

WRE

Hydrology

Example 3.2.1

At a climate station, air pressure is measured as 100 kPa, air temperature at 20°C and the wet bulb, or dew point temperature as 16°C . Calculate the corresponding vapor pressure, relative humidity, specific humidity and air density.

Solution:

Here,

$$P_a = 100 \text{ kPa}$$

$$T = 20^{\circ}\text{C}$$

$$T_d = 16^{\circ}\text{C}$$

Gas constant for dry air, $R_d = 287 \text{ J/kg}\cdot\text{K}$

Saturated vapor pressure at dew point

= Actual vapor pressure at
air temp

Now,

actual vapour pressure

$$e = 611 \exp\left(\frac{17.27 T_d}{237.3 + T_d}\right)$$

$$= 611 \exp\left(\frac{17.27 \times 16}{237.3 + 16}\right)$$

$$= 1819 \text{ Pa}$$

[T_d must be in Degree Celsius
and pressure in Pascal]

Saturated vapour pressure,

$$e_s = 611 \exp\left(\frac{17.27 T}{237.3 + T}\right)$$

$$= 611 \exp\left(\frac{17.27 \times 20}{237.3 + 20}\right)$$

$$= 2339 \text{ Pa}$$

Relative humidity

$$RH = \frac{e}{e_s}$$

$$= \frac{1819}{2339}$$

$$= 0.78$$

$$= 78\%$$

Specific humidity

$$q_v = 0.622 \frac{e}{p}$$

$$= 0.622 \times \left(\frac{1819}{100 \times 10^3} \right)$$

$$= 0.0113 \text{ kg/kg moist air}$$

the gas is constant,

$$R_a = R_d (1 + 0.608 q_v)$$

$$= 287 (1 + 0.608 \times 0.0113)$$

$$= 289 \text{ J/kg.K}$$

air density, $\rho_a = \frac{p_a}{R_a T}$

$$= \frac{100 \times 10^3}{289 \times (273 + 20)}$$

$$= 1.18 \text{ kg/m}^3$$

Here, T must be in Kelvin

2012-13

3(b)

The relative humidity and saturation pressure are computed to be 70% and 2400 Pa respectively. Assuming standard air pressure, find out the following.

- i) air temperature
- ii) actual vapour pressure at air temp.
- iii) dew point temperature
- iv) specific humidity
- v) density of moist air

Solution:

$$R_h = 70\%$$

$$e_s = 2400 \text{ Pa}$$

$$R_h = \frac{e}{e_s}$$

$$\Rightarrow 0.7 \times e_s = e$$

$$\Rightarrow e = 0.7 \times 2400$$

$$= 1680 \text{ Pa}$$

$$2400 = 611 \exp\left(\frac{17.27 T}{237.3 + T}\right)$$

$$\Rightarrow 3.928 = \exp\left(\frac{17.27 T}{237.3 + T}\right)$$

$$\Rightarrow \ln(3.928) = \frac{17.27 T}{237.3 + T}$$

$$\Rightarrow 1.368 = \frac{17.27 T}{237.3 + T}$$

$$\Rightarrow 324.65 + 1.368 T = 17.27 T$$

$$\Rightarrow T = 20.42^\circ$$

$$\therefore \text{air temp.} = 20.42^\circ$$

$$1680 = 611 \exp\left(\frac{17.27 T_d}{237.3 + T_d}\right)$$

$$\Rightarrow T_d = 14.76^\circ \text{C}$$

$$\therefore \text{dew point temp.} = 14.76^\circ \text{C}$$

$$\text{specific humidity, } q_v = 0.622 \frac{e}{p}$$

$$= 0.622 \times \frac{1680}{101.325 \times 10^3}$$

$$= 0.0103 \text{ kg water / kg moist air}$$

density of moist

air,

$$\rho_a = \frac{p}{R_a T}$$

$$= \frac{101.325 \times 10^3}{R_a \times 287 (1 + 0.608 \times 0.0103) \times (20.42 + 273)}$$
$$= 1.19 \text{ kg/m}^3$$

2006-07 7(d)

(Am.)

The air temperature is 20°C and the
dew-point temperature is 12°C . calculate
relative humidity and specific humidity.
Assume any reasonable value for
missing data.

Solution:

$$T = 20^\circ\text{C}$$

$$T_d = 12^\circ\text{C}$$

$$e_s = 611 \exp\left(\frac{17.27T}{237.3+T}\right)$$

$$= 611 \exp\left(\frac{17.27 \times 20}{237.3+20}\right)$$

$$= 2339 \text{ Pa}$$

$$e = 611 \exp\left(\frac{17.27 T_d}{237.3+T_d}\right)$$

$$= 611 \exp\left(\frac{17.27 \times 12}{237.3+12}\right)$$

$$= 1403 \text{ Pa}$$

$$\text{relative humidity, } RH = \frac{e}{e_s}$$

$$= \frac{1403}{2339}$$

$$= 59.98\%$$

$$= 60\%$$

$$\text{specific humidity, } q_v = 0.622 \frac{e}{p}$$

$$= 0.622 \times \frac{1403}{101.325 \times 1000}$$

$$= 0.0086 \text{ kg water/kg}$$

moist air

Problem - 2 Runoff

An urban area has a runoff coefficient of 0.30 and an area of 0.85 km². The slope of the catchment is 0.006 and the maximum length of travel of water is 950 m. The maximum length of travel of water is 950 m. The maximum depths of rainfall along with directions for a 25-year return period are given below:

Duration (min)	5	10	20	30	40	60
Max ^m Depth of Rainfall (mm)	17	26	40	50	57	62

Solutions

time of concentration

$$t_c (\text{min}) = 0.01948 L^{0.77} S^{-0.385}$$

$$= 0.01948 (950)^{0.77} \times (0.006)^{-0.385}$$

$$= 27.4 \text{ min}$$

time of concentration = duration of rainfall

By interpolation from the given data,

$$\text{maximum depth of rainfall} = 47.4 \text{ mm}$$

$$\therefore \text{Intensity of rainfall} = \frac{47.4}{27.4} \times 60$$

$$= 103.8 \text{ mm/h}$$

Peak discharge

$$Q_p = C_i A$$

$$= \frac{0.30 \times 103.8 \times 0.25}{3.6}$$

$$= 7.35 \text{ m}^3/\text{s}$$

Q(c)

The design precipitation intensity for a storm with a T -year return period with of 0.00425 and maximum length of travel of water of 1100 m for the catchment is 31 mm/hr. Estimate the design period (T). Also estimate the design precipitation volume (m^3) as well. Also find out the design peak discharge (m^3/s) using rational method for catchment. The area of catchment is 2 km^2 and runoff coefficient is 0.5. Use the IDF curves (fig 1.) and Kirpich formula for your estimation.

Solutions

$$S = 0.00425$$

$$L = 1100 \text{ m}$$

Intensity of rainfall, $i = 3 \text{ m/hr}$

Time of concentration

$$t_c = 0.01947 \times 1100^{0.72} \times (0.00425)^{-0.385}$$
$$= 34.98 \text{ min}$$

$$t_c = 35 \text{ min}$$

time of concentration = duration of rainfall

From IDF curve

$$T = 10 \text{ years (return period)}$$

Peak discharge,

$$Q_p = C_i A$$

$$= 0.5 \times \frac{3 \times 2.54}{100 \times 3600} \times 2 \times (1000)^2$$

$$= 21.167 \text{ m}^3/\text{s}$$

design precipitation volume

$$V = \frac{3 \times 2.54}{2 \times 100 \times 3600} (\text{m}^3/\text{s}) \times (35 \times 60) \text{s} \times 2 \times (10^3)^2 \text{m}^2$$
$$= 88900 \text{ m}^3$$

(Ans.)

2010-11

4(c)

consider a catchment with longitudinal slope = 0.005, area = 2 km^2 and runoff coefficient = 0.1. The peak discharge is computed to be $4.2 \text{ m}^3/\text{s}$. compute the corresponding intensity of rainfall, time of concentration for the catchment and maximum length of travel of water for a return period of 100 years. use rational method, IDF curves (fig 1.) and Kirpich formula for your estimation.

Solution:

$$S = 0.005$$

$$A = 2 \text{ km}^2$$

$$Q = 4.2 \text{ m}^3/\text{s}$$

$$T = 100 \text{ years}$$

$$C = 0.1$$

$$Q_p = C_i A$$

$$\Rightarrow i = \frac{Q_p}{CA}$$

$$= \frac{4.2}{0.1 \times 2 \times (1000)^2}$$

$$= 2.1 \times 10^{-5} \text{ m/s}$$

$$= 7.56 \text{ cm/hr}$$

$$= 2.967 \text{ in/hr}$$

From IDF curve

$$t_c = 68 \text{ min}$$

$$t_c = 0.01947 L^{0.77} S^{-0.385}$$

$$\Rightarrow 68 = 0.01947 \times L^{0.77} \times (0.005)^{-0.385}$$

$$\Rightarrow L^{0.77} (0.005)^{-0.385} = 3492.55$$

$$\therefore L = 2825 \text{ m}$$

2009-10

5(d)

An urban catchment has a drainage area of $295 \times 10^5 \text{ sq. m}$. The slope of

$A_1 = 90$

$\frac{90}{A_1} = i$

A_1

$\frac{S.P.}{A_1}$

$\frac{(200.0) \times 1.0}{90}$

$\frac{2.22 \times 10^6}{90}$

$\frac{(1.11 \times 10^6)}{90}$

$\frac{1.11 \times 10^6}{90}$

From the map

$100.80 = 100$

$280.0 - 285.0 = 5.0$

$285.0 - (200.0) \times 1.0 = 85.0$

$285.0 - (200.0) \times 1.0 = 85.0$

$100.80 = 100$

Solution:

$$A_{\text{ren}} = 295 \times 10^5 \text{ m}^2$$

$$S = 0.0036$$

$$T = 20 \text{ years}$$

$$L = 1.65 \times 1000 \text{ m}$$

$$K = 6.16, \quad \alpha = 0.694, \quad q = 0.5, \quad m = 0.972$$

$$i^0 = \frac{K T \alpha}{(t_c + q)^m}$$

$$= \frac{6.16 \times 20^{0.694}}{(t_c + 0.5)^{0.972}}$$

Now,

$$t_c = 0.01947 \times L^{0.72} \times S^{-0.385}$$

$$= 0.01947 \times (1.65 \times 1000)^{0.72} \times (0.0036)^{-0.385}$$

$$= 51 \text{ min}$$

$$\therefore i = \frac{6.16 \times 20^{0.694}}{\left(\frac{51}{60} + 0.5\right)^{0.972}}$$

$$= 36.8 \text{ (cm/hr)} \quad [\text{Empirical}]$$

$$= 36.8 \times \frac{1}{100 \times 3600} \text{ m/s}$$

$$= 1.022 \times 10^{-4} \text{ m/s}$$

penk discharge

$$Q_p = (0.45 \times 0.85 + 0.25 \times 0.6 + 0.2 \times 0.4 + 0.1 \times 0.7)$$

$$\times 1.092 \times 10^{-4} \times 2.95 \times 10^5$$

$$= 2058 \text{ m}^3/\text{s}$$

2008-09

5(d)

Given that,

$$A_{\text{area}} = 550 \text{ ha}$$

$$= 550 \times 10^4 \text{ m}^2$$

$$S = 0.0025$$

$$L = 2.2 \text{ km} = 2.2 \times 1000 \text{ m}$$

$$T = 30 \text{ years.}$$

$$Q_p = ?$$

time of concentration

$$t_c = 0.01947 L^{0.77} S^{-0.385}$$

$$= 0.01947 \times (2.2 \times 1000)^{0.77} \times (0.0025)^{-0.385}$$

$$= 73.25 \text{ min}$$

time of concentration = duration of
rainfall
so from the given chart,

Rainfall calculations

$$\frac{73.25 - 75}{75 - 90} = \frac{x - 96}{96 - 110}$$

$$\frac{73.25 - 60}{60 - 75} = \frac{x - 85}{85 - 96}$$

$$\Rightarrow x = 94.72 \text{ mm}$$

$$\therefore \text{Rainfall depth} = 94.72 \text{ mm}$$

$$\therefore I = \frac{94.72}{73.25} \times 60$$

$$= 77.58 \text{ mm/hr}$$

$$= \frac{77.58}{1000 \times 3600}$$

$$= 2.155 \times 10^{-5} \text{ m/s}$$

$$\Delta P = C' A$$

$$= (0.50 \times 0.65 + 0.2 \times 0.95 + 0.3 \times 0.4) \times 2.155$$

$$\times 10^{-5} \times 550 \times 10^4$$

$$= 75.27 \text{ m}^3/\text{s}$$



2009-10

4(c)

① Solution

Two runoff co-efficient 0.4 and 0.7 are given.

For catchment area A, during rainy season, it is already filled with water i.e. that's in saturated condition. So runoff co-efficient will be higher.

Again, heavy suspended solid in infiltrating water will tend to block the pores of the soil surface. So infiltration will be less. Runoff co-efficient will be higher.

Additionally, from eqn $Q = c i A$, for a given discharge Area c is ^{inversely} proportional to A . As the area of catchment area of A is less, so c will be higher.

$$C_A = 0.7$$

$$C_B = 0.4$$

2008-09

4cc)

- i) catchment area possess clayey soil & it has low permeability. so its runoff co-efficient will be higher.
- ii) catchment area has no vegetative cover. ~~otherw~~ on the other hand B has high vegetative cover. so runoff co-efficient of B will be less.
- iii) As the area of A is lower, its runoff co-efficient will be higher.

Precipitation problem

Problem 3.2.2

Calculate the precipitable water in a saturated air column 10 km high above 1 m² of ground surface. The surface pressure 101.3 kPa. The surface air temperature is 30°C and the lapse rate is 6.5 °C/km.

Solution

Let's take the increment elevation, $\Delta z = 2 \text{ km}$

Now,

incremental mass of precipitable water

$$\Delta m_p = \bar{\alpha}_v \bar{p}_n A \Delta z$$

$$A = 1 \text{ m}^2, \quad \Delta z = 2 \text{ km}$$

$$\bar{\alpha}_v = \frac{\alpha_{v1} + \alpha_{v2}}{2}$$

$$\bar{p}_n = \frac{p_{n1} + p_{n2}}{2}$$

$$\alpha_v = 0.622 \frac{e}{p}$$

For the 1st interval (from ground to 2 km)

$$\begin{aligned} \rho_1 &= 611 \exp\left(\frac{17.27 T}{237.3 + T}\right) \\ &= 611 \exp\left(\frac{17.27 \times 30}{237.3 + 30}\right) \\ &= 4244 \text{ Pa} \\ &= 4.24 \text{ kPa} \end{aligned}$$

$$T_1 = 30^\circ \text{C}$$

$$\begin{aligned} T_2 &= 30 - 6.5 \times 2 \\ &= 17^\circ \text{C} \end{aligned}$$

$$\begin{aligned} \rho_2 &= 611 \exp\left(\frac{17.27 T_2}{237.3 + T_2}\right) \\ &= 611 \exp\left(\frac{17.27 \times 17}{237.3 + 17}\right) \\ &= 1.94 \text{ kPa} \end{aligned}$$

$$P_1 = 101.3 \text{ kPa}$$

$$\begin{aligned} P_2 &= P_1 \left(\frac{T_2}{T_1}\right)^{\frac{g}{\alpha R_g}} \\ &= 101.325 \times \left(\frac{290}{303}\right)^{\frac{9.81}{0.0065 \times 287}} \\ &= 80.4 \text{ kPa} \end{aligned}$$

So,

$$\begin{aligned}\bar{v} &= 0.622 \left(\frac{e_1/p_1 + e_2/p_2}{2} \right) \\ &= \frac{0.622 \left(\frac{4.24}{101.3} + \frac{1.94}{80.4} \right)}{2} \\ &= 0.0205 \text{ kg/kg}\end{aligned}$$

Now,

$$\begin{aligned}\rho_{u1} &= \frac{p_1}{R_u \times T_1} \\ &= \frac{101.3 \times 1000}{287 \times 303} \text{ kg/m}^3\end{aligned}$$

$$\rho_{u2} = \frac{p_2}{R_u \times T_2} = 0.97 \text{ kg/m}^3$$

$$\begin{aligned}\bar{\rho}_u &= \frac{\rho_{u1} + \rho_{u2}}{2} \\ &= 1.02 \text{ kg/m}^3\end{aligned}$$

$$\Delta m_p = \bar{v} \bar{\rho}_u A \Delta z$$

$$\begin{aligned}&= 0.0205 \times 1.02 \times 1 \times 2000 \\ &= 41.82 \text{ kg}\end{aligned}$$

Elevation	Temp. (°C)	Temp. (K)	Atmospheric P	Density ρ_a	Vapor pressure P _v	Sp. humid ratio w	$\bar{w}$	$\bar{p}_n$	cm
0	30°	303	101.3	1.16	4.24	0.026	0.0205	1.065	43.67
2	17	290	80.4	0.97	1.94	0.015	0.0115	0.88	20.2
4	4	272	63.2	0.79	0.81	0.008	0.006	0.72	8.64
6	-9	264	49.1	0.65	0.31	0.0039	0.0028	0.585	3.3
8	-22	251	37.6	0.52	0.10	0.0012	0.0012	0.47	1.1
10	-35	238	28.5	0.42	0.03	0.0002			
									76.9444
									772.44

2010-11

1(c)

calculate precipitable water for surface temperature 10°C in first 1 km of saturated atmospheric column if the surface pressure = 101.3 kPa and lapse rate = $6.5^{\circ}\text{C}/\text{km}$. Also compute precipitable water for surface temperature of 25°C in first 1 km of similar column and calculate the percent increase or decrease from the previously computed value. Justify your calculations. Assume any reasonable for missing data.

Solutions:

For surface temp. 25°C

$$T_1 = 25^{\circ}\text{C}$$

$$T_2 = 25 - 6.5 \times 1$$
$$= 18.5^{\circ}\text{C}$$

$$P_1 = 101.3 \text{ kPa}$$

$$P_2 = P_1 \left(\frac{T_2}{T_1} \right)^{\frac{\gamma}{\gamma-1}}$$

$$= 101.3 \left(\frac{18.5+273}{25+273} \right)^{\frac{1.21}{1.21-1}}$$

$$= 90.23 \text{ kPa}$$

$$e_1 = 611 \exp \left(\frac{17.27 T_1}{237.3 + T_1} \right)$$

$$= 611 \exp \left(\frac{17.27 \times 25}{237.3 + 25} \right)$$

$$= 3.165 \text{ kPa}$$

$$e_2 = 611 \exp \left(\frac{17.27 T_2}{237.3 + T_2} \right)$$

$$= 611 \exp \left(\frac{17.27 \times 18.5}{237.3 + 18.5} \right)$$

$$= 2.13 \text{ kPa}$$

$$\bar{w} = 0.622 \left(\frac{e_1}{P_1} + \frac{e_2}{P_2} \right)$$

$$= 0.622 \times \left(\frac{3.165}{101.3} + \frac{2.13}{90.23} \right)$$

$$= 0.0171 \text{ kg/kg}$$

$$\rho_{a1} = \frac{P_1}{R_a T_1}$$

$$= \frac{101.325 \times 1000}{287 \times 298}$$

$$= 1.18 \text{ kg/m}^3$$

$$\rho_{a2} = \frac{P_2}{R_a T_2}$$

$$= \frac{90.23 \times 1000}{287 \times (18.5 + 273)}$$

$$= 1.078 \text{ kg/m}^3$$

$$\therefore \bar{\rho}_a = \frac{\rho_{a1} + \rho_{a2}}{2}$$

$$= 1.13 \text{ kg/m}^3$$

$$\therefore \dot{m} = \bar{\rho}_a \bar{V}_a A \times A_2$$

$$= 1.13 \times 0.0171 \times 1 \times 1000$$

$$= 19.32 \text{ kg}$$

Assume $A = 1 \text{ m}^2$

For surface temp. at 10°C

$$T_1 = 10^\circ\text{C}$$

$$P_1 = 101.3 \text{ kPa}$$

$$T_2 = 10 - 6.5$$

$$= 3.5^\circ\text{C} = 276.5 \text{ K}$$

$$P_2 = P_1 \left(\frac{T_2}{T_1} \right)^{\frac{\gamma}{\gamma-1}}$$
$$= 101.3 \times \left(\frac{276.5}{283} \right)^{\frac{0.81}{0.0065 \times 282}}$$
$$= 89.65 \text{ kPa}$$

$$\rho_1 = 611 \exp\left(\frac{17.27 T_1}{237.3 + T_1} \right)$$
$$= 1.23 \text{ kPa}$$

$$\rho_2 = 611 \exp\left(\frac{17.27 T_2}{237.3 + T_2} \right)$$
$$= 0.285 \text{ kPa}$$

$$\bar{v}_v = \frac{q_{w1} + v_{v2}}{2}$$

$$= \frac{0.622}{2} \left(\frac{1.23}{101.3} + \frac{0.785}{89.65} \right)$$

$$= 0.0065 \text{ kg/kg}$$

$$\bar{p}_a = \frac{1}{287 \times 2}$$

$$\bar{p}_a = \frac{p_{a1}}{R_a T_1}$$

$$= \frac{101.3 \times 1000}{287 \times 283} = 1.25 \text{ kg/m}^3$$

$$\bar{p}_{a2} = \frac{p_{a2}}{R_a T_2}$$

$$= \frac{89.65 \times 1000}{287 \times 276.5}$$

$$= 1.13 \text{ kg/m}^3$$

$$\therefore \bar{p}_a = 1.19 \text{ kg/m}^3$$

$$\Delta mp = \bar{W} \bar{P}_u A \Delta z$$

$$= 0.0065 \times 1.19 \times 1 \times 1000$$

$$= 7.725 \text{ kg}$$

$$\therefore \text{Percent increase} = \frac{19.32 - 7.725}{7.725} \times 1000$$

$$= 150\%$$

Surface temp. 10°C

Question

2009-10

1(0)

The relative humidity, saturation vapor pressure and air pressure at ground level are computed to be 80%, 2500 Pa and 101.3 kPa respectively. The relative humidity at 2 km elevation is 90%. compute the precipitable water in the first 2 km of air column above a m of ground surface. Assume reasonable value for missing data.

Solution:

Relative humidity, $Rh_1 = 80\%$ (at ground)

" " , $Rh_2 = 90\%$ (at 2 km)

Q5 $P_1 = 2500 \text{ Pa}$

$P_1 = 101.3 \text{ kPa}$

$$e_{s1} = 611 \exp\left(\frac{17.27 T_1}{237.3 + T_1}\right)$$

$$\Rightarrow 2500 = 611 \exp\left(\frac{17.27 T_1}{237.3 + T_1}\right)$$

$$\Rightarrow T_1 = 21.08^\circ\text{C}$$

assume,

$$\alpha = 6.5^\circ\text{C/km}$$

$$T_2 = 21.08 - (6.5^\circ\text{C} \times 2)$$

$$= 8.08^\circ\text{C}$$

$$P_2 = P_1 \left(\frac{T_2}{T_1} \right)^{\frac{g}{\alpha P_a}}$$

$$= 101.3 \times \left(\frac{8.08 + 273}{21.08 + 273} \right)^{\frac{9.81}{0.0065 \times 282}}$$

$$= 79.86 \text{ kPa}$$

$$e_{s2} = 611 \exp\left(\frac{17.27 \times 8.08}{237.3 + 8.08}\right)$$

$$= 1079 \text{ Pa}$$

$$P_{n2} = \frac{e_2}{e_{s2}}$$

$$e_2 = 0.9 \times 1079$$

$$= 971.1 \text{ Pa}$$

$$P_{n1} = \frac{e_1}{e_{s1}}$$

$$\therefore e_1 = 0.8 \times 2500$$

$$= 2000 \text{ Pa}$$

$$\bar{q}_v = \frac{q_{v1} + q_{v2}}{2}$$

$$= 0.00922 \text{ kg/kg}$$

$$\bar{P}_n = \frac{1}{2 \times 28 \times} \left(\frac{101.3 \times 1000}{294.08} + \frac{29.86 \times 1000}{281.08} \right)$$

$$= 1.095 \text{ kg/m}^3$$

precipitable water

$$= 1.095 \times 0.00922 \times 2 \times 2000$$

$$= 43.45 \text{ kg}$$

2007-08

219)

The amount of precipitable water in first 2 km from the ground is 500 kg corresponding to a ground area of 10 m^2 . Assume linear variation of air density and specific humidity in the column. The

$$\frac{0.001 \times 28.97}{80.18} + \frac{0.001 \times 2.101}{80.102} \times \frac{1}{0.858} = 2.9$$

$$0.013 \times 28.1 =$$

$$10 \text{ km} \times 0.0025 \times 28.1 =$$

$$0.0025 \times 0.0025 \times 28.1 =$$

$$0.0025 \times 28.1 =$$

Solution:

$$\Delta m = 500 \text{ kg}$$

$$A = 10 \text{ m}^2$$

$$\rho_a = 1 \text{ kg/m}^3$$

$$\Delta z = 2 \times 1000$$

$$\Delta m = \bar{\rho}_v \bar{\rho}_a A \Delta z$$

$$\Rightarrow 50 = \bar{\rho}_v \times 1 \times 2000 \times 10$$

$$\therefore \bar{\rho}_v = 0.025 \text{ kg/kg}$$

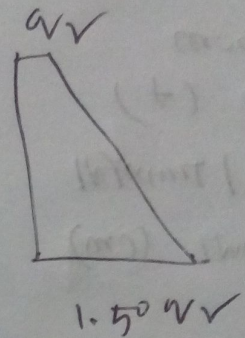
$$\bar{\rho}_v = \frac{(1 + 1.50) \rho_v}{2}$$

$$\therefore \rho_v = 0.02 \text{ kg/kg}$$

specific gravity at ground

$$\text{surface} = 0.02 \times 1.5$$

$$= 0.03 \text{ kg/kg}$$



Example - 3.58

A storm with 10.0 cm precipitation produced a direct runoff of 5.8 cm. Given the time distribution of the storm as below, estimate the ϕ index of the storm.

Time from start (h)	0	1	2	3	4	5	6	7	8
Incremental rainfall each hour (cm)	0	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5

Solution:

$$\text{Total rainfall} = 10 \text{ cm}$$

$$\text{Total runoff} = 5.8 \text{ cm}$$

$$\therefore \text{Total infiltration} = 4.2 \text{ cm}$$

So, let,

$$\text{time of rainfall excess} = 8 \text{ hr}$$

$\therefore$ for the first trial,

$$\begin{aligned}\phi &= \frac{4.2}{8} \\ &= 0.525\end{aligned}$$

But first and 8th hour rainfall $\angle$
 ϕ index

$$\text{So, } t_e = 8 - 2 \\ = 6 \text{ hr}$$

$$\therefore \text{Infiltration} = 4.2 - 0.4 - 0.5$$

$$= 3.3 \text{ cm}$$

$$\therefore \phi \text{ index} = \frac{3.3}{6} \\ = 0.55 \text{ cm/hr}$$

2012-13

2(d)

In a 140 min storm, the following intensities of rainfall observed in successive 20 min interval 20 min intervals: 3.3, 3.6, 9.0, 6.6, 0.6, 0.9 and 6.0 cm/hr. Assume ϕ index value to be 3 cm/hr. compute i) total volume of runoff ii) total volume of infiltration and iii) time of rainfall excess. The catchment area is 2 km².

Ans: 3

$$\phi \text{ index} = \frac{3 \text{ cm/hr}}{20 \text{ min}} = 1 \text{ cm/20 min}$$

Time (min)	20	40	60	80	100	120	140
rainfall (cm)	$\frac{3.3}{3} = 1.1$	$\frac{3.6}{3} = 1.2$	$\frac{9}{3} = 3$	$\frac{6.6}{3} = 2.2$	$\frac{0.6}{3} = 0.2$	$\frac{0.9}{3} = 0.3$	$\frac{6}{3} = 2$
infiltration (cm)	1	1	1	1	0.2	0.3	1
runoff	0.1	0.2	2	1.2	0	0	1

$$\therefore \text{Total runoff} = 0.1 + 0.2 + 2 + 1.2 + 1 = 4.5 \text{ cm}$$

$$\therefore \text{Total volume of runoff} = \frac{4.5}{100} \times 2 \times (1000)^2 = 90,000 \text{ m}^3$$

$$\therefore \text{Total volume of infiltration} = \frac{5.5}{100} \times 2 \times (1000)^2 = 110,000 \text{ m}^3$$

$$\therefore \text{Time of rainfall excess} = 100 \text{ min}$$

