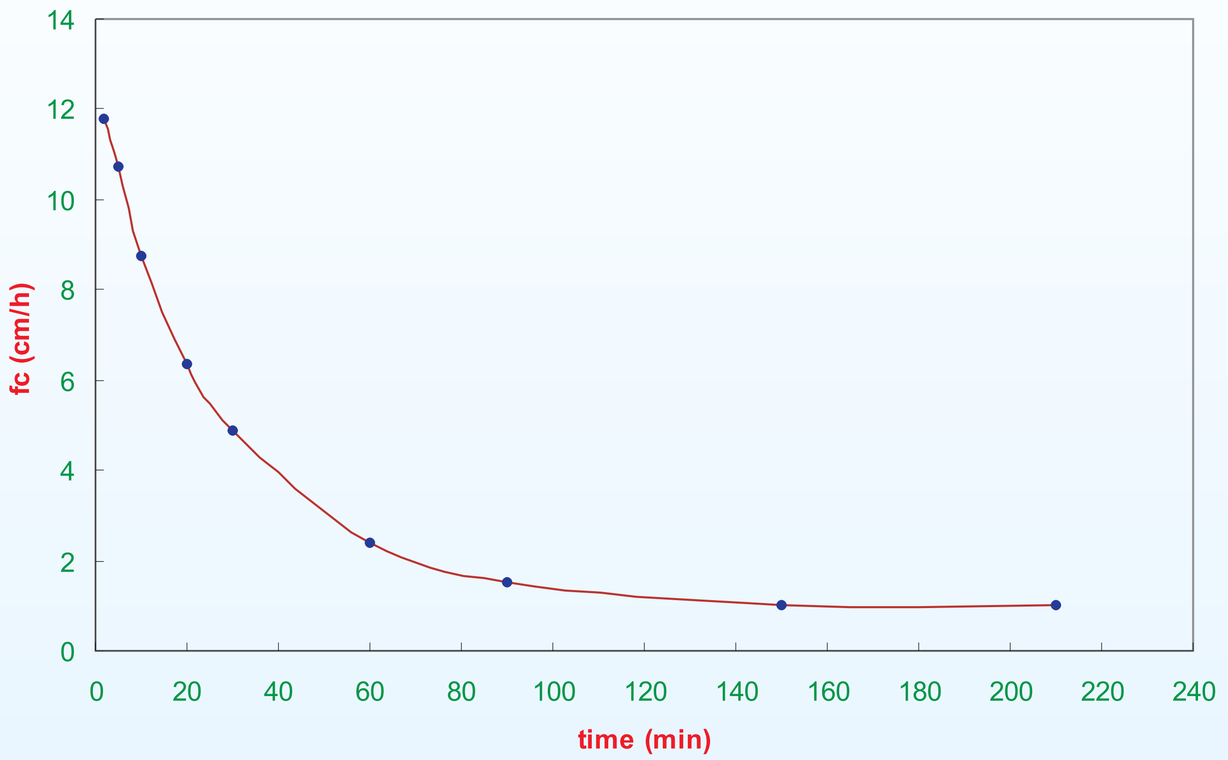

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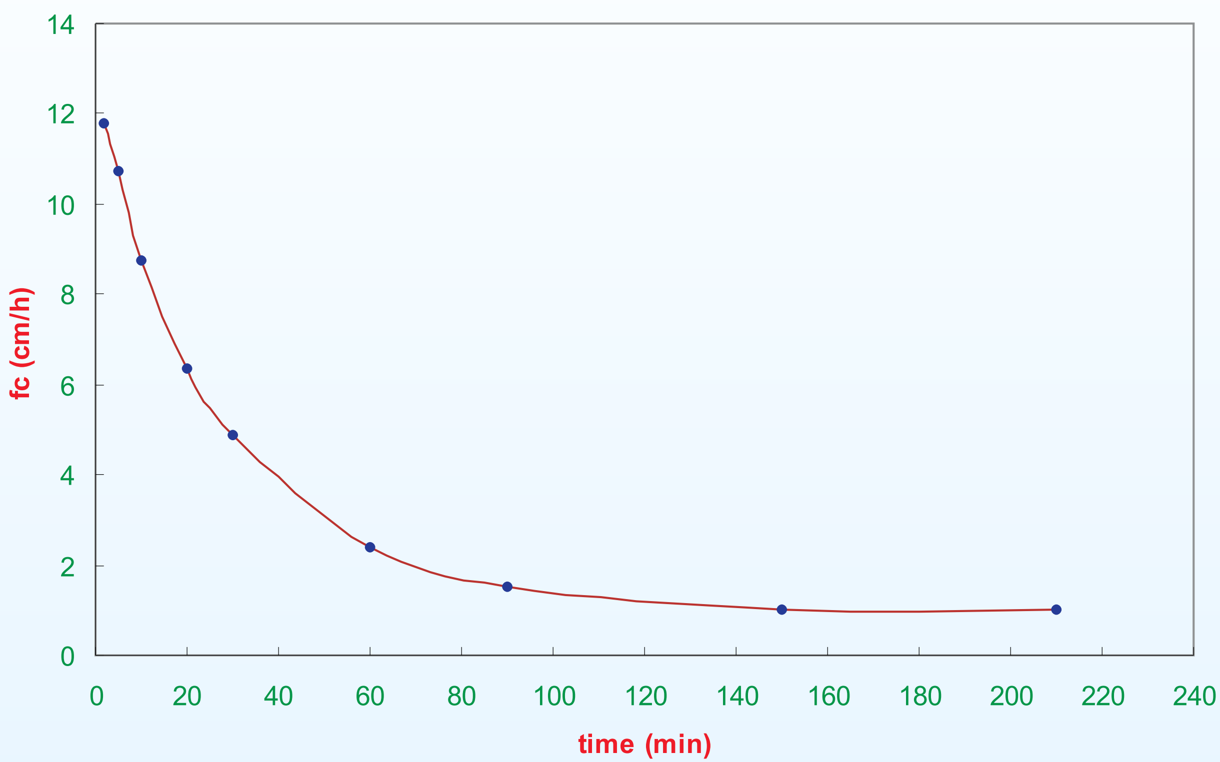
Average infiltration rate for the first 30 minutes =

Solution



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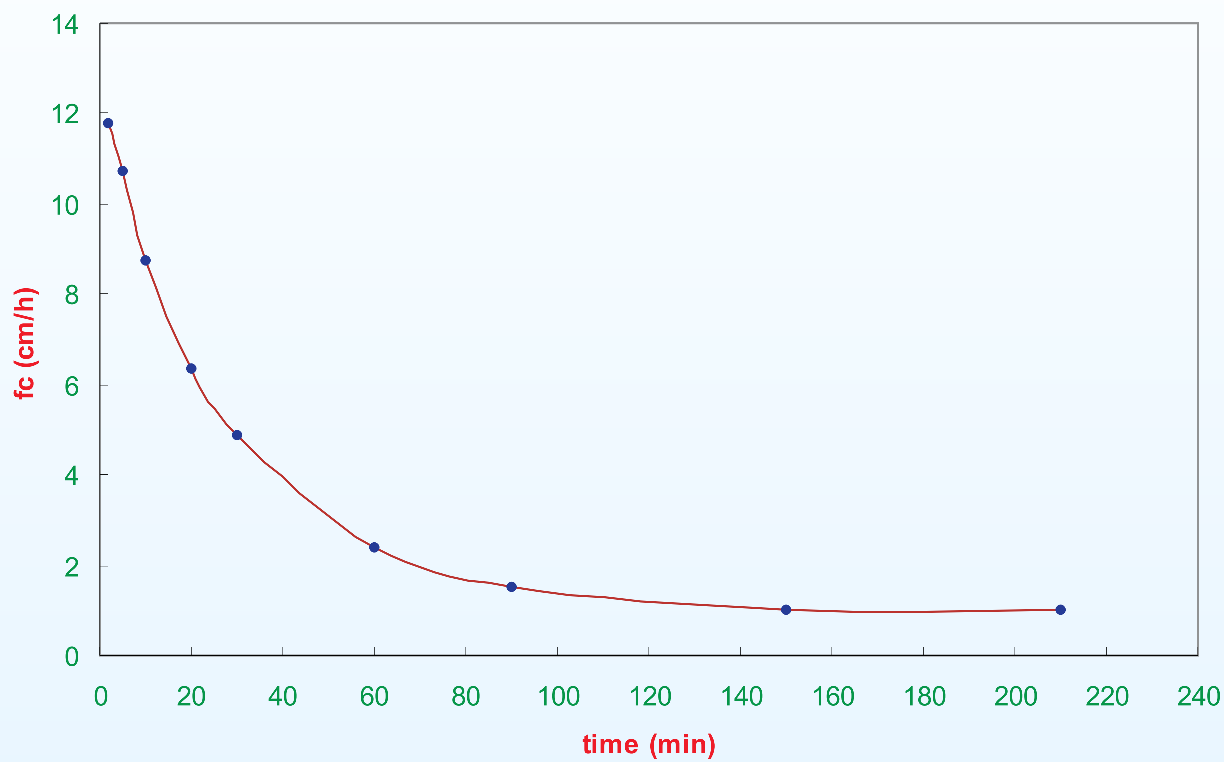
Average infiltration rate for the first 30 minutes = [(2500 - 0) / A] / (30/60) =

Solution



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Average infiltration rate for the first 10 minutes = [(1173 - 0) / A] / (10/60) = 9.956 cm/h

Average infiltration rate for the first 30 minutes = [(2500 - 0) / A] / (30/60) = 7.074 cm/h

Horton's Equation

Horton (1930) suggested the following equation for the infiltration capacity curve:

$$f_{ct} = f_{cf} + (f_{c0} - f_{cf})\, e^{-Kt} \qquad \text{for } 0 \le t \le t_d$$

where,

f_{ct} = infiltration capacity at any time t from start of rainfall

f_{c0} = initial infiltration capacity at $t = 0$

f_{cf} = final value of infiltration capacity

t_d = duration of rainfall

K = a constant depending on the soil characteristics and vegetation cover (unit h^{-1})

Usually, it is difficult to estimate the values of f_{c0}, f_{cf} and K.

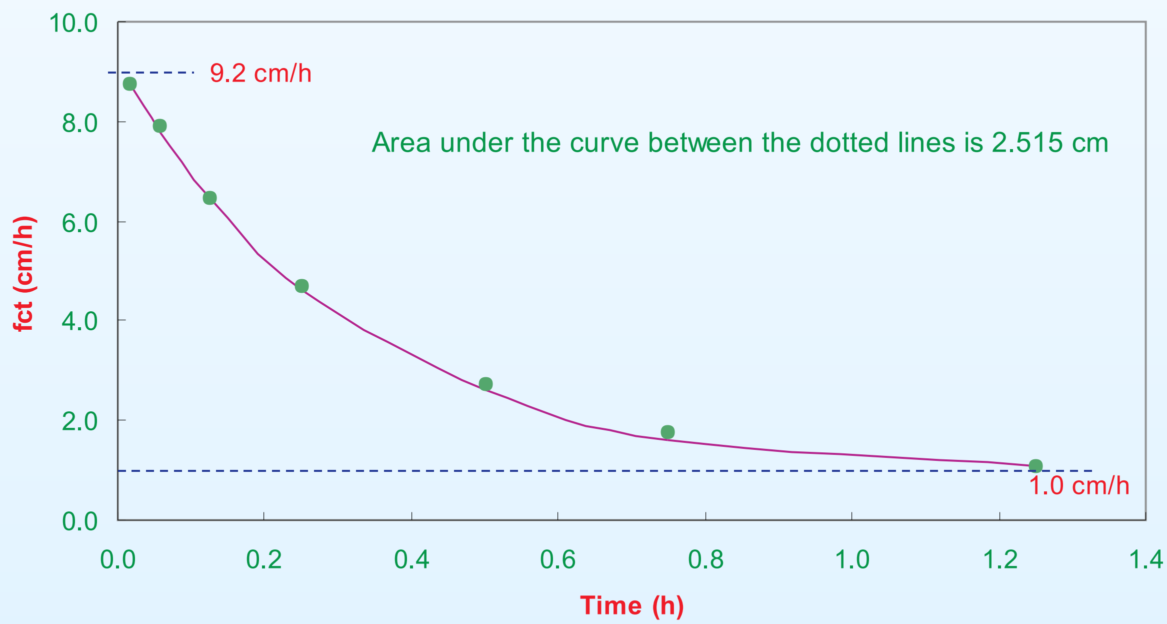
Example 2

From a double ring infiltrometer the following infiltration rates were observed. Determine the constants f_{c0}, f_{cf} and K of Horton's equation.

Time (h)	0.0167	0.0583	0.125	0.25	0.50	0.75	1.25
f_{ct} (cm/h)	8.76	7.90	6.45	4.68	2.75	1.76	1.10

Solution:

The above data is plotted on an arithmetic graph paper.



Infiltration Capacity Curve

Solution

From the graph, values of f_{c0} and f_{cf} are obtained as 9.2 cm/h and 1.0 cm/h respectively.

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$$f_{ct} = f_{cf} + (f_{c0} - f_{cf})\, e^{-Kt}$$

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It can be re-written as

$$(f_{ct} - f_{cf}) = (f_{c0} - f_{cf})\, e^{-Kt}$$

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So, $K = (f_{c0} - f_{cf})/F_c = (9.2 - 1.0)/2.515 = 3.26$ /h

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Hence, the equation of the infiltration capacity curve is

$$f_{ct} = 1.0 \,+\, 8.2\, e^{-3.26t}$$

Question 1

The cumulative depth of infiltration in an experiment on a tube infiltrometer is observed to follow the equation $F = 0.165\,t^{0.65}$, where F is cumulative infiltration in cm and t is in minutes. Determine the equation for infiltration capacity and the average infiltration rate.

(Hint: Calculate dF/dt for equation. For f_{av}, calculate F/t)

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Solution:

$$f_{ct} = 1.5353\, t^{-0.35}; \quad f_{av} = 2.362\, t^{-0.35}$$

Question 2

The Horton's infiltration equation for a basin is given by $f_{ct} = 6 + 16\,e^{-2t}$, where f_{ct} is in mm/h and t is in h. What are the values of f_{c0}, f_{cf} and K ? If a storm occurs on this basin with an intensity of more than 22 mm/h, determine the depth of infiltration for the first 45 minutes and the average infiltration rate for the first 75 minutes.

(Hint: Integrate f_{ct} between 0 to t to get F_t. Determine $f_{av}$from F_t/t)

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(Hint: Integrate f_{ct} between 0 to t to get F_t. Determine f_{av} from F_t/t)

Solution:

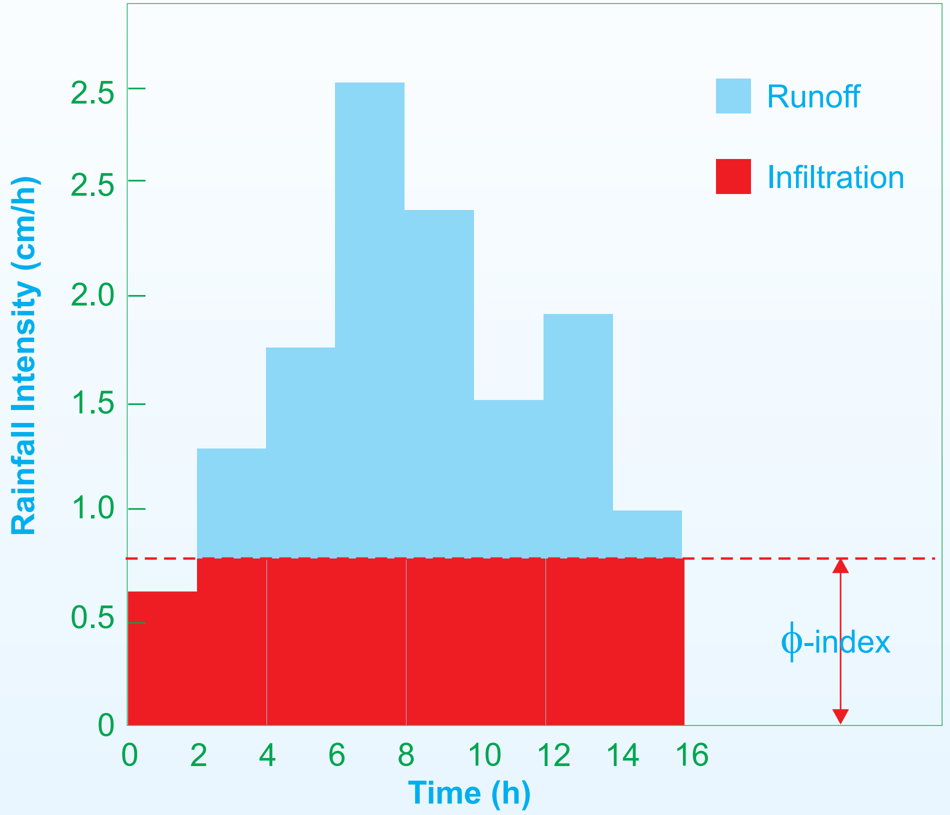
F = 10.715 cm and f_{av} = 11.874 cm/h.

Infiltration Indices

In flood hydrograph studies, it is convenient to use a constant, average value of infiltration loss for the duration of the storm, instead of an exponentially decaying infiltration capacity curve. The average infiltration rate is known as *infiltration index*. It assumes a lower infiltration loss at the beginning of the storm and a higher value at the end of the storm, which is actually opposite of the real situation.

Two types of infiltration index are in use: ϕ - index and W - index.

ϕ - Index



ϕ - index is defined as the average rainfall intensity above which rainfall volume is equal to runoff volume. It is derived from the hyetograph of a known storm and resulting runoff, using the following equation

$$\phi = (P - R)/t_e$$

P = Total depth of precipitation; R = Depth of runoff; t_e = Effective duration, during which runoff occurred.

ϕ - Index

Note:

- In deriving ϕ - index from rainfall hyetograph, it is treated as a constant infiltration loss.
- If the rainfall intensity i is less than ϕ, then infiltration rate is equal to i and there is no runoff.
- If rainfall intensity i is more than ϕ, then infiltration rate is equal to ϕ and $(i - \phi) \times \Delta t$ is the runoff during Δt.
- ϕ - index includes initial losses alongwith infiltration loss.

Example 1

A storm with 10.0 cm precipitation produced a direct runoff of 5.8 cm. Mass curve of this storm is given below. Estimate the ϕ - index of the storm.

Time (h)	0	1	2	3	4	5	6	7	8
Cum. Rainfall (cm)	0	0.4	1.3	2.8	5.1	6.9	8.5	9.5	10.0

Solution

Here P = 10.0 cm and R = 5.8 cm. First estimate the rainfall intensities.

Time (h)	0	1	2	3	4	5	6	7	8
Cum. Rainfall (cm)	0	0.4	1.3	2.8	5.1	6.9	8.5	9.5	10.0
Inc. Rainfall (cm)	-	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5
Rainfall Intensity (cm/h)	-	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5

1st trial:

Let us assume, t_e = duration of the storm = 8 h. That is, runoff occurred throughout the duration of the storm.

Then, ϕ = (10.0 - 5.8)/8 = 0.525 cm/h. But looking at the table above, it is observed that rainfall intensities in the first hour (0.4 cm/h) and last hour (0.5 cm/h) are less than ϕ = 0.525 cm/h. So, there will be no runoff during these two hours. Hence, t_e = (8 - 2) = 6 h and net loss during this duration is (10.0 - 5.8 - 0.4 $\times$1 - 0.5$\times$1) cm = 3.3 cm

2nd Trial:

ϕ = (10.0 - 5.8 - 0.4$\times$1 - 0.5$\times$1)/6 = 0.55 cm/h. This value of ϕ is less than all rainfall intensity values during 2h to 7 h. So, runoff will occur and assumption of t_e = 6h is correct. Hence the value of ϕ is 0.55 cm/h.

Questions

Question 1

The rainfall on five successive days on a catchment were 2, 6, 9, 5 and 3 cm. If the ϕ - index for the storm can be assumed as 3 cm/day, find the total surface runoff.

Answer:

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Question 2

The mass curve of rainfall of duration 100 min. is given below. If the catchment had an initial loss of 0.6 cm and a ϕ - index of 0.6 cm/h, calculate the total surface runoff from the catchment.

Time from start (min)	0	20	40	60	80	100
Cumulative rainfall (cm)	0	0.5	1.2	2.6	3.3	3.5

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Time from start (min)	0	20	40	60	80	100
Cumulative rainfall (cm)	0	0.5	1.2	2.6	3.3	3.5

Answer: 2.5 cm

Questions

Question 1

The rainfall on five successive days on a catchment were 2, 6, 9, 5 and 3 cm. If the ϕ - index for the storm can be assumed as 3 cm/day, find the total surface runoff.

Answer: 11.0 cm

Question 2

The mass curve of rainfall of duration 100 min. is given below. If the catchment had an initial loss of 0.6 cm and a ϕ - index of 0.6 cm/h, calculate the total surface runoff from the catchment.

Time from start (min)	0	20	40	60	80	100
Cumulative rainfall (cm)	0	0.5	1.2	2.6	3.3	3.5

Answer: 2.5 cm

Time from start (min)	0	20	40	60	80	100
Cumulative rainfall (cm)	0	0.5	1.2	2.6	3.3	3.5
Inc. Rainfall (cm)	-	0.5	0.7	1.4	0.7	0.2
Rainfall Intensity (cm/h)	-	1.5	2.1	4.2	2.1	0.6
ϕ- index (cm/h)	-	0.6	0.6	0.6	0.6	0.6
Runoff (cm)	-	0.3	0.5	1.2	0.5	0

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Question 3

An isolated 3-h storm occurred over a basin in the following fashion. Estimate the runoff from this catchment.

% of catchment area	ϕ- index (cm/h)	Rainfall (cm)		
		1st hour	2nd hour	3rd hour
20	1.00	0.8	2.3	1.5
30	0.75	0.7	2.1	1.0
50	0.50	1.0	2.5	0.8

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Answer: 2.24 cm

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Answer: 2.24 cm

Question 4

An isolated storm in a catchment produced a runoff of 3.5 cm. The mass curve of the average rainfall depth over the catchment was as below. Calculate the ϕ - index for the storm.

Time (h)	0	1	2	3	4	5	6
Acc. rainfall (cm)	0.0	0.50	1.65	3.55	5.65	6.80	7.75

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Time (h)	0	1	2	3	4	5	6
Acc. rainfall (cm)	0.0	0.50	1.65	3.55	5.65	6.80	7.75

Answer: 0.75 cm/h

W-Index

W-index is a modified version of ϕ - index, where initial losses are separated from the total loss. It is defined as

$$W = \frac{P - R - I_a}{t_e}$$

where, P = total precipitation in cm; R = total runoff in cm; I_a = initial abstractions in cm and t_e = duration of rainfall excess, during which runoff occurred.