OMICS Group eBOOKS
www.esciencecentral.org/ebooks

HANDBOOK OF IRRIGATION ENGINEERING PROBLEMS

Mohammad Valipour

Handbook of Irrigation Engineering Problems

Edited by: Mohammad Valipour

Published Date: June 2014

Published by **OMICS Group eBooks**

731 Gull Ave, Foster City. CA 94404, USA

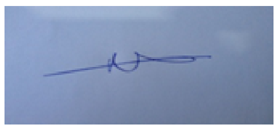
A free online edition of this book is available at www.esciencecentral.org/ebooks

Additional hard copies can be obtained from orders @ www.esciencecentral.org/ebooks

Preface

Yes, irrigation! In near future, energy become a luxury item and water is considered as the most vital item in the world due to reduction of water resources in most regions. Furthermore, the most water consumption belongs to agriculture and irrigation. In this condition, role of water science researchers and irrigation experts is important more than ever. If an irrigation engineer student is not educated well, he/she will not solve problems of water sciences in the future. Many engineer students learn all necessary lessons in the university, but they cannot to answer to the problems or to pass the exams because of forgetfulness or lack of enough exercise. This book contains one hundred essential problems related to irrigation engineering with a small volume. Undoubtedly, many problems can be added to the book but the author tried to mention only more important problems and to prevent increasing volume of the book due to help to feature of portability of the book. To promote student's skill, both SI and English systems have been used in the problems and a list of important symbols has been added to the book. All of the problems were solved completely. This book is useful for not only exercising and passing the university exams but also for use in actual project as a handbook. The handbook of irrigation engineering problems is usable for agricultural, civil, and environmental students, teachers, experts, researchers, engineers, designers, and all enthusiastic readers in surface and pressurized irrigation, drainage engineering, agricultural water management, water resources, hydrology, hydrogeology, hydro climatology, hydrometeorology, and hydraulic fields. The prerequisite to study the book and to solve the problems is each appropriate book about irrigation science; however, the author recommends studying the references to better understanding the problems and presented solutions. It is an honor for the author to receive any review and suggestion to improve quality of the book.

- Mohammad Valipour



About Author

Mohammad Valipour is a Ph.D. candidate in Agricultural Engineering-Irrigation and Drainage at Sari Agricultural Sciences and Natural Resources University, Sari, Iran. He completed his B.Sc. Agricultural Engineering-Irrigation at Razi University, Kermanshah, Iran in 2006 and M.Sc. in Agricultural Engineering-Irrigation and Drainage at University of Tehran, Tehran, Iran in 2008. Number of his publications is more than 50. His current research interests are surface and pressurized irrigation, drainage engineering, relationship between energy and environment, agricultural water management, mathematical and computer modeling and optimization, water resources, hydrology, hydrogeology, hydro climatology, hydrometeorology, hydro informatics, hydrodynamics, hydraulics, fluid mechanics, and heat transfer in soil media.

Contents	Page #
Abbreviations	1
Problems	6
References	58

OMICS Group eBooks

Handbook of Irrigation Engineering Problems

Mohammad Valipour*

Young Researchers and Elite Club, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran

***Corresponding author:** Mohammad Valipour, Young Researchers and Elite Club, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran, E-mail: vali-pour@hotmail.com

Abstract

a_{psy} coefficient of psychrometer [°C^{-1}]

a_s fraction of extraterrestrial radiation reaching the earth on an overcast day [-]

a_s+b_s fraction of extraterrestrial radiation reaching the earth on a clear day [-]

c_p specific heat [MJ kg^{-1} °C^{-1}]

c_s soil heat capacity [MJ m^{-3} °C^{-1}]

C_R capillary rise [mm day^{-1}]

D_e cumulative depth of evaporation (depletion) from the soil surface layer [mm]

D_r cumulative depth of evapotranspiration (depletion) from the root zone [mm]

d zero plane displacement height [m]

d_r inverse relative distance Earth-Sun [-]

D_P deep percolation [mm]

D_{Pe} deep percolation from the evaporation layer [mm]

E evaporation [mm day^{-1}]

E_{pan} pan evaporation [mm day^{-1}]

e°(T) saturation vapor pressure at air temperature T [kPa]

e_s saturation vapor pressure for a given time period [kPa]

e_a actual vapor pressure [kPa]

$e_s - e_a$ saturation vapor pressure deficit

EC_e electrical conductivity of the saturation extract of the soil [dS m^{-1}]

$EC_{e,threshold}$ electrical conductivity of the saturation extract of the soil above which yield begins to decrease [dS m^{-1}]

ET evapotranspiration [mm day^{-1}]

ET_o reference crop evapotranspiration [mm day^{-1}]

ET_c crop evapotranspiration under standard conditions [mm day^{-1}]

ET_c adj crop evapotranspiration under non-standard conditions [mm day^{-1}]

exp[x] 2.7183 (base of natural logarithm) raised to the power x

Fr resistance correction factor [-]

f_c fraction of soil surface covered by vegetation (as observed from overhead) [-]

$f_{c\ eff}$ effective fraction of soil surface covered by vegetation [-]

$1\text{-}f_c$ exposed soil fraction [-]

f_w fraction of soil surface wetted by rain or irrigation [-]

f_{ew} fraction of soil that is both exposed and wetted (from which most evaporation occurs) [-]

G soil heat flux [MJ m^{-2} day^{-1}]

G_{day} soil heat flux for day and ten-day periods [MJ m^{-2} day^{-1}]

G_{hr} soil heat flux for hourly or shorter periods [MJ m^{-2} $hour^{-1}$]

G_{month} soil heat flux for monthly periods [MJ m^{-2} day^{-1}]

G_{sc} solar constant [0.0820 MJ m^{-2} min^{-1}]

H sensible heat [MJ m^{-2} day^{-1}]

H_{WR} height to width ratio

h crop height [m]

I irrigation depth [mm]

I_w irrigation depth for that part of the surface wetted [mm]

J number of day in the year [-]

K_c crop coefficient [-]

$K_{c\ ini}$ crop coefficient during the initial growth stage [-]

$K_{c\ mid\text{-}crop}$ coefficient during the mid-season growth stage [-]

$K_{c\ end}$ crop coefficient at end of the late season growth stage [-]

$K_{c\ max}$ maximum value of crop coefficient (following rain or irrigation) [-]

$K_{c\ min}$ minimum value of crop coefficient (dry soil with no ground cover) [-]

K_{cb} basal crop coefficient [-]

$K_{cb\ full}$ basal crop coefficient during mid-season (at peak plant size or height) for vegetation with full ground cover of LAI > 3 [-]

$K_{cb\ ini}$ basal crop coefficient during the initial growth stage [-]

$K_{cb\ mid}$ basal crop coefficient during the mid-season growth stage [-]

$K_{cb\ end}$ basal crop coefficient at end of the late season growth stage [-]

$K_{e\ soil}$ evaporation coefficient [-]

$K_{p\ pan}$ coefficient [-]

$K_{r\ soil}$ evaporation reduction coefficient [-]

K_s water stress coefficient [-]

K_y yield response factor [-]

k_{Pa} atmospheric pressure

k_{von} Karman's constant [0.41] [-]

k_{Rs} adjustment coefficient for the Hargreaves' radiation formula [°C-0.5]

L_{ini} length of initial growth stage [day]

L_{dev} length of crop development growth stage [day]

L_{mid} length of mid-season growth stage [day]

L_{late} length of late season growth stage [day]

L_z longitude of centre of local time zone [degrees west of Greenwich]

L_m longitude [degrees west of Greenwich]

LAI leaf area index [m^2 (leaf area) m^{-2} (soil surface)]

LAIactive active (sunlit) leaf area index [-]

N maximum possible sunshine duration in a day, daylight hours [hour]

n actual duration of sunshine in a day [hour]

n/N relative sunshine duration [-]

P rainfall [mm]

$p_{evapotranspiration}$ depletion factor [-]

R specific gas constant [0.287 kJ kg^{-1} K^{-1}]

R_a extraterrestrial radiation [MJ m^{-2} day^{-1}]

R_l long wave radiation [MJ m^{-2} day^{-1}]

R_n net radiation [MJ m^{-2} day^{-1}]

R_{nl} net long wave radiation [MJ m^{-2} day^{-1}]

R_{ns} net solar or shortwave radiation [MJ m^{-2} day^{-1}]

R_s solar or shortwave radiation [MJ m^{-2} day^{-1}]

R_{so} clear-sky solar or clear-sky shortwave radiation [MJ m^{-2} day^{-1}]

r_a aerodynamic resistance [s m^{-1}]

r_l bulk stomatal resistance of well-illuminated leaf [s m^{-1}]

r_s (bulk) surface or canopy resistance [s m^{-1}]

R_s/R_{so} relative solar or relative shortwave radiation [-]

R_{AW} readily available soil water of the root zone [mm]

R_{EW} readily evaporable water (i.e., maximum depth of water that can be evaporated from the soil surface layer without restriction during stage 1) [mm]

R_H relative humidity [%]

RH_{hr} average hourly relative humidity

RH_{max} daily maximum relative humidity [%]

RH_{mean} daily mean relative humidity [%]

RH_{min} daily minimum relative humidity [%]

RO surface runoff [mm]

$Sc_{seasonal}$ correction factor for solar time [hour]

S_F subsurface flow [mm]

T_{air} temperature [°C]

TK_{air} temperature [K]

TK_v virtual air temperature [K]

T_{dew} dew point temperature [°C]

T_{dry} temperature of dry bulb [°C]

T_{max} daily maximum air temperature [°C]

$T_{max,K}$ daily maximum air temperature [K]

T_{mean} daily mean air temperature [°C]

T_{min} daily minimum air temperature [°C]

$T_{min,K}$ daily minimum air temperature [K]

T_{wet} temperature of wet bulb [°C]

T_{AW} total available soil water of the root zone [mm]

T_{EW} total evaporable water (i.e., maximum depth of water that can be evaporated from the soil surface layer) [mm]

t time [hour]

u_2 wind speed at 2 m above ground surface [m s^{-1}]

u_z wind speed at z m above ground surface [m s^{-1}]

W soil water content [mm]

Y_a actual yield of the crop [kg ha^{-1}]

Y_m maximum (expected) yield of the crop in absence of environment or water stresses [kg ha^{-1}]

Z_e depth of surface soil layer subjected to drying by evaporation [m]

Z_r rooting depth [m]

$z_{elevation,}$ height above sea level [m]

z_h height of humidity measurements [m]

z_m height of wind measurements [m]

z_{om} roughness length governing momentum transfer [m]

z_{oh} roughness length governing heat and vapor transfer [m]

α albedo [-]

γ psychrometric constant [kPa °C^{-1}]

γ_{psy} psychrometric constant of instrument [kPa °C^{-1}]

Δ slope of saturation vapor pressure curve [kPa °C^{-1}]

ΔSW variation in soil water content [mm]

Δt length of time interval [day]

Δz effective soil depth [m]

δ solar declination [rad]

ε ratio molecular weight of water vapor/dry air (= 0.622)

η mean angle of the sun above the horizon

θ soil water content [m^3(water) m^{-3}(soil)]

θ_{FC} soil water content at field capacity [m^3(water) m^{-3}(soil)]

θ_t threshold soil water content below which transpiration is reduced due to water stress [m^3(water) m^{-3}(soil)]

θ_{WP} soil water content at wilting point [m^3(water) m^{-3}(soil)]

λ latent heat of vaporization [MJ kg^{-1}]

λ_{ET} latent heat flux [MJ m^{-2} day^{-1}]

ρ_a mean air density [kg m^{-3}]

ρ_w density of water [kg m^{-3}]

σ Stefan-Boltzmann constant [4.903 10-9 MJ K^{-4} m^{-2} day^{-1}]

φ latitude [rad]

ω solar time angle at midpoint of hourly or shorter period [rad]

ω1 solar time angle at beginning of hourly or shorter period [rad]

ω2 solar time angle at end of hourly or shorter period [rad]

ωs sunset hour angle [rad]

Problems

1. In the table, available water has been showed in each quarter of root depth. Maximum allowable depletion is 50 percent and daily crop water requirement is 8 millimeters. Determine critical quarter in commence of irrigation and irrigation interval.

Quarter of root depth	Soil texture	Available water	Allowed water depletion
1	CL	50	40
2	CL	50	30
3	SL	20	20
4	SiL	60	10

Readily available water = (Available water − Allowed water depletion) × Maximum allowable depletion

Quarters of root depth	Readily available water
1	5
2	10
3	6
4	24

Quarter 1 is critical quarter.

$$\text{Irrigation interval} = \frac{\sum(\text{Readily available water})}{\text{Crop water requirement}} = \frac{(5+10+6+24)}{8} = 5.625 \cong 5 \text{ days}$$

2. In a sprinkle irrigation system, Distance of irrigation machine movement is 60 meters, the velocity is 36 meters per hour, and discharge of gun sprinkler is 50 cubic meters per hour. Determine value of precipitation as millimeter.

S_l = 60m v=36m/hr Q_g= 50m³/hr

$$I = \frac{Q_g}{S_l \times v} = \frac{50}{60 \times 36} = 23.148 \text{ mm}$$

3. In a trickle irrigation system, maximum allowable depletion is 35 percent, moisture area is 46 percent, root depth is 1.8 meters, soil water holding capacity is 95 millimeters (in root depth), water requirement is 5 millimeters, canopy is 75 percent, electrical conductivity of saturated paste extract is 8 deciSiemens per meter, and electrical conductivity of irrigation water is 0.3 deciSiemens per meter. Determine maximum net irrigation depth, maximum daily transpiration, maximum irrigation interval, and

leaching requirement.

MAD = 35% P_w = 46% Z = 1.8 m U_d = 5 mm P_d = 75% EC_e = 8 dS/m

$w_a = \frac{95\text{ mm}}{1.8\text{ m}}$ EC_w = 0.3 dS/m

$$\text{Maximum net irrigation depth} = \frac{MAD}{100} \times \frac{P_W}{100} \times Z \times w_a = \frac{35}{100} \times \frac{46}{100} \times 1.8 \times \frac{95}{1.8} = 15.295\text{ mm}$$

$$\text{Maximum daily transpiration} = \text{Maximum net irrigation depth} \times \frac{P_d}{100} = 15.295 \times \frac{75}{100} = 11.5\text{ mm / day}$$

$$\text{Maximum irrigation interval} = \frac{U_d}{T_d} = \frac{5}{11.471} = 10.461\text{ hr} \cong 10\text{ hr}$$

$$\text{Leaching requirement} = \frac{EC_W}{5 \times EC_e - EC_W} = \frac{0.3}{5 \times 8 - 0.3} = 0.008$$

4. In a square area (640000 m²), irrigation efficiency of a center pivot system is 70 percent, maximum daily evapotranspiration is 7.6 millimeters, effective radius of end sprinkler is 14 meters, readily available water is 40 millimeters, and maximum irrigation depth is 18 millimeters. Determine discharge of center pivot system, maximum time of irrigation, acceptable rotational velocity as hour, and rotational velocity of end sprinkler as meter per minute.

l= 800 m E_a = 70% DDIR = 7.6 mm/day R_e = 14m RAW = 40 mm

$A = \pi \text{ X } R^2 = \pi \text{ X } 400^2 = 5.027 \text{ X } 10^5 \text{ m}^2$

$$Q_{CP} = \frac{A \times DDIR}{E_a} = \frac{5.027 \times 10^5 \times 7.6 \times 10^{-3}}{0.7} = 1.516\text{ m}^3\text{ / s}$$

$$\text{Maximum time of irrigation} \le \frac{RAW}{DDIR} \le \frac{40}{7.6} \le 126.316 \cong 126\text{ hr}$$

$$A_p = \frac{60 \times Q_{CP}}{R \times R_e} = \frac{60 \times 1.516}{400 \times 14} \times 100 = 1.624\text{ cm / min}$$

$$S_r \le \frac{D_m}{DDIR} \le \frac{18}{7.6} \le 56.842 \rightarrow \text{acceptable rotational velocity is less than 56 hours in each rotation}$$

$$q_r = \frac{2 \times R_e}{R} \times Q_s = \frac{2 \times 14}{400} \times 1.516 \times 60 = 6.4\text{ m}^3\text{ / min}$$

$A_r = \pi \times R_e^2 = \pi \times 142 = 615 \text{ m}^2$

$$v_r = \frac{q_r}{A_r} = \frac{6.4}{615} = 0.01\text{ m / min}$$

5. According to the table, determine preference of limited available water to obtain maximum production per unit area in May and June.

Month	March	April	May	June	July	August
Growth stage						
Corn	Plant establishment	Chlorophyll	Flowering	Product formation		
Cotton	Plant establishment	Chlorophyll	Flowering	Flowering	Product formation	Reach
Sunflower	Plant establishment	Chlorophyll	Chlorophyll	Flowering	Product formation	
k_y						
Corn	0.4	0.4	1.5	0.5		
Cotton	0.2	0.2	0.5	0.5	0.5	0.25
Sunflower	0.25	0.25	0.5	1.0	0.8	

$$\frac{Y_a}{Y_m} = 1 - k_y \times \left(1 - \frac{ET_a}{ET_w}\right)$$

According to the formula, while k_y increase, right side of the formula will decrease that it will show production decreasing. Therefore, in May, since k_y of corn is more than other plants, preference of limited available water is for corn and in June, since k_y of sunflower is more than other plants, preference of limited available water is for it.

6. Determine Richards' equation in an anisotropic porous media using Darcy's law and the formula.

$$\phi\frac{\partial S}{\partial t} = -\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_x}{\partial y} + \frac{\partial q_z}{\partial z}\right) + Q$$

$$v_x = k_x\frac{\partial \phi}{\partial x} \qquad v_y = k_y\frac{\partial \phi}{\partial y} \qquad v_z = k_z\frac{\partial \phi}{\partial z} \qquad Q = \phi\frac{\partial S}{\partial t} + S\frac{\partial v_x}{\partial x} + S\frac{\partial v_y}{\partial y} + S\frac{\partial v_z}{\partial z}$$

$$C(\phi)\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial x}\left(k_x\frac{\partial \phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y\frac{\partial \phi}{\partial y}\right) + \frac{\partial}{\partial y}\left(k_z\frac{\partial \phi}{\partial z}\right) - \frac{q}{dxdydz}$$

7. According to the table (related to the corn), if irrigation efficiency is 40 percent and performance ratio is 70 percent, determine optimum irrigated area.

Growth stage	Plant establishment	Chlorophyll	Flowering	Product formation
Time (day)	25	30	30	38
ET_m (mm/day)	3.6	6.4	9.5	7.2
Available water (m^3)	130000	240000	260000	370000
k_y	0.4	0.4	1.5	0.5

T_1 = 25 days T_2 = 30 days T_3 = 30 days T_4 = 38 days ET_{m1} = 3.6 mm/day

ET_{m2} = 6.4 mm/day ET_{m3} = 9.5 mm/day ET_{m4} = 7.2 mm/day V1 = 130000m3

V_2 = 240000m3 V_3 = 260000m3 V_4 = 370000m3 K_{y1} = 0.4

K_{y2} = 0.4 K_{y3} = 1.5 K_{y4} = 0.5 E = 40% $\frac{Y_a}{Y_m} = 70\%$

$$\frac{Y_a}{Y_m} = 1 - k_y \times \left(1 - \frac{ET_a}{ET_w}\right)$$

$$ET_{a1} = \frac{V_1 \times E}{100 \times A_1 \times T_1} \times 1000 = \frac{130000 \times 40 \times 1000}{100 \times A_1 \times 25} = \frac{2.08 \times 10^6}{A_1}$$

$$1 - 0.7 = 0.4 \times \left(1 - \frac{5.778 \times 10^5}{A_1}\right) \to A_1 \cong 231 \text{ ha}$$

$$ET_{a2} = \frac{V_2 \times E}{100 \times A_2 \times T_2} \times 1000 = \frac{240000 \times 40 \times 1000}{100 \times A_2 \times 30} = \frac{3.2 \times 10^6}{A_2}$$

$$1 - 0.7 = 0.4 \times \left(1 - \frac{5 \times 10^5}{A_2}\right) \to A_2 = 200 \text{ ha}$$

$$ET_{a3} = \frac{V_3 \times E}{100 \times A_3 \times T_3} \times 1000 = \frac{260000 \times 40 \times 1000}{100 \times A_3 \times 30} = \frac{3.467 \times 10^6}{A_3}$$

$$1 - 0.7 = 1.5 \times \left(1 - \frac{3.644 \times 10^5}{A_3}\right) \to A_3 \cong 46 \text{ ha}$$

$$ET_{a4} = \frac{V_4 \times E}{100 \times A_4 \times T_4} \times 1000 = \frac{370000 \times 40 \times 1000}{100 \times A_4 \times 38} = \frac{3.895 \times 10^6}{A_3}$$

$$1 - 0.7 = 0.5 \times \left(1 - \frac{5.409 \times 10^5}{A_4}\right) \to A_4 \cong 135 \text{ ha}$$

Maximum irrigated area is related to the plant establishment stage (231 ha), however optimum irrigated area is calculated as follows:

A = Min { A1,A2,A3,A4 } = Min {231,200,46,135} = 46 ha

Due to high value of ky3 and for achievement to relative performance (70%), 46 hectares from area can only be irrigated as optimum in flowering stage.

8. In a basin irrigation system, infiltration equation is $Z=6T^{0.5}$ (T as min and Z as millimeter), discharge in width unit is 0.000286 cubic meters per second per meter, available discharge for irrigation is 0.00283 cubic meters per second, there is not runoff, basin width is 6 meters, requirement effective storage in root depth is 100 millimeters,

and final infiltration after 4 hours (when water reach to the end of basin) is 10 millimeters per hour. Determine length of basin, irrigation time, and average deep percolation.

$q = 0.286 \times 10^{-3} \dfrac{m^3}{s.m}$ Q = 0.00283 m^3/s Runoff = 0 w = 6 m Dr = 100 mm

Tt = 4 hr i = 10 mm/hr

$T_{co} = \dfrac{i_n \times L}{q}$ $i = \dfrac{dz}{dt}$ $\dfrac{10}{60} = 3 \times T_{co}^{-0.5}$ T_{co} = 324 min

$$\frac{d^2Z}{dt^2} = -\frac{0.05}{60}\frac{dz}{dt} = -1.5 \times T^{-1.5} = -\frac{0.05}{60} \times 3 \times T_l^{-0.5} \rightarrow T_l = 600 \text{ min}$$

Z = 6 X $600^{0.5}$ = 146.969 mm

$d_{dp} = Z - D_r$ – Runoff = 146.969 – 100 - 0 = 46.969 mm

$i_n = i \times T_{co}$ = 10 × 5.4 = 54 mm

$$60 \times 324 = \frac{54 \times 10^{-3} \times L}{0.286 \times 10^{-3}} \rightarrow L = 102.96 \text{ m}$$

9. According to the table, determine coefficients of the infiltration equation.

$Z = Kt^a + f0^t$

t(min)	0	1	2	4	6	10	20	30	60	120	180	240	360	480	600	960	1140	1320	1480
Z(mm)	0	4	5	6	7	8	10	11	14	18	21	24	29	34	38	50	56	61	65

$$z = \frac{dZ}{dt} = aKt^{a-1} + f_0$$

t_1 = 0.5 min t_2 = 1400 min $t_3 = \sqrt{t_1 \times t_2} = \sqrt{0.5 \times 1400} = 26.458$ min

z_1 = 4 mm/min z_2 = 0.0025 mm/min z_3 = 0.1 mm/min

$$f_0 = \frac{z_1 \times z_2 - z_3^2}{z_1 + z_2 - 2 \times z_3} = \frac{4 \times 0.025 - 0.1^2}{4 + 0.025 - 2 \times 0.1} = 0.024 \text{ mm / min}$$

1 – 0.024 = aK X 1.5^{a-1} 0.1 – 0.024 = aK x 26.458^{a-1} a = 0.111

K = 12.615 mm/min^a

10. In a border irrigation system, readily available water is 100 millimeters, length of border is 200 meters, width of border is 0.6 meters, input discharge is 30 liters per minute, and infiltration and advance functions are Z=0.124t0.75 (t as minute and Z as centimeter) and $x=5.67t_x^{0.72}$ (t_x as minute and x as meter), respectively. Determine deep percolation, runoff, and application efficiency. In addition, if advance time is quarter of infiltration time, determine irrigation time.

RAW = 100 mm l = 200 m w = 0.6 m Q = 30 l/min

$$\frac{d^2Z}{dt^2}=-\frac{0.05}{60}\frac{dz}{dt}=-\frac{0.05}{60}\times 0.124\times 0.75\times t_1^{0.75-1}=-0.093\times 0.25\times t_1^{-0.25-1}$$

t_1 = 300 min 1 = 5.67 X t_t0.72 200 = 5.67 x tt0.72→ t_t = 141.058 min

$$v=\frac{l}{t}=\frac{200}{141.058}=1.418\ m/min \qquad A=\frac{i_n\times w}{2}$$

A x v = 0.3 X i_n X 1.418 = 0.03 →i_n = 70.5 mm

x = 5.67 X $300^{0.72}$ = 344.437 m 344.437 – 200 = 144.437 = 5.67 x $t^{0.72}$ → t = 89.72 min

$$V=\frac{144.437}{89.72}=1.61\ m/min$$

0.3 x Runoff x 1.61 = 0.03 → Runoff = 62.111 mm

$$E_a=\frac{i_n}{i_n+Runoff}=\frac{70.5}{70.5+62.111}=53.171\%$$

t_n = 4x t_t

i_n < RAW → dp = 0 $t_t=\frac{300}{4}=75$ min x = 5.67 X750.72 = 126.948 m

$$30\times 10^{-3}=126.948\times\frac{0.6\times 70.522}{t_{co}\times 2}\times 10^{-3}\rightarrow t_{co}=89.526\ min$$

11. In a horizontal permeability experiment (sandy soil), initial moisture is 10 percent and saturated moisture is 50 percent. Value of advance is 10 centimeters at 10 minutes and saturated hydraulic conductivity of soil is 0.01 centimeters per minute. Determine coefficients of Philip's infiltration equation and integrated infiltration at 10, 100, and 1000 minutes.

A_p = K = 0.01 cm/min 10 = S_p x $16^{0.5}$ + 0.01 X 16 → S_p = 2.46 cm/$min^{0.5}$

i = 2.46 x $t^{0.5}$ + 0.01 X t

i_{10} = 2.46 x $10^{0.5}$ + 0.01 X 10 = 7.879 cm

i_{100} = 2.46 x $100^{0.5}$ + 0.01 X 100 = 25.6 cm

i_{1000} = 2.46 x $1000^{0.5}$ + 0.01 X 1000 = 87.792 cm

12. In a mercury tensiometer, Z_0 is 50 centimeters and Z is 62 centimeters. Determine matrix potential.

Z_{Hg} = Z – Z_0 = 62 – 50 = 12 cm Φ_m = Z_0 – 12.6 x Z_{Hg} = 50 – 12.6 x 12 = -101.2 cm

13. In a metallic tensiometer, Z0 is 100 centimeters and gage shows 34 centibars. Determine matrix potential.

Φ_m – Z_0 = -34 x 10 Φ_m – 100 = -340 → Φ_m = -240 cm

14. Solve Kostiakov-Lewis infiltration equation using Newton-Raphson method.

$Z = Kt^a + f_0 t$

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \qquad \tau_{i+1} = \tau_i - \frac{Z - K\tau_i^{\,a} - f_0\tau_i}{-\dfrac{aK}{\tau_i^{\,1-a}} + (-f_0)} \rightarrow |\tau_{i+1} - \tau_i| \le \text{tolerance}$$

$$f(\tau) = Z - K\tau^a - f_0\tau$$

$$Q_{in} \times t = \sigma_y \times A \times x + \sigma_Z K t_x^{\,a} x + \frac{f_0 t_x x}{1+r}$$

$x=\rho t^r$

$$(t_l)_{i+1} = (t_l)_i - \frac{Q_{in}(t_l)_i - \sigma_y A l - \sigma_Z K (t_l)_i^{\,a}\, l - \dfrac{f_0 (t_l)_i\, l}{1+r_j}}{-\dfrac{aK\sigma_Z l}{(t_l^{\,1-a})_i - \dfrac{f_0 l}{1+r_j}} + Q_{in}}$$

$$(t_{l/2})_{i+1} = (t_{l/2})_i - \frac{Q_{in}(t_{l/2})_i - \sigma_y A l/2 - \sigma_Z K (t_{l/2})_i^{\,a}\, l/2 - \dfrac{f_0 (t_{l/2})_i\, l/2}{1+r_j}}{-\dfrac{aK\sigma_Z l/2}{(t_{l/2}^{\,1-a})_i - \dfrac{f_0 l/2}{1+r_j}} + Q_{in}}$$

r = constant $\rightarrow r_{j,i},\ (t_l)_i,\ (t_{l/2})_i \rightarrow$ initial try $\rightarrow |(t_l)_{i+1} - (T_l)_i| \le$ tolerance

Suggestions:

$$t_l = \frac{5 \times A \times l}{Q_{in}}$$

$t_{l/2} = 0.33 \text{ X } t_l\ t_{l/2}$ $r = 0.5$ to 0.6 $t_{co} = \tau + t_l$

$$r_{j+1} = \frac{\log\left(\frac{1}{1/2}\right)}{\log\left(\frac{t_1}{t_{1/2}}\right)} \rightarrow \left|r_{j+1} - r_j\right| \le \text{tolerance}$$

15. In a trickle irrigation system, number of four emitters has been established for each tree. Root depth is 1.5 meters, distance of emitters is 1 meter, w=1.2 m, S_p=3 m, and S_r=4 m. Determine percentage of wetted area.

$$P_w = \frac{N_p \times S_e \times (S_e + w)/2}{S_p \times S_r} \times 100 = \frac{4 \times 1 \times (1+1.2)/2}{3 \times 4} \times 100 = 55\%$$

16. In a border irrigation system, equation of infiltration rate into the soil is I=20t-0.5, net irrigation requirement is 5 centimeters, and advance time is 48 minutes. Determine amount of infiltrated water in beginning of border.

i_n = 5cm T_t = 48 min

$$i = \int I \, dt = \int 20t^{-0.5} \, dt = 40t^{0.5} + C$$

t_n = 4 x t_t = 4 x 48 = 192 min

$$50 = 40 \times \left(\frac{192}{60 \times 24}\right)^{0.5} + C \rightarrow C = 35.394 \text{ mm} \quad \frac{dI}{dt} = -10 \times t_o^{-1.5} = -\frac{0.05}{60} \times 20 \times t_o^{-0.5} \rightarrow t_o = 600 \text{ min}$$

$$i = 40 \times t^{0.5} + 35.394 = 40 \times \left(\frac{600}{60 \times 24}\right)^{0.5} + 35.394 = 61.214 \text{ mm}$$

17. In a two layers soil, root depth is 50 centimeters, maximum daily evapotranspiration is 8 millimeters, maximum allowable depletion is 50 percent, and application efficiency is 60 percent. According to the table, determine irrigation interval.

Soil layers	Depth (cm)	θ_m (%) in FC	θ_m (%) in PWP	ρ (g/cm³)
First layer	30	24	12	1.5
Second layer	20	20	10	1.6

D_r = 50 cm d_1 = 30 cm d_2 = 20 cm FC_1 = 24% FC_2 = 20% PWP_1 = 12%

PWP_2 = 10% ρ_1 = 1.5 g/cm³ ρ_2 = 1.6 g/cm³ ET_p = 8 mm/day

RAW = 50% AW E_a = 60%

$$\frac{dI}{dt} = -10 \times t_o^{-1.5} = -\frac{0.05}{60} \times 20 \times t_o^{-0.5} \rightarrow t_o = 600 \text{ min}$$

RAW = 0.5 x 2.2 = 1.1 cm

$$f = \frac{RAW}{\left(ET_a \times ET_p\right)} = \frac{1.1 \times 10}{0.6 \times 8} \cong 2 \text{ days}$$

18. In a center pivot system, length of span is 200 meters, considered area for irrigation is 14.5 hectares, wetted diameter of end emitter is 30 meters, net desired depth is 6 centimeters, design daily irrigation requirement is 10 millimeters, application efficiency is 85 percent, effective radius is 50 percent of wetted diameter of end emitter, and amount of water for irrigation without runoff is 70 percent of total amount of water for irrigation. Determine required discharge of system and irrigation time.

R = 200 m A = 14.5 ha D_e = 30 m D = 6 cm DDIR = 10 mm/day

E_a =85 % R_e = 50% D_e D_m = 70% D_a $R_e = \frac{50}{100} \times 30 = 15 \text{ m}$

S = 0.4 x D_e = 0.4 x 30 = 12 m $L = 2 \times \pi \times \left(R + \frac{R_e}{2}\right) = 2 \times \pi \times \left(200 + \frac{15}{2}\right) = 1303.761 \text{ m}$

$$H \le \frac{D}{DDIR} \le \frac{10 \times 6}{10} \le 6 \text{ days} \rightarrow H = 6 \text{ days}$$

D_a = H x DDIR = 6 x 10 = 6cm D_a

$$Q_{cp} = \frac{A \times DDIR}{E_a} = \frac{14.5 \times 10^4 \times 10 \times 10^{-3} \times 10^{-3}}{0.85 \times 60 \times 24} = 1185 \frac{1}{\text{min}}$$

$$Q_{cp} = Q_S = \frac{D_m \times L \times S}{(H - Tm) \times E_a} \rightarrow 1185 \times 10^{-3} = \frac{0.7 \times 6 \times 10^{-2} \times 1303.761 \times 12}{(H - Tm) \times 0.85} \rightarrow (H - Tm) \cong 11 \text{ hr}$$

19. In a spool sprinkle system, travel velocity is 7 meters per hour, distance of travel lines is 100 meters, and length of hose is 400 meters. Determine irrigated area at one hour. In addition, determine irrigated area as hectare.

In one hour, value of travel is 7 meters. Since distance of travel lines is 100 meters, irrigated area is equal to 700 cubic meters or 0.07 hectares. All of hose can irrigate 4 hectares.

20. In a farm experiment, depth of infiltrated water (as millimeter) obtained as follows:

40	35	34	37
39	33	34	35
26	28	27	32
37	30	28	26
40	35	32	43

If full depth of irrigation is 32.5 millimeters, determine uniformity coefficient and distribution uniformity.

$\bar{x} = 33.6$ mm $\quad$ S=4.7mm $\quad$ $\sum|d|$=73mm

$$C_u = 100\left(1 - \frac{\sum|d|}{n\bar{x}}\right) = 100\left(1 - \frac{73}{20 \times 33.6}\right) = 89.1\%$$

Or $$C_u = 100 - 80\left(\frac{0.47 \times 10}{33.6}\right) = 88.8\%$$

$$\bar{x}_{LQ} = \frac{26 + 26 + 27 + 28 + 28}{5} = 27 \text{ mm}$$

$$D_u = 100 \times \frac{\bar{x}_{LQ}}{\bar{x}} = 100 \times \frac{27}{33.6} = 80.4\%$$

or

D_u = 100 – 1.59 x (100 – C_u) = 100 – 1.59 x (100 – 89.1) = 83%

21. In a sprinkle irrigation system, diameter of sprinkler nozzle is 4.8 millimeters, S_p=12 m, S_r=18 m, nozzle pressure is 400 kilopascals, nozzle coefficient is 0.95, and precipitation efficiency is 100 percent. Determine nozzle discharge as millimeter per hour.

D=4.8mm $\quad$ P = 400 KPa = 40 m $\quad$ C = 0.95 $\quad$ E_p = 100% $\quad$ g = 9.806 m/s²

$$A = \frac{\pi D^2}{4} = \frac{\pi \times 4.8^2}{4} = 18.096 \times 10^{-6} \text{ mm}^2$$

$$Q = \frac{CAE_p\sqrt{2gP}}{100} = \frac{0.95 \times 18.096 \times 100 \times \sqrt{2 \times 9.806 \times 40}}{100} = 0.481 \times 10^{-3} \text{ m}^3/\text{s}$$

Q = S_p x S_r x v $\quad$ 0.481 x 10^{-3} = 12 x 18 x v → v = 8.025 mm/hr

22. In a furrow irrigation system, length of furrow is 200 meters, advance time is 240 minutes, advance equation is x=pt_x^r that 'p' and 'r' are 8 and 0.7, respectively. Distances of selected stations from beginning of furrow are 40, 80, 120, 160, and 200 meters. Integrated infiltration equation is Z=$5t^{0.56}$ (t as minute and Z as millimeter).

Determine time of infiltration opportunity and depth water into the soil in each station. In addition, if width of furrow is 0.8 meters, input discharge into the furrow is 1.5 liters per second, and root depth is 90 millimeters, determine deep percolation and runoff.

$x = 8t_x^{0.7}$ $40 = 8t_{x1}^{0.7}$ $80 = 8t_{x2}^{0.7}$ $120 = 8t_{x3}^{0.7}$ $160 = 8t_{x4}^{0.7}$ $200 = 8t_{x5}^{0.7}$

t_{x1} = 9.966 min t_{x2} = 26.827 min t_{x3} = 47.877 min t_{x4} = 72.213 min

t_{x5} = 99.325 min $t_n = t_{co} - t_x$ t_{co} = 240 min t_{n1} = 240 – 9.966 = 230.034 min

t_{n2} = 240 – 26.827 = 213.173 min t_{n3} = 240 – 47.877 = 192.123 min

t_{n4} = 240 – 72.2136 = 167.787 min t_{n5} = 240 – 99.325 = 140.675 min

$Z_1 = 5\text{x } 230.034^{0.56} = 105.093$ mm $Z_2 = 5 \text{ x } 213.173^{0.56} = 100.707$ mm

$Z_3 = 5\text{x } 192.123^{0.56} = 95.011$ mm $Z_4 = 5 \text{ x } 167.787^{0.56} = 88.071$ mm

$Z_5 = 5 \text{ x } 140.675^{0.56} = 79.794$ mm $Q = \dfrac{i_n \times w \times \times L}{t_{co}}$ $1.5 = \dfrac{i_n \times 0.8 \times 200}{240 \times 60} \to i_n = 135 \text{ mm}$

$$Z_{avg} = \frac{Z_1 + Z_2 + Z_3 + Z_4 + Z_5}{5} = \frac{105.093 + 100.707 + 95.011 + 88.071 + 79.794}{5} = 93.735 \text{ mm}$$

$D_{dp} = Z_{avg} - d_r$ = 93.735 – 90 = 3.735 mm Runoff = $i_n - Z_{avg}$ = 135 – 93.735 = 41.3mm

23. In a basin irrigation system, length of basin is 200 meters, advance time is 80 minutes, and infiltration equation is $Z=0.0021\tau^{0.331}+0.00015\tau$. Non-erosive velocity in the soil is 13 meters per minute, considered depth to store in the end of basin is 10 centimeters, and Manning's coefficient is 0.04. Determine cutoff time, infiltrated water depth in beginning of the basin, and deep percolation.

$$10 = 0.0021 \times \tau^{0.331} + 0.00015 \times \tau \to \tau = 1103.744 \text{ min}$$

$$t_{co} = \tau + t_t = 1103.744 + 80 = 1183.744 \text{ min}$$

$Z = 0.0021 \text{ x } (60 \text{ x } 1183.744)^{0.331} + 0.00015 \text{ x } (60 \text{ x } 1183.744) = 10.738$ cm

$$Q_{max} = \left[V_{max} \times \left(\frac{n^2 L}{7200} \right)^{0.23} \right]^{1.827} = \left[13 \times \left(\frac{0.04^2 \times 200}{7200} \right)^{0.23} \right]^{1.827} = 1.608 \text{ m}^3 / \text{min}$$

$Q_{max} = V_{max} \text{ x } i_n$ $1.608 = 13 \text{ x } i_n \to i_n = 12.369$ cm

$d_{dp} = i_n - Z$ = 12.369 – 10.738 = 1.631 cm

24. In a sprinkle irrigation system, length of lateral is 390 meters, discharge of sprinkler is 21 liters per minute, height of riser is 1.5 meters, downhill slop is 0.015, k_d=3.8, S_e=13 m, and C=130. Determine allowed pressure loss, proper diameter (among 2, 3, 4, 5, and 6) as inch, input pressure, end pressure, and value and position of minimum

pressure. Furthermore, investigate pressure variations in the lateral.

$H_{fa} = 0.2 \times H_a$ $\quad q_a = k_d\sqrt{H_a}$ $\quad 21 = 3.8 \times \sqrt{H_a} \rightarrow H_a = 30.54\ \text{m}$

$H_{fa} = 0.2 \times 30.54 = 6.108\ \text{m}$

$$S = 7.89 \times 10^7 \times \left[Q_L - \frac{x}{S_e} q_a\right]^{1.75} D^{-4.75}$$

$$Q_L = \frac{L}{S_e} \times q_a = \frac{390 \times 0.35}{13} = 10.5\ \text{l/s}$$

$$0.015 = 7.89 \times 10^7 \times \left[10.5 - \frac{x}{13} \times 0.35\right]^{1.75} D^{-4.75}$$

If: $D = 2\ \text{in} = 50.8\ \text{mm} \rightarrow x \cong 390\ \text{m}$ if: $D = 6\ \text{in} = 152.4\ \text{mm} \rightarrow x \cong 303\ \text{m} \rightarrow H_{end} = H_{min}$

$$H_{max} - H_{min} = 6.108 = H_f - 0.5 \times 0.015 \times 390 \rightarrow H_f = 9.033\ \text{m}$$

$$9.033 = \frac{J \times 0.36 \times 390}{100} \rightarrow J = 6.434$$

$$6.434 = 7.89 \times 10^7 \times 10.5^{1.75} \times D^{-4.75} \rightarrow D = 73.886\ \text{mm} = 2.91\ \text{in} \cong 3\ \text{in}$$

$J = 7.89 \times 10^7 \times 10.5^{1.75} \times (3 \times 25.4)^{-4.75} = 5.557$

$$H_f = \frac{J \times F \times L}{100} = \frac{5.557 \times 0.36 \times 390}{100} = 7.802\ \text{m}$$

$$H_L = H_a + H_r + \frac{3}{4} H_f - \frac{1}{2} \Delta EL = 30.54 + 1.5 + \frac{3}{4} \times 7.802 - \frac{1}{2} \times 0.015 \times 390 = 34.967\ \text{m}$$

$$H_{end} = H_L - H_f + \frac{1}{2} \Delta EL = 34.967 - 7.802 + \frac{1}{2} \times 0.015 \times 390 = 30.09\ \text{m}$$

$\Delta H = H_L - H_{end} = 34.967 - 30.09 = 4.887\ \text{m} \rightarrow \Delta H < H_{fa} \rightarrow \text{OK}$

$$0.015 = 7.89 \times 10^7 \times \left[10.5 - \frac{x}{13} \times 0.35\right]^{1.75} \times 76.2^{-4.75} \rightarrow x = 376.721\ \text{m}$$

$$H_f = \frac{J \times F \times L}{100} = \frac{0.015 \times 0.36 \times 376.721}{100} = 0.02\ \text{m}$$

$$H_{min} = 34.967 - 7.802 + \frac{1}{2} \times (0.015 \times 376.721) = 29.99\ \text{m} \rightarrow H_{min} < H_{end} < H_L \rightarrow \text{OK}$$

25. In a five hectares farm (sugar beet), leaching requirement is 25 percent and application efficiency is 35 percent. According to the table, determine net irrigation requirement using Blaney-Criddle method.

Month	October	November	December	January	February	March	April	May
ET_o (mm)	175	120	60	55	80	125	170	250
K_c	0.40	0.90	0.90	1.03	1.10	1.10	1.10	0.77

A =5ha L = 0.25 x ET E_a = 0.35 d = 241 days n = 8

$$ET=\sum_{i=1}^{n}k_iET_{oi}=k_1ET_{o1}+k_2ET_{o2}+k_3ET_{o3}+k_4ET_{o4}+k_5ET_{o5}+k_6ET_{o6}+k_7ET_{o7}+k_8ET_{o8}\cong 1\text{ m}$$

$$I=\frac{ET+L}{E_a}=\frac{893.65+0.25\times 893.65}{0.35}=3191.61\text{ mm}\rightarrow i=5.77\text{ mm / day}$$

26. In a five hectares farm (grains), volume of irrigation is 52000 cubic meters and evapotranspiration is 1000 millimeters. Determine irrigation efficiency and deep percolation. If irrigation efficiency is 80 percent, determine water requirement. Do not consider effective rain.

A = 5ha V = 52000 m³ ET = 1000 mm $I=\frac{V}{A}=\frac{52000}{50000}=1.04\text{ m}$

$$I=\frac{ET}{E_i}\qquad 1.04=\frac{1000}{E_i}\rightarrow E_i=96.2\%$$

L= 40 mm Ei = 0.8

$$I=\frac{ET+L}{E_a}=\frac{1000+40}{0.8}=1300\text{ mm}\rightarrow V=65000\text{ m}^3$$

27. Relative transpiration of a crop is decreasing 50 percent in a matrix potential equal to −31 meters and is stopping in a matrix potential equal to −31 meters. Beginning of decrease in relative transpiration because of moisture shortage is occurring in a matrix potential equal to −1000 centimeters and volumetric moisture of soil during water stress period is 0.15 cm³/cm³. According to the formulas and the table, determine value of performance decreasing.

$$\text{Linear: }\alpha=\frac{h_3-h}{h_3-h_4}\quad \text{Nonlinear: }\alpha=\frac{1}{1+\left(\dfrac{h^*-h}{h^*-h_{50}}\right)^P}$$

ψm (m)	50	2.5	1	0
θv	0.15	0.35	0.45	0.5

$H_3 = h_m$ = -1000 cm h_{50} = -31 m h = -50 m h_4 = -80 m

$$\alpha = \frac{-10-(-50)}{-10-(-80)} = 0.57 \rightarrow \text{transpiration and performance is decreasing by43 percent}$$

$$P = \frac{h^*}{h^* - h_{50}} = \frac{-10}{-10-(-31)} = -0.48$$

$$\alpha = \frac{1}{1+\left(\dfrac{-10-(-50)}{-10-(-31)}\right)^{-0.48}} = 0.58 \rightarrow \text{transpiration and performance is decreasing by42 percent}$$

Note that obtained results from both linear and nonlinear equations are almost similar.

28.Threshold Value of performance of Soya is 5 DeciSiemens per meter and its decreasing slope is 20 percent per DeciSiemens per meter. According to the equations, determine relative transpiration while salinity of soil saturation extract is decreasing from 16 to 26 DeciSiemens per meter.

Linear: yr = 1 – a(EC – EC*) Nonlinear: $\alpha = \dfrac{1}{1+\left(\dfrac{h^*-h}{h^*-h_{50}}\right)^{P}}$

EC*=5dS/ a=20%dS/m EC_1=16dS/m EC_2=26dS/m

$$P = \frac{0.36\times 5}{0.36\times(5-7.5)} = -2$$

$$\alpha = \frac{1}{1+\left(\dfrac{0.36\times(5-16)}{0.36\times(5-7.5)}\right)^{-2}} = 0.95 \rightarrow \text{relative transpiration is0.05}$$

EC = 26 -16 = 10 dS/m y_r = 1- 0.2(10-5) = 0

29. In a farm soil, bulk density is 1.4 grams per cubic centimeter and moisture characteristic equation is θm=0.26−0.07 (log Ψ−1.0), which θm is soil moisture and Ψ is water potential in the soil as centimeter. Discharge of pumped water to the farm is 250 liters per second and area of the farm is 25 hectare. Determine pump operating time for increase soil moisture to field capacity. In beginning of pumping, 65 percent of soil moisture has been discharged (till 50 centimeters depth). Soil suction in the field capacity is 270 centimeters and crop extractable water is 2000 centimeters.

ρ_b = 1.4 gr/cm³ A = 25 ha Q = 250 l/s Ψ_{FC} = 270 cm Ψ_{PWP} = 2000 cm

θ_{FC} = 0.26 – 0.07(log270 – 1.0) = 0.16 θ_{PWP} = 0.26 – 0.07(log2000 – 1.0) = 0.10

$$\rho_b = \frac{M_s}{V_t} \rightarrow 1.4 \times 10^6 = \frac{M_s}{25 \times 10^4 \times 0.5} \rightarrow M_s = 17.5 \times 10^{10} \text{ gr}$$

$\theta_v = \theta_{FC} - \theta_{PWP}$ = 0.16 – 0.10 = 0.06

$$\theta_v = \frac{M_w}{M_s} \rightarrow 0.06 = \frac{M_w}{17.5 \times 10^{10}} \rightarrow M_w = 1.05 \times 10^{10} \text{ gr}$$

$$V_w = \frac{M_w}{\tilde{n}_w} = \frac{1.05 \times 10^{10}}{10^6} = 1.05 \times 10^4 \text{ m}^3 \quad t = \frac{V_w}{Q} = \frac{1.05 \times 10^4}{250 \times 10^{-3} \times 3600} \cong 12 \text{ hr}$$

30. In an anisotropic soil, water table and water leveling for point ‘a’ are 25 and 1950 meters, respectively. Determine time that the water reach to point b (distance from point ‘a’ is 500 meters). Soil hydraulic conductivity in the top layer (15 meters) is 55 meters per day and in the bottom layer (20 meters) is 40 meters per day. Water table and water leveling for point b are 20 and 18000 meters, respectively. Soil porosity is 30 percent.

n = 30% h_a = 25 m h_b = 20 m Z_a = 1950 m Z_b = 1800 m D = 500 m

K_1 = 55 m/day L_1 = 15 m K_2 = 40 m/day L_2 = 20 m

$\theta_a = h_a + Z_a$=25+1950=1975m

$\theta_b = h_b + Z_b$=20+1800=1820m

$$K_h = \frac{K_1 L_1 + K_2 L_2}{L_1 + L_2} = \frac{55 \times 15 + 40 \times 20}{15 + 20} = 46.43 \text{ m/day}$$

$$V = K_h \frac{\Delta\phi}{D} = 46.43 \times \frac{1975 - 1820}{500} = 14.39 \text{ m/day} \quad V_s = \frac{V}{n} = \frac{14.39}{0.3} = 47.98 \text{ m/day}$$

$$t = \frac{L}{V_s} = \frac{500}{47.98} \cong 10 \text{ days}$$

31. In a lysimeter, soil depth is 1.5 meters and volumetric moisture at beginning of period is 35 percent. Effective precipitation for rainfalls>20 millimeters is 50 percent of the rainfalls and for rainfalls<20 millimeters is 75 percent of the rainfalls. According to the table, determine evapotranspiration in the growth period. In addition, determine crop coefficient in the growth period using the equation.

Month	Monthly temperature (◦C)	Relative humidity (%)	Rainfall (mm)	Irrigation (mm)	Drainage (mm)	Volumetric moisture (%)
April	10	45	40	120	20	22
May	12	42	32	130	25	18
June	15	38	22	150	40	19
July	20	35	18	180	35	20

August	25	32	10	200	40	22
September	20	37	5	120	25	20

$ET_0 = 0.45 + 1.5\ RH_{min}(0.46T + 8.13)$

$ET = 1 + P_e - L - D_{rz}(\theta_f - \theta_i)$ $D_{rz} = 1.5$ m $\theta_i = 35\%$ $Kc = \frac{ET}{ET_o}$

$ET_{April} = 120 + 0.5 \times 40 - 20 - 1.5 \times 1000 \times (0.22 - 0.35) = 315$ mm

$ET_{May} = 130 + 0.5 \times 32 - 25 - 1.5 \times 1000 \times (0.18 - 0.35) = 376$ mm

$ET_{June} = 150 + 0.5 \times 22 - 40 - 1.5 \times 1000 \times (0.19 - 0.35) = 361$ mm

$ET_{July} = 180 + 0.75 \times 18 - 35 - 1.5 \times 1000 \times (0.20 - 0.35) = 383.5$ mm

$ET_{August} = 200 + 0.75 \times 10 - 40 - 1.5 \times 1000 \times (0.22 - 0.35) = 362.5$ mm

$ET_{September} = 120 + 0.75 \times 5 - 25 - 1.5 \text{ X } 1000 \times (0.20 - 0.35) = 323.75$ mm

$ET_{0April} = 0.45 + 1.5 \times 45 \times (0.46 \times 10 + 8.13) = 859.725$ mm

$ET_{0May} = 0.45 + 1.5 \times 42 \times (0.46 \times 12 + 8.13) = 860.4$ mm

$ET_{0June} = 0.45 + 1.5 \times 38 \times (0.46 \times 15 + 8.13) = 857.16$ mm

$ET_{0July} = 0.45 + 1.5 \times 35 \times (0.46 \times 20 + 8.13) = 910.275$ mm

$ET_{0August} = 0.45 + 1.5 \times 32 \times (0.46 \times 25 + 8.13) = 942.69$ mm

$ET_{0September} = 0.45 + 1.5 \times 37 \times (0.46 \times 20 + 8.13) = 862.265$ mm

$$Kc_{April} = \frac{315}{859.725} = 0.366$$

$$Kc_{May} = \frac{376}{860.4} = 0.437$$

$$Kc_{June} = \frac{361}{857.16} = 0.421$$

$$Kc_{July} = \frac{383.5}{910.275} = 0.421$$

$$Kc_{August} = \frac{362.5}{942.69} = 0.385$$

$$Kc_{September} = \frac{323.75}{862.265} = 0.336$$

32. In a farm soil, infiltration rate equation is $i=0.095t^{-0.36}$, which t is time as minute and i is infiltration rate as centimeter per minute. Determine time to reach the final infiltration rate and amount of infiltrated water in the soil.

$$\frac{di}{dt} = -0.0342t^{-1.36}$$

$$-0.0342t^{-1.36} = -\frac{0.05}{60}\left(0.095t^{-0.36}\right) \rightarrow t = 432 \text{ min}$$

$$I = \int_0^t i\ dt = \int_0^{432} 0.095t^{-0.36}\ dt = 7.215 \text{ cm}$$

33. In a surface irrigation system, water electrical conductivity is 0.5 deciSiemens per meter and leaching fraction is 0.15. Electrical conductivity of water resource (a well) is 5 deciSiemens per meter and annual crop evapotranspiration is 100 millimeters. For a desired efficiency, the electrical conductivity of the saturation extract and the electrical conductivity of the irrigation water must be 3 and 2 deciSiemens per meter, respectively. Determine mixing ratio of the surface water and the well water.

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad LR_S = \frac{0.5}{5 \times 3 - 0.5} = 0.034 < 0.15$$

$$LR_w = \frac{5}{5 \times 3 - 5} = 0.5$$

$$AW_S = \frac{100}{1 - 0.15} \cong 118 \text{ mm / year}$$

$$AW_w = \frac{100}{1 - 0.5} = 200 \text{ mm / year}$$

Using only well water, led to 50 percent more consumption (200 versus 100).

EC_S x a + EC_w x b = max EC_{mix} → 0.5 x (1-b) + 5 x b = 2 →b = 0.33

34. Two tensiometers have been established in depths of 40 and 80 centimeters, Gauged pressures by them are 60 and 120 centimeters, respectively. Value of rainfall is 10 millimeters per day in study area. Determine soil hydraulic conductivity.

$$R = k\frac{\Delta\phi}{\Delta L} \rightarrow 10 = k\frac{120 - 60}{80 - 40} \rightarrow k = 6.667 \text{ mm / day}$$

35. In an irrigated area, evapotranspiration is 1655 millimeters per year, deep percolation is 695 millimeters per year, and LR_r=140 mm. Electrical conductivity for irrigation water is 1.75 millimhoses per centimeter, soil saturation extract is 3.5 millimhoses per centimeter, and EC_p=7.0 mmhos/cm. Determine LR_i and leaching percentage.

$ET = 1655$ mm $R = 695$ mm $EC_i = 1.75$ mmhos/cm

$ETR_c = R - LR_r = 695 - 140 = 555$ mm

$I_c = ET - R_c = 1655 - 555 = 1100 \text{ mm} = (I_c + LR_i) \times EC_i = (1100 + LR_i) \times 1.75$

$LR \times EC_p = (LR_i + LR_r) \times EC_p = (LR_i + 140) \times 7 = 7LR_i + 980$

$925 + 1.75LR_i = 7LRi + 980 \rightarrow LR_i = 180$ mm

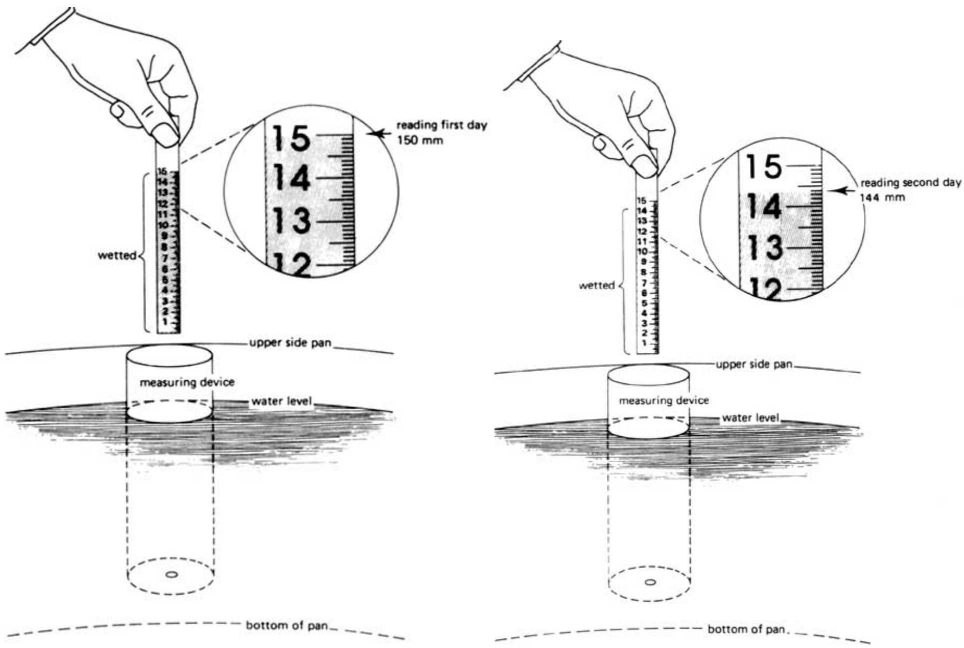
$I = I_c + LR_i = 1100 + 180 = 1280$ mm

$$LR = \frac{LR_i}{I} \times 100 = \frac{180}{1280} \times 100 = 14\%$$

36. Determine evapotranspiration using below information and the figures:

Rainfall (during 24 hours) = 0 mm

K pan = 0.75



$ET_o = K \text{ pan} \times E \text{ pan}$

$E_{pan} = 150 - 144 = 6$ mm/day

$ET_o = 0.75 \times 6 = 4.5$ mm/day

37. Determine evapotranspiration using below information:

Water depth in pan on day 1 = 411 mm

Water depth in pan on day 2 = 409 mm (after 24 hours)

Rainfall (during 24 hours) = 7 mm

$K_{pan} = 0.90$

$ET_o = K_{pan} \times E_{pan}$

$E_{pan} = 411 - 409 + 7 = 9$ mm/day

$ET_o = 0.90 \times 9 = 8.1$ mm/day

38. Given:

Latitude - 35° North

Mean T max in April = 29.5°C

Mean T min in April = 19.4°C

Find: Determine for the month April the mean ET_o in mm/day using the Blaney-Criddle method

$ET_o = p\ (0.46\ T\ mean + 8)$

Step 1: determine T mean:

$$T_{mean} = \frac{T_{max} + T_{min}}{2} = \frac{29.5 + 19.4}{2} = 24.5℃$$

Step 2: determine p:

p = 0.29

Step 3: calculate ET_o: $ET_o = 0.29\ (0.46 \times 24.5 + 8) = 5.6$ mm/day

Thus the mean reference crop evapotranspiration ET_o =5.6 mm/day during the whole month of April.

39. Estimate the duration of the four growth stages for the following crops: cotton (190 days), lentils (160 days), sweet maize (100 days), potatoes (130 days), tomatoes/ transplanted (140 days from transplant).

Crop	Initial stage	Crop dev. Stage (days)	Mid-season stage (days)	Late season stage
Cotton (190- days)	30	50	60	50
Lentils (160 days)	25	30	65	40
Sweet maize (100 days)	20	30	40	10

Potatoes (130 days)	30	35	40	25
Tomatoes/transplanted (140 days from transplant)	15	40	60	25

40. Determine the crop water need of tomatoes using the figure:

Month	Jan	Feb Mar	Apr	May	June	July
ET_o (mm/day)	4.0	5.0 5.8	6.3	6.8	7.1	6.5
Humidity	medium	(60%)				
Windspeed	medium	(3m/sec)				
Duration of growing period (from sowing): 150 days						
Planting date: 1 February (direct sowing)						

Step 1: Estimate the duration of the various growth stages

Crop	Total growing period (days)	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Tomatoes	150	35	40	50	25

Step 2: The ETo values and the duration of the growth stages.

Note: When calculating the crop water needs, all months are assumed to have 30 days. For the calculation of the reference crop evapotranspiration, the actual number of days of each month is used e.g., January 31 days, February 28 or 29 days, etc.

Crop: tomatoes planting date: 1 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_o (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		Initial st	Crop dev st	Mid-season at	Late s. st							

Planting date	1 Feb
Initial stage, 35 days	1 Feb-5 Mar
Crop development stage, 50 days	6 Mar- 15 Apr
Mid-season stage, 50 days	16 Apr- 5 Jun
Late season stage, 25 days	6 Jun- 30 Jun
Last day of the harvest	30 Jun

Step 3: Estimate the Kc factor for each of the 4 growth stages

$K_{c,}$ initial stage =0.45

$K_{c,}$ crop development stage =0.75

$K_{c,}$ mid-season stage =1.15

$K_{c,}$ late season stage =0.8

It can be seen from the table above that the months and growth stages do not correspond. As a consequence the ET_o and the K_c values do not correspond.

Yet the ET crop (= $ET_o \times K_c$) has to be determined on a monthly basis. It is thus necessary to determine the K_c on a monthly basis, which is done as follows:

February: K_c Feb = 0.45

March: 5 days: K_c = 0.45, 25 days: Kc = 0.75

$$Kc_{March} = \frac{5}{30} \times 0.45 + \frac{25}{30} \times 0.75 = 0.07 + 0.62 \cong 0.70$$

April: 15 days: Kc = 0.75, 15 days: Kc = 1.15

$$Kc_{April} = \frac{15}{30} \times 0.75 + \frac{15}{30} \times 1.15 = 0.38 + 0.58 \cong 0.95$$

May: Kc, May = 1.15

June: 5 days: Kc = 1.15, 25 days: Kc = 0.80

$$Kc_{June} = \frac{5}{30} \times 1.15 + \frac{25}{30} \times 0.80 = 0.19 + 0.67 \cong 0.85$$

Step 4: Calculate, on a monthly basis, the crop water need, using the formula:

ET crop = ET_o × Kc (mm/day)

February: ET crop = 5.0 × 0.45 = 2.3 mm/day

March: ET crop = 5.8 × 0.70 = 4.1 mm/day

April: ET crop = 6.3 × 0.95 = 6.0 mm/day

May: ET crop = 6.8 × 1.15 = 7.8 mm/day

June: ET crop = 7.1 × 0.85 = 6.0 mm/day

Step 5: Calculate the monthly and seasonal crop water needs.

Note: all months are assumed to have 30 days.

February: ET crop = 30 × 2.3 = 69 mm/month

March: ET crop = 30 × 4.1 = 123 mm/month

April: ET crop = 30 × 6.0 = 180 mm/month

May: ET crop = 30 × 7.8 = 234 mm/month

June: ET crop = 30 × 6.0 = 180 mm/month

The crop water need for the whole growing season of tomatoes is 786 mm.

41. Calculate the effective rainfall for the following monthly rainfall figures: P = 35, 90,116, 5, 260, 75 mm

P (mm/month0	Formula	Pe (mm/month)
35	Pe =0.6 P- 10	1
90	Pe = 0.8 P – 25	47
116	Pe =0.8 P – 25	68
5	Pe =0.6 P – 10	0
260	Pe = 0.8 P – 25	183
75	PE = 0.8 P – 25 or 0.6 P - 10	35

42. Calculate the irrigation water need (IN) of paddy rice for the month of April when given:

- **ET_o = 6 mm/day**
- **Kc = 1.1**
- **the root zone has already been saturated in the previous month**
- **PERC = 5 mm/day**
- **the water layer (100 mm) needs to be established during April**
- **Pe = 135 mm/month**

IN = ET crop + SAT + PERC + WL - Pe

ET crop = ET_o × Kc = 6 × 1.1 = 6.6 mm/day = 6.6 × 30 = 198 mm/month

SAT = 0 mm

PERC = 5 mm/day = 5 × 30 = 150 mm/month

WL = 100 mm

Pe = 135 mm/month

IN = 198 + 0 + 150 + 100 - 135 = 313 mm/month = 10.4 mm/day

Thus the irrigation water need during April is 313 mm or 10.4 mm/day.

43. The base period, duty of water and area under irrigation for various crops under a canal system are given in the figure. If the losses in the reservoir and canals are respectively 15%, 25%, determine the reservoir capacity.

Crop	Wheat	Sugar cane	Cotton	Rice	V. table
Base period B (days)	120	320	180	120	120
Duty, D (ha/cumec)	1800	1600	1500	800	700
Area irrigated (ha)	15000	10000	5000	7500	5000

Total volume of water 47,910 ha-m

$$\text{Volume at head of canal} = \frac{47910}{0.75} = 63880 \text{ ha} - \text{m}$$

$$\text{Volume of reservoir} = \frac{63880}{0.85} = 75150 \text{ ha} - \text{m}$$

44. Determine the consumptive use for wheat from the following data by Blaney-Criddle method. Take K= 0.7

Month	nov	dec	jan	Feb
Mean temperature, oC, T_m	20	16	14	15
% month day light hrs, P	7.19	7.15	7.3	7.03

For the month of November

$$f = P \times \frac{4.6T_m + 81.3}{100} = 7.19 \times \frac{4.6 \times 20 + 81.3}{100} = 12.46$$

u = kf = 0.7 X 12.46 = 8.72 cm

Likewise, the values of u for months Dec., Jan. and Feb. are computed as 7.75, 7.44 and 7.40cm respectively. Thus, seasonal consumptive use,

$$U = \sum_{i=1}^{4} u_i = 8.72 + 7.75 + 7.44 + 7.40 = 31.31 \text{ cm}$$

45. Estimate the potential evapo-transpiration for a crop for the month of June using the Thornthwaite equation from the following data.

Month	Apr	May	June	july	Aug	Sep	Oct
Temp, T_m (oC)	4.5	12.5	20.4	20.2	21.5	10.5	5.5
Max sun shine hrs	370	380	365	358	355	350	345

Step 1: Obtain the monthly heat index, i

Step 2: Calculate the annual heat index, I

Step 3: Determine the constants a & b and finally estimate PET for each month. The monthly heat index is determined as:

$$i = \left(\frac{T_m}{5}\right)^{1.514}$$

Month	Apr	May	June	July	Aug	Sep	Oct
Heat index i	0.85	4.00	8.40	8.28	9.10	3.07	1.16
Factor B	1.03	1.06	1.01	0.99	0.99	0.97	0.96

a = 1.051 a

b = 1.01 b

Then potential evapotranspiration for the month June is given by:

$$PET = 1.6b\left(\frac{10T_m}{I}\right)^a = 1.6 \times 1.01 \times \left(\frac{10 \times 20.4}{34.86}\right)^{1.051} = 10.35 \text{ cm}$$

46. Given the wind, speed at 3 m height is 250 km/day; calculate the wind function f (U) by applying the correction factor for the wind speed.

U (applying correction) = 0.93 x 250 = 232 km/day

f(u) = 0.90

Or

$$f(u) = 0.27 \times \left(1 + \frac{U_2}{100}\right)$$

47. Determine evapotranspiration using below information:

W=0.77

Rn=6.6

f(u)=0.9

e_a-e_d=17.5

C=1.01

ET_O = 1.01 (0.77 x 6.6 + 0.23 x 0.9 x 17.5) = 8.8 mm/day

48. A stream size of 150 lit /sec was released from the diversion headwork to irrigate a land of area 1.8 hectares. The stream size when measured at the delivery to the field channels is 120lit/sec. The stream continued for h hours. The effective root zone depth is 1.80m. The application losses in the field are estimated to be 440m³. The depth of water penetration was 1.80m and 1.20m at the head and tail of the run respectively. The available water holding capacity of the soil is 21cm/m and irrigation was done at 60% depletion of Am. Find E_c, E_f, E_a, E_s and E_d. The stream size delivered to the plot was 100 lit/sec.

$$E_c = \frac{W_f}{W_d} \times 100 = \frac{120}{150} \times 100 = 80\% \quad E_f = \frac{W_p}{W_f} \times 100 = \frac{100}{120} \times 100 = 83.3\%$$

$$\text{Water delivered to the plot} = \frac{100 \times 60 \times 60 \times 8}{1000} = 2880 \text{ m}^3$$

Water stored in the root zone = Water delivered to the plot – Application loss

Water stored in the root zone = 2880 – 2440 m3

$$E_a = \frac{W_s}{W_p} \times 100 = \frac{2440}{2880} \times 100 = 84.7\%$$

$$\text{Total A.M.} = \frac{21\text{cm}}{\text{m}} \times 1.80\text{m} = 37.80 \text{ cm}$$

$$\text{RAM} = \frac{60}{100} \times 37.80 = 22.68 \text{ cm}$$

$$\text{RAM} = \frac{22.68}{100} \times 1.8 \times 10^4 = 4082.4 \text{ m}^3$$

$$E_s = \frac{W_s}{W_n} \times 100 = \frac{2440}{4082.4} = 59.8\% \cong 60\%$$

$$\text{Average water penetration} = d = \frac{1.8+1.2}{2} = 1.5 \text{ m}$$

Numerical deviation at upper end = 1.8 – 1.5 = 0.3 m

Numerical deviation at lower end = 1.5 – 1.2 = 0.3 m

$$\text{Average numerical deviation} = \frac{2 \times 0.3}{2} = 0.3 \text{ m}$$

$$E_d = 100\left(1 - \frac{y}{d}\right) = 100\left(1 - \frac{0.3}{1.5}\right) = 80\%$$

49. A crop has in effective root zone of 120 cm (1.20 m) prior to irrigation; soil samples were taken from different depths to determine the moisture status of the soil.

Depth of root zone (m)	Weight of soil sample (gm)	Weight of oven dry soil (g)
0 -0.30	98.80	94.60
0.30- 0.60	96.60	92.10
0.60- 0.90	95.00	90.60
0.90- 1.20	94.00	89.40

The water holding capacity of the soil at field capacity is 19.60 cm/meter. The apparent specific gravity of the soil is 1.60. Determine the moisture content in the root zone at different depths total depth of water available in the root zone at different depths, total depth of water available in the root zone and the soil moisture deficit.

For depth from 0-0.3 m:

Mass of water = 98.8 – 94.6 = 4.2 gm

$$\text{Moisture content} = W = \frac{4.2}{94.6} \times 100 = 4.44\%$$

In depth of water

$d = A_s D_p$ = 1.6 X 0.3 X 0.0444 = 0.0213 m = 2.13 cm

For depth 0.3-0.6 m:

Mass of Water = 96.6 – 92.1 = 4.5 gm

$$\text{Moisture content} = W = \frac{4.5}{92.1} \times 100 = 4.88\%$$

In depth of water

$d = A_s D_p$ = 1.6 X 0.3 X 0.0488 = 0.0234 m = 2.34 cm

For depth 0.6-0.9 m:

Mass of Water = 95.0 – 90.6 = 4.4 gm

$$\text{Moisture content} = W = \frac{4.4}{90.6} \times 100 = 4.86\%$$

In depth of water

$d = A_s D_p$ = 1.6 X 0.3 X 0.0486 = 0.0233 m = 2.33 cm

For depth 0.9-1.2 m:

Mass of Water = 94.0 – 89.4 = 4.6 gm

$$\text{Moisture content} = W = \frac{4.6}{89.4} \times 100 = 5.14\%$$

In depth of water

$d = A_s D_p$ = 1.6 X 0.3 X 0.0514 = 0.0247 m = 2.47 cm

The total depth of water in the root zone is the total of all the water retained at different depths.

$$\text{Total depth} = \sum_{i=1}^{4} d_i = 2.13 + 2.34 + 2.33 + 2.47 = 9.27 \text{ cm}$$

Water retained at field capacity = 19.6 x 1.2 = 23.52 cm

Water in the root zone = 19.6 x 1.2 = 23.52 cm

The soil moisture deficit prior to irrigation is therefore,

FC – depth of water during sampling = 23.52 – 9.27 = 14.25 cm

This deficit is the amount of water, which should be added to the soil to bring the soil moisture content to field capacity. Thus, it represents the depth of irrigation. Assuming that the peak rate of consumptive use during the stage of the plant is 8mm/day

$$i = \frac{\text{depth}}{\text{peack cu}} = \frac{142.5}{8} = 17.8 \text{ days} \rightarrow i = 17 \text{ days}$$

The next watering will be done after 17 days. The interval should not be made 18 days, because the plant may suffer shortage of water for one day.

50. In an agricultural area high water table occur. A subsurface drainage system is to be installed to control the water table under the following conditions:

Design discharge rate is 1mm/d;

The depth of the water table midway between the drains is to be kept a 1.0 m below the ground surface.

Drains will be installed at a depth of 2m;

PVC drainpipes with a radius of 0.10 m will be used

A deep auguring revealed that there is a layer of low conductivity at 6.8 m, which can be regarded as the base of the flow region. Auger-hole measurements were made to calculate the hydraulic conductivity of the soil above the impervious layer. Its average value was found to be 0.14 m/d.

If we assume a homogeneous soil profile, we can use the Hooghoudt Equation to calculate the drain spacing. We have the following data:

Q = 1mm/d = 0.001 m/d

h = 2.0 - 1.0 = 1.0m

r0 = 0.10 m

K = 0.14 m/d

D = 6.8 - 2.0 = 4.8m

Substitution of the above values into Hooghoudt equation yields

$$L^2 = \frac{8Kdh + 4Kh^2}{q} = \frac{8 \times 0.14 \times d \times 1 + 4 \times 0.14 \times 1^2}{0.001} = 1120d + 560$$

As the equivalent depth, d, is a function of L (among other things), we can only solve this quadratic equation for L by trial and error.

First estimate: L = 75 m. We can determine the equivalent depth, d using the equation given above

=> d = 3.40

Thus, L^2 = 1120 × 3.40 + 560 = 4368 m^2. This is not in agreement with L^2 =75^2 = 5625 m^2. Apparently, the spacing of 75 m is too wide.

Second estimate: L, = 50 m.

=> d = 2.96

Thus L^2 = 1120 × 2.96 + 560 = 3875 m^2. This is not in agreement with L^2 = 502=2500 m^2.

Thus, spacing of 50 m is too narrow.

Third estimate: L = 65 m

=> d =3.22

Thus L^2 = 1120 × 3.22 + 560 = 4171 m^2. This is sufficiently close to $L^2 = 65^2 = 4225m^2$.

Therefore, we can select a spacing of 65 m.

51. A trial configuration of a hand- move sprinkler system has a lateral running down slope form a mainline along a constant grade of 0.005m/m. the design operating pressure of the nozzle is 310 kpa. The trial length of the lateral results in a distance of 400m between the first and the last sprinkler. Determine maximum allowable head loss to friction as m/m.

$$H_a = \frac{P}{\rho g} = \frac{310 \times 10^3}{10^3 \times 9.81} = 31.61\ m$$

Since the elevation decreases along the lateral, the increase in elevation is –ve

H_e = -s x l = - .005 x 400 = 2 m

Setting the allowable pressure difference between the critical sprinklers equal to 20%.

$$H_c = \frac{0.2 \times 31.61 — 2}{400} 400 = 0.021\ m/m$$

52. Calculate the specific capacity of an open well from the following data,

Initial depression head = 5 m

Final depression head = 2 m

Time of recuperation = 2 hr

Diameter of well = 3 m

Calculate also the specific yield and yield of the well under head of 3 m.

$$A = \frac{\pi}{4} \times 3^2 = 7.07\ m^2$$

T= 2 hr H_1=5 m H_2=2 m H=3 m

$$K = \frac{2.303 \times A}{T} \log\left[\frac{H_1}{H_2}\right] = \frac{2.303 \times 7.07}{2} \log\left[\frac{5}{2}\right] = 3.24\ m^3/hr/unit\ head$$

So, the specific capacity is 3.24 m^3/hr/unit head

$$Specific\ yield = \frac{K}{A} = \frac{3.24}{7.07} = \frac{0.458 \frac{m^3}{hr}}{m^2}$$ Yield of well = Q = K X H = 3.24 X 3 = 9.72 m^3/hr

53. Find the diameter of an open well to give the discharge of 3 l/s. The depression head is 3 m and specific yield is 1 m³/hr/m².

$$Q = KH = \frac{K}{A}AH \quad \frac{K}{A} = \frac{1\frac{m^3}{hr}}{m^2}$$

$$A = \frac{\pi}{4} \times d^2 \; (assuming\ the\ diameter\ of\ well\ as\ d\ m)$$

H = 3 m

$$Q = 3\frac{l}{s} = \frac{3 \times 60 \times 60}{1000} = 10.8\frac{m^3}{hr}$$

$$10.8 = 1 \times \frac{\pi}{4} \times d^2 \times 3 \rightarrow d = 2.14\ m$$

54. A channel is to be designed for irrigation 5000 hectares in Kharif crop and 4000 hectares in Rabi crop. The water requirement for Kharif and Rabi are 60 cm and 25 cm, respectively. The Kor period for Kharif is 3 weeks and for Rabi is 4 weeks. Determine the discharge of the channel for which it is to be designed.

$$\text{n} = \frac{8.64 \times B}{D} = 60\ cm$$

B= 3 weeks = 21 days

$$Duty = \frac{8.64 \times 21}{0.6} = 302.4\frac{ha}{m^3}$$

Area to be irrigated = 5000 ha

$$Required\ discharge\ of\ channel = \frac{5000}{302.4} = 16.53\ m^3/s$$ Δ = 25 cm

B= 4 weeks = 28 days

$$\text{Duty} = \frac{8.64 \times 28}{0.25} = 967.684\frac{\text{ha}}{\text{m}^3}$$

Area to be irrigated = 4000 ha

$$\text{Required discharge of channel} = \frac{4000}{967.68} = 4.13\ \text{m}^3/\text{s}$$

So, the channel is to be designed for the maximum discharge of 16.53 m³/s, because this discharge capacity of the channel will be able to supply water to both the seasons.

55. Given:

IF=0.5

e_d=80%

Q_u=0.005 m^3/s

I_n=100 mm

N=0.15

Find:

T_n, L, T_{co}, and d_{max}

$$T_n = \left[\frac{i_n - c}{a}\right]^{\frac{1}{b}} = \left[\frac{100-7}{1.196}\right]^{\frac{1}{0.748}} = 337\ min$$

$$\frac{T_t}{T_n} = 0.58 \rightarrow T_t = 195\ min$$

$$L = \frac{6\times10^4 \times Q_u \times T_t}{\frac{a(T_t)^b}{1+b} + c + 1798 n^{\frac{3}{8}} (Q_u)^{\frac{9}{16}} (T_t)^{\frac{3}{16}}}$$

$$L = \frac{6\times10^4 \times 0.005 \times 195}{\frac{1.196(195)^{0.748}}{1+0.748} + 7 + 1798\times0.15^{\frac{3}{8}} (0.005)^{\frac{9}{16}} (195)^{\frac{3}{16}}} = 359\ m$$

$$T_{co} = \frac{i_n L}{600 Q_u \times e_d} = \frac{100\times359}{600\times0.005\times80} = 150\ min$$

$$d_{max} = 2250 n^{\frac{3}{8}} (Q_u)^{\frac{9}{16}} (T_t)^{\frac{3}{16}} = 2250\times0.15^{\frac{3}{8}} (0.005)^{\frac{9}{16}} (195)^{\frac{3}{16}} = 151\ mm$$

56. Given:

IF=0.5

i_n=100 mm

S=0.001 m/m

n=0.15

e_d=70%

d_{max}=150 mm

L=250 m
Crop=Alfalfa
Find:
T_n, T_{rl}, Q_u, T_{co}, and d_h

$$T_n = \left[\frac{i_n - c}{a}\right]^{\frac{1}{b}} = \left[\frac{100-7}{1.196}\right]^{\frac{1}{0.748}} = 337\ min\ Q_u = \frac{0.00167 i_n L}{(T_n - T_{rl}) e_d} = \frac{0.00167 \times 100 \times 250}{(337 - T_{rl}) 70}$$

T_{rl} = 17 min → Q_u = 0.00186 m^2/s
T_{rl} = 13 min → Q_u = 0.00184 m_2/s

$$T_{rl} = \frac{Q_u^{\ 0.2} \times n^{1.2}}{120\left[S + \frac{0.0094 n (Q_u)^{0.175}}{T_n^{\ 0.88} \times \sqrt{S}}\right]^{1.6}}$$

$$T_{rl} = \frac{0.00184^{0.2} \times 0.15^{1.2}}{120\left[0.001 + \frac{0.0094 \times 0.15 (0.00184)^{0.175}}{337^{0.88} \times \sqrt{0.001}}\right]^{1.6}} = 13.4\ min$$

$T_{co} = T_n - T_{rl}$ = 337 – 13 = 324 min

d_h = 2454 x $(T_{rl})^{0.1875}$ x $(Q_u)^{0.5625}$ x $(n)^{0.1875}$

d_h = 2454 x $(13)^{0.1875}$ x $(0.00184)^{0.5625}$ x $(0.15)^{0.1875}$ = 80 mm

57. Given:

DDIR=0.3 in/day

S=40 ft

L=60 ft

L_l=1320 ft

N_l=5

D=2 in

T_m=0.5 hr

A_f=100 acre

Find:

Discharge of sprinkle irrigation system

$$P_f = \frac{L_l \times L \times N_l}{435.6 A_f} = \frac{1320 \times 60 \times 5}{435.6 \times 100} = 9.09\%\ H \leq \frac{0.24 \times 9.09 \times 2}{0.3}$$

H ≤ 14.54 → H = 12 hr

$$D_a = \frac{H \times DDIR}{0.24 \times P_f} = \frac{12 \times 0.3}{0.24 \times 9.09} = 1.65\ in$$

$$Q = \frac{1.04 \times D_a \times L \times S}{(H - T_m)E_a} = \frac{1.04 \times 1.65 \times 60 \times 40}{(12 - 0.5)75} = 4.77\ gpm$$

58. Given:

IF=0.3

L=275 m

S=0.004 m/m

W=0.75 m

n=0.04

i_n=75 mm

Q_1=0.6 l/s

Q_2=0.3 l/s (when water meet end of the furrow)

Find:

T_{co}, d_{ro}, d_{dp}, and e_d

T_{cb} = T_t = 144 min

$$P_2 = 0.265\left(\frac{Qn}{\sqrt{S}}\right)^{0.425} + 0.227 = 0.265\left(\frac{0.3 \times 0.04}{\sqrt{0.004}}\right)^{0.425} + 0.227 = 0.36\ m$$

$$T_n = \left[\frac{i_n \frac{W}{P} - c}{a}\right]^{\frac{1}{b}} = \left[\frac{75\frac{0.75}{0.36} - 7}{0.9246}\right]^{\frac{1}{0.72}} = 1165\ min$$

T_{co} = T_t + T_n = 144 + 1165 = 1309 min

T_{avg} = 47.6 min

$$i_{avg} = \left[a\left(T_{co} - T_{avg}\right)^b + c\right]\frac{P_2}{W} + \left[a\left(T_{avg}\right)^b + c\right]\frac{P_1 - P_2}{W} = 80\ mm$$

i_g = 127 mm

d_{ro} = i_g – i_{avg} = 127 – 80 = 47 mm

d_{dp} = i_{avg} – i_n = 80 – 75 = 5 mm

$$e_d = 100\frac{i_n}{i_g} = 100\frac{75}{127} = 59\%$$

59. Given:

S=0.005 m/m

P=310 kPa

L=400 m

Find:

H_L in a sprinkle irrigation system

$$H_a = \frac{P}{ñg} = \frac{\frac{310000}{1000}}{9.81} = 31.61\text{m}$$

H_e = -Sl = - 0.005 x 400 = - 2m

$$H_L = \frac{\Box H \times H_a - H_e}{l} = \frac{0.2 \times 31.61 - (-2)}{400} = 0.021\ \text{m/m}$$

60. The figure gives the details for a certain crop. Using Blaney-Cridle equation and a crop factor k=0.75, determine the following (i) consumptive use, (ii) consumptive irrigation requirement, (iii) field irrigation requirement, if water application efficiency is 0.7. The latitude of the place is 30° N.

Month (1)	Monthly tepm (Av.) oC (2)	Monthly % of day time hours of the year (3)	Useful rain fall (cm) (4)
Nov.	19.0	7.19	-
Dec.	16.0	7.15	1.2
Jan.	12.5	7.30	0.8
Feb.	13.0	7.03	-

The monthly temperature and useful rainfall data are average values for the last 10 years. The consumptive use is computed from the Blany-Criddle equation:

$C_u = k \sum f$

Where

$$f = \frac{p}{40}[1.8t + 32]$$

Month (1)	to C (2)	p% (3)	F (4)
Nov	19.0	7.19	11.90
Dec	16.0	7.15	10.9
Jan	12.5	7.30	9.9

Feb	13.0	7.03	9.7
			∑f = 42.4

C_u = 0.75 x 42.4 = 31.8 cm

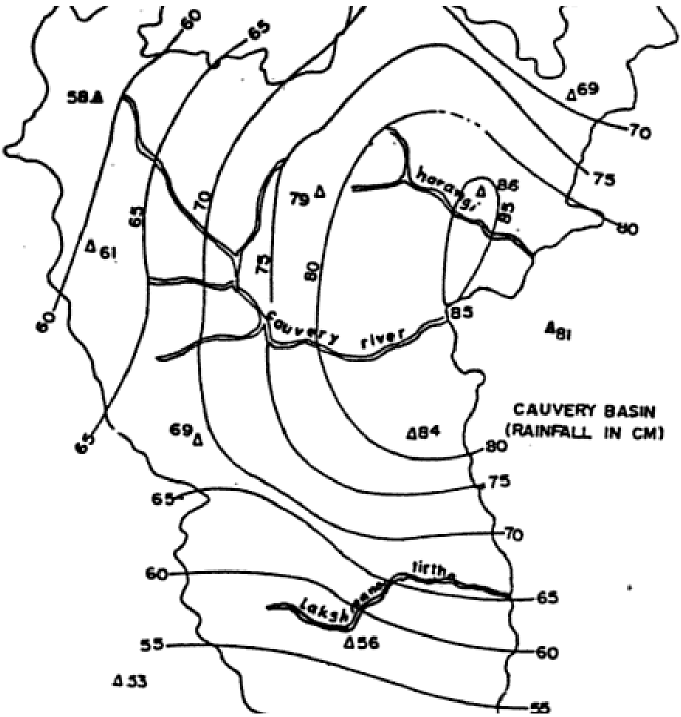
R_e = 1.2 + 0.8 = 2 cm

CIR = C_u – R_e = 31.8 – 2 = 29.8 cm

NIR = CIR (since on water is used for deep percolation)

$$FIR = \frac{NIR}{\eta_a} = \frac{29.8}{0.7} = 42.6\ cm$$

61. The figure shows the map of Cauvery basin with rainfall observations in cm of water marked at various rain gauge stations. Compute the average rainfall by (1) Arithmetic average method (2) Isohyetal, method and (3) Thiessen Polygon method.



(i) Arithmetic Average Method: It is clear from the figure that stations having gauge reading as 53, 81, and 68 are located outside the basin. Hence they are not included in taking the arithmetical average.

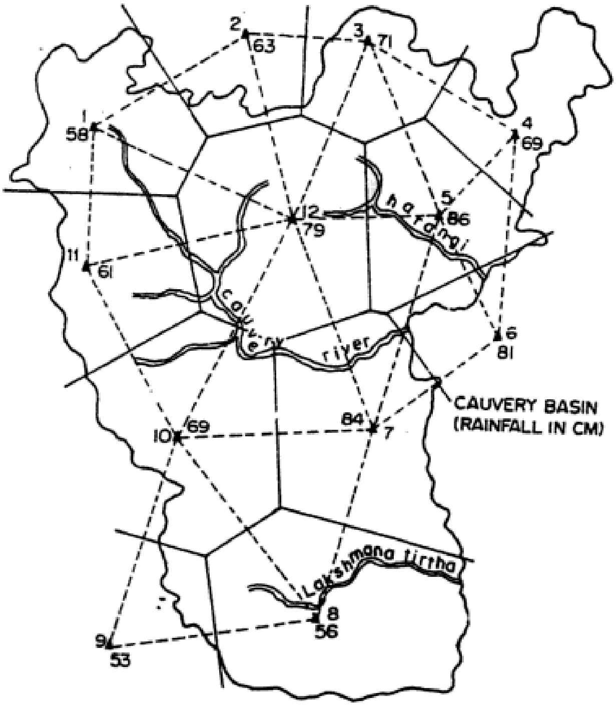
Average rainfall = 70

$$\text{Arithmetic mean} = \frac{1}{9}\left(58+71+69+86+84+56+69+79+61\right) = 70.34\ \text{cm}$$

(ii) Isohyetal method: The isohyets are drawn, just as contours, as shown in the figure. Area between adjacent isohyets is determined by a planimeter.

$$P_{av} = \frac{\sum A \frac{(P_1 + P_2)}{2}}{\sum A} = \frac{2121.2}{40.40} \cong 69\ cm$$

(iii) Thiessen Polygon Method. Area of each polygon is determined by planimeter.



Area of Thiessein polygon A (cm^2)	Observed precipitation P (cm)	Product A x P
3.26	58	189.0
0.39	63	24.6
1.61	71	114.2
2.04	69	140.8
2.46	86	211.5
0.84	81	68.0
3.91	84	328.5
5.09	56	285.0
0.41	53	217.5
3.94	69	272.0
2.06	61	125.7
4.40	79	347.5
Sum 30.41		2324.3

$$P_{av} = \frac{\sum AP}{\sum A} = \frac{2324.3}{33.41} = 76.4\ m$$

62. A precipitation station X was inoperative for some time during which a storm occurred. The storm totals at three stations A, B, and C surrounding X, were respectively 6.60, 4.80, and 3.70 cm. The normal annual precipitation amounts at stations X, A, B, and C are respectively 65.6, 72.6, 51.8, and 38.2. Estimate the storm precipitation for station P.

If N_X, N_A, N_B, and N_C are the average annual precipitation amounts at X, A, B, and C and P_A, P_B, and P_C are the storm totals of stations A, B, and C surrounding X, the storm precipitation at station X is given by.

$$P_X = \frac{1}{3}\left[\frac{N_X}{N_A} \times P_A + \frac{N_X}{N_B} \times P_B + \frac{N_X}{N_C} \times P_C\right]$$

If storm precipitations at four stations surrounding the faulty stations X are known and annual precipitations of all the five are known, the average precipitation at X during the storm is given by

$$P_X = \frac{1}{4}\left[\frac{N_X}{N_A} \times P_A + \frac{N_X}{N_B} \times P_B + \frac{N_X}{N_C} \times P_C + \frac{N_X}{N_D} \times P_D\right]$$

$$P_X = \frac{1}{3}\left[\frac{65.6}{72.6} \times 6.6 + \frac{65.6}{51.8} \times 4.8 + \frac{65.6}{38.2} \times 3.7\right] = 6.11\ cm$$

63. A 12-hour storm rainfall with the following depths in cm occurred over a basin:

2.0, 2.5, 7.6, 3.8, 10.6, 5.0, 7.0, 10.0, 6.4, 3.8, 1.4, and 1.4

The surface run-off resulting from the above storm is equivalent to 25.5 cm of depth over the basin. Determine the average infiltration index for the basin.

Total rainfall in 12 hours=2.0+2.5+7.6+3.8+10.6+5.0+7.0+10.0+6.4+3.8+1.4+1.4=61.5

Total run-off in 12 hours=25.5 cm

Total infiltration in 12 hours=61.5-25.5=36 cm

Average infiltration=36/12=3 cm/hr.

It will be observed from the above data that rainfall is less than average infiltration in 1^{st}, 2^{nd}, 11^{th}, and 12^{th}, hour. Hence during these hours, rate of infiltration will be equal to the rainfall. In the central period, the rainfall is more than infiltration.

Hence if f is the average rate of infiltration during the central 8 hours, we have

8f + 2 + 2.5 + 1.4 + 1.4 = 36 → f = 3.6 cm/hr

64. From the storm data given in below:

2.0, 2.5, 7.6, 3.8, 10.6, 5.0, 7.0, 10.0, 6.4, 3.8, 1.4, and 1.4

Determine the average depth of hourly rainfall excess for a basin of area of 120

hectares. The basin consists A_1, A_2, and A_3 having average infiltration indices given below:

Area designation	A1	A2	A3
Area (hectares)	20	40	60
Infiltration Index (cm/hr)	7.6	3.8	1.0

The run-off coming out from the individual areas A_1, A_2, and A_3 will have to be spread over the entire basin and hence its depth will be reduced.

65. The figure gives flood data for 16 years recorded at the Bhakra Dam site on Sutlej River:

Year	Discharge (cumes)	year	Discharge (cumes)
1937	3110	1944	2290
1938	5800	1945	2380
1939	3090	1946	3810
1940	1723	1947	7800
1941	3630	1948	4525
1942	6600	1949	3254
1943	5260	1950	4980
		1951	9200

Find out the recurrence interval for the flood of various magnitudes by the following methods: (i) California method, (ii) Hazen's method, and (iii) Gumbel's method.

The recurrence interval has been calculated by the three methods. The value of C for Gumbel's method has been taken by N=15.

66. A well fully penetrating a confined aquifer is pumped at a uniform rate of 2500 liters per minute. The drawdown in an observation well situated at 60 m away is given in the figure. Determine the formation constants of the aquifer.

Time since pumping began t (min)	Drawdown s (min)	t (min)	s (m)	t (min)	s (m)
0	0.00	12	0.59	150	1.03
1.0	0.20	14	0.62	180	1.05
1.5	0.26	18	0.66	210	1.08
2.0	0.30	24	0.71	240	1.10
2.5	0.33	30	0.75		
3	0.36	40	0.80		
4	0.41	50	0.83		
5	0.45	60	0.86		
6	0.48	80	0.91		
8	0.53	100	0.95		
10	0.56	120	0.98		

s = 0.52 cm W(u)=2.96 $r^2/t=7\times10^5$ $u=3\times10^{-2}$ Q=2500 l/min=2.5 m^3/min=3600 m^3/day

$$T=\frac{Q}{4\pi s}W\left(u\right)=\frac{3600}{4\times\pi\times0.52}\times2.96=\frac{1631\frac{m^3}{day}}{m}\quad S=\frac{4uT}{\frac{r^2}{t}}=\frac{4\times3\times10^{-2}}{7\times10^5}\times1631=0.00028$$

Time t		r^2/t	t (m)	Time t		r^2/t	t (m)
min	Days	m^2/day		min	Days	m^2/day	
0	0	0	0.5	18	12.5×10^{-2}	$2.88 \times 1^{0}5$	0.66
1.0	6.94×10^{-4}	$5.18 \times 1^{0}6$	0.20	24	1.67×10^{-2}	2.16×10^{5}	0.71
1.5	1.04×10^{-3}	3.96×10^{6}	0.26	30	2.08×10^{-2}	1.73×10^{5}	0.75
2.0	1.39×10^{-3}	2.59×10^{6}	0.30	40	$2.78 \times 10\text{-}^{2}$	1.30×10^{5}	0.80
2.5	$1.74 \times 1^{0\text{-}}3$	2.07×10^{6}	0.33	50	3.47×10^{-2}	1.04×10^{5}	0.83
3.0	2.08×10^{-3}	1.73×10^{6}	0.36	60	4.17×10^{-2}	8.64×10^{4}	0.86
4.0	2.78×10^{-3}	1.30×10^{6}	0.41	80	5.56×10^{-2}	6.48×10^{4}	0.91
5.0	3.47×10^{-3}	1.04×10^{6}	0.45	100	6.94×10^{-2}	5.18×10^{4}	0.95
6	4.17×10^{-3}	$8.64 \times 1^{0}5$	0.48	120	8.33×10^{-2}	1.32×10^{4}	0.98
8	5.56×10^{-3}	6.48×10^{5}	0.53	150	1.04×10^{-2}	3.46×10^{4}	1.03
10	6.94×10^{-3}	$5.18 \times 1^{0}5$	0.56	180	1.25×10^{-1}	3.88×10^{4}	1.05
12	8.33×10^{-3}	4.32×10^{5}	0.59	210	1.46×10^{-1}	1.47×10^{4}	1.08
14	9.72×10^{-3}	3.07×10^{5}	0.62	240	1.67×10^{-1}	2.16×10^{4}	1.10

67. A saddle siphon has the following data:

Full reservoir level=435 m

Level of centre of siphon outlet=429.6 m

High flood level=435.85 m

High flood discharge=600 cumecs.

If the dimensions of the throat of the siphon are: with=4 m and height= 2 m determine the number of siphon units required to pass the flood safety.

The siphon discharge freely in air.

Maximum operative head = H = H. F. L. – R. L. of outlet centre

H= 435.85 x 429.6 = 6.25 m

The discharge is given by

$$Q = CA\sqrt{2gH} = 0.95 \times 4 \times 2 \times \sqrt{2 \times 9.81 \times 6.25} = 57.8 \text{ cumecs.}$$

$$\text{Number of units required} = \frac{600}{57.8} = 11$$

68. For the following data, calculate the total available water and soil-moisture deficit.

Soil depth (cm)	G_b	W_{fc}	W_{wp}	W
0-15	1.25	0.24	0.13	0.16
15- 30	1.30	0.28	0.14	0.18
30 – 60	1.35	0.31	0.15	0.23
60 – 90	1.40	0.33	0.15	0.26
90-120	1.40	0.31	0.14	0.28

Depth of soil layers d (mm)	$w_{fc} = G_{b.} W_{fc}$	$w_{wp} = G_{b.} W_{wp}$	$W_t = (w_{fc} - w_{wp})d$ (mm)	$w = G_{b.} W$	$D_s = (w_{fc} - w)d$ (mm)
150	0.3	0.1625	20.625	0.2	15.0
150	0.364	0.182	27.300	0.234	19.5
300	0.4185	0.2025	64.800	0.3105	32.4
300	0.462	0.21	75.600	0.364	29.4
300	0.434	0.196	71.400	0.392	12.6
		total	259.725		108.9

Total available water=259.725 mm ≅ 260 mm

Soil moisture deficit=108.9 mm ≅ 109 mm

69. The culturable command area for a distributary channel is 15000 hectares. The intensity of irrigation is 35% for wheat and 20% for rice. The kor period for wheat and rice are 4 and 3 weeks, respectively. The kor watering depths for wheat and rice are 135 and 190 mm, respectively. Estimate the distributary discharge.

Since the water demands for wheat and rice are at different times, these are not cumulative. Therefore, the distributary channel should be designed for higher of the two values, i.e., 3.14 m^3/s.

70. A ground water basin consists of 20 km2 of plains. The maximum fluctuation of ground water table is 3 m, assuming a specific yield of 15%, determine the available ground water storage.

Available ground water storage = Area of basin x depth of fluctuation x specific yield = $20 \times 10^6 \times 3 \times 0.15 = 9 \times 10^6$ m^3

71. In an aquifer whose area is 100 ha, the water table dropped by 3 m. Assuming porosity and specific retention of the aquifer material as 305 and 10% respectively, determine the specific yield of the aquifer and the change in ground water storage.

Porosity = Specific yield + specific retention

Specific yield = Porosity – specific retention = 30 – 10 = 20%

Reduction in ground water storage = $100 \times 10^4 \times 3 \times 0.2 = 60 \times 10^4$ m^3

72. A soil sample was taken with a core samples from a field when soil reached field capacity. The oven dry sample weighed 1.065 kg. The inside diameter of the core was 7.5 cm and the length was 15 cm. Determine the bulk density and the apparent specific gravity of the soil.

$$\text{The volume of the core} = \pi r^2 h = \frac{22}{7} \times 3.75 \times 3.75 \times 15 = 663 \text{ cm}^3$$

$$r = 3.75 \text{ cm} \quad h = 15 \text{ cm}$$

Weight of even dry sample = 1.065 kg = 1065 g

$$\text{The bulk density of the soil} = \frac{1065}{663} = 1.61 \frac{\text{g}}{\text{cm}^3}$$

The apparent specific gravity = 1.61

73. Calculate the (a) bulk density, (2) water content on weight basis (mass wetness) and (c) water content on volume basis (volume wetness) of a soil when a soil core of 10 cm diameter and 8 cm length weighs 1113.14 g immediately after sampling and 980.57 g after oven drying at 105◦c.

(a) $$\text{Volume of the soil core} = \pi r^2 h = \pi \times \left(\frac{10}{2}\right)^2 \times 8 = 628.57\ \text{cm}^3$$

$$\text{Bulk density} = \text{Bd} = \frac{980.57}{628.57} = 1.56\frac{\text{g}}{\text{cm}^3}$$

(b) $$\text{Water content on weight basis} = \frac{\text{Weight of fresh core} - \text{Weight of oven dry core}}{\text{Weight of oven dry soil core}}$$

$$P_w = \frac{1113.14 - 980.57}{980.57} \times 100 = 13.52\%$$

(c) Water content on volume basis = P_v = P_w x Bd = 13.52 x 1.56 = 21.09%

74. Find out the particle density of a soil from the following data:

(i) Weight of an empty 100 cm^3 pycnometer (W_1) is 33.3 g

(ii) Weight of pycnometer+oven dry soil (W_2) is 53.33 g

(iii) Weight of the ptcnometer+soil+water making the total volume to 100 cm^3 (W_3) is 145.78 g

(iv) Weight of the pycnometer filled with 100 cc soil (W_4) is 133.3 g

(v) Density of water (ρ_w) is 1 g/cm^3

$$\text{Particle density} = \text{Pd} = \frac{\text{Oven dry weight of soil sample}}{\text{Volume of water displaced by soil sample}} = \frac{\tilde{n}_{w(W_2 - W_1)}}{(W_4 - W_1) - (W_3 - W_2)}$$

$$\text{Pd} = \frac{1 \times (53.5 - 33.3)}{(133.3 - 33.3) - (145.78 - 53.3)} = \frac{200}{100 - 92.48} = 2.66\frac{\text{g}}{\text{cm}^3}$$

75. Calculate the total porosity of a soil when the particle density is 2.65 g/cm³ and the bulk density of soil is 1.56 g/cm³.

Particle density of the soil = Pd = 2.65 gr/cm^2

Bulk density of the soil = Bd = 1.56 g/cm^3

$$\text{Prosity of the soil} = E = \left(1 - \frac{\text{Bd}}{\text{Pd}}\right) \times 100 = \left(1 - \frac{1.56}{2.65}\right) \times 100 = 41.13\%$$

76. A soil sample was drawn with a core sampler having an inside dimension of 10 cm diameter and 5 cm length. The fresh and oven dry weights of the soil core were 700 g and 625 g respectively. Calculate the bulk density of soil and soil water content on volume basis.

Volume of the soil core = π x 25 x 5 = 392.5 cm^3

$$\text{Soil water content} = \text{Pw} = (700-625)\times\frac{100}{625} = 12\%$$

$$\text{Bulk density of the soil} = \frac{625}{392.5} = 1.59\frac{g}{cm^3}$$

Soil water content on volume basis = Pv = 12 x 1.59 = 10.08%

77. The volume of water present in a 395 cm^3 soil core is 75 ml. The oven dry weight of the soil core is 625 g. Calculate the soil water content on weight basis.

$$\text{Bulk density of the soil} = \frac{\text{Oven dry weight of soil core}}{\text{Volume of soil core}} = \frac{625}{395} = 1.58\ g/cm^3$$

$$\text{Soil water content on volume basis} = \frac{\text{Volume of water}}{\text{Volume of soil core}}\times 100 = \frac{75}{395}\times 100 = 19\%$$

$$\text{Soil water content on weight basis} = \frac{\text{Soil water content on volume basis}}{\text{Bulk density of soil}}$$

$$\text{Soil water content on weight basis} = \frac{19}{1.58} = 12.03\%$$

78. A 663 cm^3 soil core taken by a core samples from a field weighed 1.065 kg on oven drying. True specific gravity of the soil was 2.65. Determine the porosity of the soil.

$$\text{The bulk density of the soil} = \frac{1.065}{663} = 1.6\frac{g}{cm^3}$$

The true specific gravity = 2.65

$$\text{Porosity of the soil} = 1-\frac{1.6}{2.65} = 0.396$$

79. Calculate the maximum water holding capacity of a soil from the following data of Keen-Raczkowski measurements.

(i) Weight of brass box+Filter paper (a)= 77.25

(ii) Weight of the brass box+Filter paper+Oven-dry soil (c)= 140.27 g

(iii) Weight of the brass box+Filter paper+Saturated soil (b)= 161.2 g

(iv) Water content of the filter paper (d) =0.35 g

$$\text{Maximum water holding capacity} = \text{MWHC} = \frac{b-c-d}{c-a}\times 100$$

$$\text{MWHC} = \frac{161.2 - 140.27 - 0.35}{140.27 - 77.25} \times 100 = \frac{20.58}{63.02} \times 100 = 32.65\%$$

80. A soil core was drawn with a core sampler having an inside dimension of 5 cm diameter and 15 cm length from a field two days after irrigation when the soil water was near field capacity. The weight of the core sampler with fresh soil sample was 1.95 kg and the weight of the same on oven drying was 1.84 kg. The empty core sampler weighted 1.4 kg. Calculate the (a) bulk density of soil, (b) water holding capacity of soil in per cent on volume basis and (c) depth of water held per meter depth of soil.

Weight of the moist soil core = 1.95 – 1.4 = 0.55 kg

Weight of the oven dry soil core = 1.84 – 1.4 = 0.44 kg

$$\text{Soil water content} = \frac{0.55 - 0.44}{0.44} \times 100 = \frac{0.11}{0.44} \times 100 = 25\%$$

(a) Volume of the soil core = $\pi r^2 h = \pi \times 2.52 \times 15 = 294.64\ cm^3$

(b) Water holding capacity of the soil = Soil water content on weight basis x Bulk density = 25 x 1.51 = 37.75%

(c) Water holding capacity of the soil per meter depth of soil = 37.75 cm

81. Find out the height to which water would rise in a capillary tube of 0.06 mm diameter when the surface tension is 72 dynes/cm at 20◦C. The density of water is 1 g/cm3 and the value of cosθ is assumed as 1.

Radius of the capillary tube (R) = 0.03 mm

Surface tension = σ = 72 dynes/cm

Acceleration due to gravity = g = 981 dynes/cm

$$\text{Density of water} = \rho_w = 1\frac{g}{cm^3}$$ Density of water = ρ_w = 1 g/cm^2

cosθ = 1

$$h = \frac{2\sigma\cos\theta}{g\rho r} = \frac{2 \times 72 \times 1}{981 \times 1 \times 0.003} = 48.93\ \text{cm}$$

82. A permeameter of 40 cm diameter discharges 1.5 lit of water in 30 min. The soil was packed to depth of 45 cm and a constant head of 15 cm was maintained. Determine the hydraulic conductivity.

Q = 1500 cm^3

L= 45 cm

t = 30 min = 0.5 hr

ΔH = 45 + 15 = 60 cm

A = $\pi r^2 = \pi \times 20^2 = 1257.14\ cm^2$

$$\text{Hydraulic conductivity} = K = \frac{1500 \times 45}{1257.14 \times 0.5 \times 60} = 1.79 \frac{\text{cm}}{\text{hr}}$$

83. Find out the water content of a soil on weight and volume basis just before irrigation from the following data. The thermo-gravimetric method is followed for determination of the water content.

(i) Weight of the empty aluminium box (W_1)=35.23 g

(ii) Weight of the aluminum box+ fresh soil sample (W_2)=95.33 g

(iii) Weight of oven dry soil+ box (W_3)=85.12 g

(iv) Density of water (ρ_w) =1 g/cm^3

(v) Bulk density of the soil=1.54 g/cm^3

Weight of the fresh soil sample = $W_2 - W_1$ = 95.33 – 35.23 = 60.1 g

Weight of water in the soil sample = $W_2 - W_3$ = 95.33 – 85.12 = 10.21 g

Weight of the oven – dry soil = 85.12 – 35.23 = 49.89 g

$$\text{Soil water content} = \frac{\text{Weight of soil water}}{\text{Weight of oven} - \text{dry soil} \times \text{density of water}} \times 100 = \frac{10.21}{49.89 \times 1} \times 100 = 20.47\%$$

Soil water content = Soil water content on weight basis x bulk density

Soil water content = Pw x Bd = 2047 x 1.54 = 31.52%

84. Calculate the Hg column reading expected in a manometer attached to a tensiometer installed at 30 cm depth in an experimental field to study the effect of irrigations at 0.4, 0.5, 0.6, 0.7, and 0.8 atmospheric tensions on a wheat crop. The mercury level in the manometer cup is 10 cm above the ground. Density of mercury is 13.6 g/cm^3.

The gravitational head = Z =

Level of Hg in the manometer cup + depth at which tensiometer installed = 10 + 30 = 40 cm

$$\text{The manometer reading above the Hg surface in the cup at soil saturation} = \frac{40}{13.6} = 2.94 \text{ cm}$$

Mercury reading at a desired tension = mercury reading at 1 atm x desired atm.tension + mercury reading at soil saturation

Mercury reading at 0.4 atm.tension = 76 x 0.4 + 2.94 = 33.34 cm

Mercury reading at 0.5 atm.tension = 76 x 0.5 + 2.94 = 40.94 cm

Similarly, the Hg height at 0.6, 0.7, and 0.8 atm. Tension would be 48.54, 56.14, and 63.74 cm respectively.

85. On a summer day, net solar energy received at a lake reaches 15 MJ per square meter per day. If 80% of the energy is used to vaporize water, how large could the depth of evaporation be?

1 MJm-2 day-1 = 0.408 mm/day

0.8 x 15 x 0.408 = 4.9 mm/day

The evaporation rate could be 4.9 mm/day.

86. Determine the atmospheric pressure and the psychometric constant at an elevation of 1800 m.

z = 1800 m

$$P = 101.3\left[\frac{293 - 0.0065 \times 1800}{293}\right]^{5.26} = 81.8 \text{ kPa}$$

$\gamma = 0.665 \times 10^{-3} \times 81.8 = 0.054$ kPa/°C

87. The daily maximum and minimum air temperature are respectively 24.5 and 15°C. Determine the saturation vapor pressure for that day.

$$e°\left(T_{max}\right) = 0.6108 \exp\left[\frac{17.27 \times 24.5}{24.5 + 237.3}\right] = 3.075 \text{ kPa}$$

$$e°\left(T_{min}\right) = 0.6108 \exp\left[\frac{17.27 \times 15}{15 + 237.3}\right] = 1.705 \text{ kPa} \quad e_s = \frac{3.075 + 1.705}{2} = 2.39 \text{ kPa}$$

Note that for temperature 19.75°C (which is Tmean), e°(T)=2.30 kPa

The mean saturation vapor pressure is 2.39 kPa.

88. Determine the vapor pressure from the readings of an aspirated psychomotor in a location at an elevation of 1200 m. The temperatures measured by the dry and wet bulb thermometers are 25.6 and 19.5°C respectively.

z = 1200 m

P = 87.9 kPa

T_{wet} = 19.5°C

$e_o(T_{wet})$ = 2.267 kPa

a_{psy} = 2.267 – 0.000662 x 87.9 x (25.6 – 19.5) = 1.91 kPa

89. Given the following daily minimum and maximum air temperature and the corresponding relative humidity data:

T_{min} = 18°C and RHmax = 82%

T_{max} = 25°C and RHmin = 54%

Determine the actual vapor pressure.

T_{min} = 18°C

$e_o(T_{min})$ = 2.064 kPa

T_{max} = 25°C

$e_o(T_{max})$ = 3.168 kPa

$$e_a = 2.064\frac{82}{100} + 3.168\frac{54}{100} = 1.70\ kPa$$

90. Given: Suppose a measurement of the air gave the temperature (T) to be 80°F and the relative humidity (RH) to be 60%.

Compute: a) the saturated vapor pressure (e°)

b) The actual vapor pressure (e)

c) The dew point temperature (T_d).

a) Calculation of saturated vapor pressure e°

$$e^\circ = \left(\frac{1648+80}{157}\right)^8 = 34.9\ mb$$

b) Calculation of the actual vapor pressure e

$$RH = \frac{e}{e^\circ}\times 100$$

$$e = e^\circ\frac{RH}{100} = 34.9\frac{60}{100} = 20.9\ mb$$

c) Calculation of the dew point temperature T_d

$T_d = 157 \times 20.9^{0.125} - 164.8 = 64.8$°F

91. Given: Suppose a total wind run of 300 miles per day was measured with an anemometer located 3 meters above the soil surface. In this area, the average daytime to nighttime wind speeds ratio is about 2. The grass at the weather station is maintained at 6 inches tall.

Compute:

a) The daily wind runs for a height of 2 meters.

b) The average daytime wind speed.

a) The wind adjustment factor (U_f) for these conditions is 0.92. Then the wind run at 2 m would be computed from:

U_{2m} = $U_f U_{3m}$ = 0.92 x 300 = 276 miles/day

b) U_d = 0.056 x 276 = 15.3 miles/hr

92. Given: Assume crop coefficient (K_c) =1.0 for this period. Pan coefficient (K_p) = 0.75.

Daily evaporation from a Class A evaporation pan, in/d

	Year									
Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.64	0.32	0.24	0.30	0.15	0.22	0.28	0.35	0.23	0.27
2	0.25	0.41	0.26	0.17	0.31	0.42	0.18	0.42	0.65	0.28
3	0.35	0.30	0.17	0.25	0.52	0.15	0.32	0.23	0.22	0.27
4	0.31	0.10	0.39	0/16	0.16	0.45	0.31	0.42	0.60	0.26
5	0.20	0.14	0.29	0.30	0.42	0.45	0.33	0.43	0.39	0.54
6	0.49	0.36	0.36	0.60	0.39	0.30	0.38	0.22	0.55	0.39
7	0.38	0.33	0.33	0.23	0.22	0.49	0.36	0.36	0.68	0.43
8	0.27	0.11	0.11	0.36	0.21	0.30	0.41	0.21	0.23	0.42
9	0.61	0.23	0.23	0.35	0.22	0.45	0.26	0.26	0.23	0.43
10	0.55	0.40	0.40	0.43	0.06	0.52	0.35	0.35	0.30	0.30

Find: Determine the peak ET_c rate for design.

Example calculation for day 1 of year 1:

$ET_o = K_p E_{pan} = 0.75 \times 0.64 = 0.48$ in/day

$ET_c = K_c ET_o = 1.0 \times 0.48 = 0.48$ in/day

The resulting daily ET_c for the crop is:

	Daily crop evapotranspiration, in/d									
	Year									
Day	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	48	0.24	0.18	0.23	0.11	0.17	0.21	0.26	0.17	0.20
2	0.19	0.31	0.20	0.13	0.23	0.32	0.14	0.32	0.49	0.21
3	0.26	0.23	0.13	0.19	0.39	0.11	0.24	0.17	0.17	0.20
4	0.23	0.08	0.29	0.12	0.21	0.34	0.23	0.32	0.45	0.20
5	0.15	0.11	0.22	0.23	0.31	0.34	0.25	0.32	0.29	0.41
6	0.37	0.27	0.27	0.45	0.29	0.23	0.29	0.17	0.41	0.29
7	0.29	0.26	0.25	0.17	0.17	0.37	0.27	0.27	0.51	0.32
8	0.20	0.27	0.08	0.27	0.16	0.23	0.31	0.16	0.17	0.32
9	0.46	0.34	0.17	0.26	0.17	0.34	0.20	0.20	0.23	0.23
10	0.41	0.35	0.30	0.32	0.05	0.39	0.34	0.26	0.23	0.23
An Max	0.48	0.35	0.29	0.45	0.39	0.39	0.34	0.32	0.51	0.41
	Ranking of annual maximum values (m)									
	1	2	3	4	5	6	7	8	9	10
Annual maximums (in/d)	0.29	0.32	0.34	0.35	0.39	0.39	0.41	0.45	0.48	0.51
P_b	9.1	18.2	27.3	36.4	45.5	54.4	63.6	72.7	81.8	90.9

93. Given:

I_F=0.5

F_n=4 in

s_0=0.001 ft/ft

n=0.15

E=65%

L=650 ft

Find:

Q_u and T_a

T_n = 328 min

T_L = 8 to 20 min

Assume T_L=14 min

$$Q_u = \frac{LF_n}{7.2(T_n - T_L)E} = \frac{650 \times 4}{7.2(328-14)65} = 0.018\frac{ft^3}{s} \rightarrow T_L = 12 \text{ min}$$

Assume T_L=12 min

$$Q_u = \frac{LF_n}{7.2(T_n - T_L)E} = \frac{650 \times 4}{7.2(328-12)65} = 0.018\frac{ft^3}{s} \rightarrow OK$$

T_a = 328 – 12 = 316 min

Check flow depth and stream size

Maximum depth of flow=0.15 ft →OK

Minimum allowable Q_u=0.00001349×650=0.0088→OK

94. Given:

IF=1.0

Fn=3 in

s0=0.001 ft/ft

n=0.15

E=75%

d1=0.3 ft

Find:

Q_u, T_a, L, L_e, and E

T_n = 106 min

Q_u = 0.049 ft²/s

T_L = 11 min

$T_a = T_n - T_L$ = 106 – 11 = 95 min

$$L = 7.2 \times 0.049 \times (106 - 11) \times \frac{75}{3} = 838\ ft$$

L_e = (1-0.75) x 0.7 x 0.75 x 838 = 110 ft L_e

$$F_g = 720 \times 0.049 \times \frac{(106 - 11)}{(838 + 110)} = 3.54\ in$$

$$E = \frac{3}{3.54} = 85\%$$

95. Given:

IF=0.3

L=275 m

S=0.004 m/m

W=0.75 m

n=0.04

i_n=75 mm

Q=0.6 l/s

Find:

T_{co}, d_{ro}, d_{dp}, and e_d

g = 1.904 x 10^{-4}

$$\beta = \frac{gx}{Q\sqrt{S}} = \frac{1.904 \times 10^{-4} \times 275}{0.6\sqrt{0.004}} = 1.38$$

$$T_t = \frac{x}{f} \exp\beta = \frac{275}{7.61} \exp(1.38) = 144\ \text{min}$$

$$P = 0.265\left(\frac{Qn}{\sqrt{S}}\right)^{0.425} + 0.227 = 0.265\left(\frac{0.6\times 0.04}{\sqrt{0.004}}\right)^{0.425} + 0.227 = 0.4\text{ m}$$

$$T_n = \left[\frac{i_n\frac{W}{P} - c}{a}\right]^{\frac{1}{b}} = \left[\frac{75\frac{0.75}{0.4} - 7}{0.9246}\right]^{\frac{1}{0.72}} = 999\text{ min}$$

$T_{co} = T_t + T_n = 144 + 999 = 1143$ min

$$i_g = \frac{60QT_{co}}{0.75\times 275} = 200\text{ mm}$$

$$T_{0-L} = T_{co} - \frac{0.0929}{fL\left(\frac{0.305\beta}{L}\right)^2}\left[(\beta - 1)\exp(\beta) + 1\right]$$

$$T_{0-L} = 1143 - \frac{0.0929}{7.61\times 275\left(\frac{0.305\times 1.38}{275}\right)^2}\left[(1.38 - 1)\exp(1.38) + 1\right] = 1095\text{ min}$$

$$i_{avg} = \left[a\left(T_{0-L}\right)^b + c\right]\frac{P}{W} = \left[0.925(1095)^{0.72} + 7\right]\frac{0.4}{0.75} = 80\text{ mm}$$

$d_{ro} = i_g - i_{avg} = 200 - 80 = 120$ mm

$d_{dp} = i_{avg} - i_n = 80 - 75 = 5$ mm

$$e_d = 100\frac{i_n}{i_g} = 100\frac{75}{200} = 37.5\%$$

96. The gross command area of an irrigation project is 1.5 lakh hectares, where 7500 hectare is unculturable. The area of kharif crop is 60000 hectares and that of Rabi crop is 40000 hectares. The duty of Kharif is 3000 ha/m³/s and the duty of Rabi is 4000 ha/m³/s.

Find (a) The design discharge of channel assuming 10% transmission loss. (b) Intensity of irrigation for Kharif and Rabi.

Culturable command area = 150000 – 7500 = 14200 ha

Discharge for Kharif crop,

Area of Kharif crop = 60000 ha

Duty of Kharif crop = 3000 ha/m^2

$$\text{Required discharge of channel} = \frac{60000}{3000} = 20 \text{ m}^3/\text{s}$$

Considering 10% loss

$$\text{Design discharge} = 20 \times \frac{10}{100} = 22 \text{ m}^3/\text{s}$$

Discharge for Rabi crop,

Area of Rabi crop = 40000 ha

Duty of Kharif crop = 4000 ha/m^2/s

$$\text{Required discharge of channel} = \frac{40000}{4000} = 10 \text{ m}^3$$

Considering 10% loss

$$\text{Design discharge} = 10 \times \frac{110}{100} = 11 \text{ m}^3/\text{s}$$

(a) So, the design discharge of the channel should be 22 m^3/s, as it is maximum.

(b) $$\text{Intensity of irrigation for Kharif} = \frac{60000}{142500} = 42.11\%$$

$$\text{Intensity of irrigation for Rabi} = \frac{40000}{142500} = 28.07\%$$

97. The gross command area of an irrigation project is 1 lakh hectares. The culturable command area is 75% of G.C.A. The intensities of irrigation for Kharif and Rabi are 50% and 55% respectively. If the duties for Kharif and Rabi are 1200 ha/m^3/s and 1400 ha/m^3/s respectively, determine the discharge at the head of the canal considering 20% provisions for transmission loss, overlap allowance, evaporation loss etc.

$$\text{Culturable command area} = 100000 \times \frac{75}{100} = 75000 \text{ ha}$$

For Kharif crop,

$$\text{Area under Kharif} = 75000 \times \frac{50}{100} = 37500 \text{ ha}$$ Duty of Kharif = 1200 ha/m^2/s

$$\text{Required discharge for Kharif} = \frac{37500}{1200} = 31.25 \text{ m}^3/\text{s}$$

For Rabi crop,

$$\text{Area under Rabi} = 75000 \times \frac{55}{100} = 41250 \text{ ha}$$ Duty of Rabi = 1400 ha/m^3/s

$$\text{Required discharge for Rabi} = \frac{41250}{1400} = 29.46 \text{ m}^3/\text{s}$$

So, to meet up the actual water requirement of the crops, the discharge of the canal at the head of the field should be 31.25m^3/s (as it is maximum). Now considering 20% provision for losses,

$$\text{Required discharge at the head of canal} = 31.25 \times \frac{120}{100} = 37.5 \text{ m}^3/\text{s}$$

98. Determine the head discharge of a canal from the following data. The value of time factor may be assumed as 0.75.

Crop	Base period in days	Area in hectare	Duty in hec tares/cumec
Rice	120	4000	1500
Wheat	120	3500	2000
sugarcane	310	3000	1200

Discharge of canal required

(a) $\text{For rice} = \frac{4000}{1500} = 2.667 \text{ m}^3/\text{s(Kharif)}$

(b) $\text{For wheat} = \frac{3500}{2000} = 1.75 \text{ m}^3/\text{s(Rabi)}$

(c) $\text{For sugarcane} = \frac{3000}{1200} = 2.5 \text{ m}^3/\text{s(perennial)}$

As, the base period of sugarcane is 310 days, it will require water both in Kharif and Rabi seasons.

Now, actual discharge required in Kharif season = 2.667+2.5=5.167 m^3/s.

Actual discharge required in Rabi season = 1.75+2.5=4.25 m^3/s.

So, the maximum discharge in Kharif season (i.e., 5.167 m^3/s) should be taken into consideration as it will be able to serve both the seasons.

$$\text{Time factor} = 0.75 = \frac{\text{Actual discharge}}{\text{Design discharge}} = \frac{5.167}{\text{Design discharge}}$$

$$\text{Design discharge} = \frac{5.167}{0.75} = 6.889\ \text{m}^3/\text{s}$$

Therefore, the required head discharge of the canal is 6.889 m^3/s.

99. Find out the capacity of a reservoir from the following data. The cultivable command area is 80000 hectares.

Crop	Base period in days	Duty in hect/cumec	Intensity of irrigation in percentage
Rice	120	1800	25
Wheat	120	2000	30
sugarcane	310	2500	20

Assume the canal and reservoir losses as 5% and 10% respectively.

$$\Delta = \frac{8.64 \times B}{D}$$

Calculation of delta for each crop

$$\Delta_{rice} = \frac{8.64 \times 120}{1800} = 0.576\ \text{m} \quad \Delta_{wheat} = \frac{8.64 \times 120}{2000} = 0.518\ \text{m} \quad \Delta_{sugarcane} = \frac{8.64 \times 320}{2500} = 1.106\ \text{m}$$

Calculation of area for each crop

$$A_{rice} = \frac{80000 \times 25}{100} = 20000\ \text{ha}$$

$$A_{wheat} = \frac{80000 \times 30}{100} = 24000\ \text{ha}$$

$$A_{sugarcane} = \frac{80000 \times 20}{100} = 16000\ \text{ha}$$

Volume of water required for each crop

V_{rice} = 20000 x 0.576 = 11520 ha - m

V_{wheat} = 20000 x 0.518 = 12432 ha - m

V_{rice} = 16000 x 17696 ha - m

Total volume of water=41648 ha-m.

Considering canal loss of 5%

$$\text{Water required at the head of canal} = 41648 \times \frac{105}{100} = 43730.4 \text{ ha} - \text{m}$$

Again considering, reservoir loss of 10%

$$\text{Capacity of reservoir} = 43730.4 \times \frac{110}{100} = 48103.44 \text{ ha} - \text{m}$$

100. The command area of a channel is 4000 hectares. The intensity of irrigation of a crop is 70%. The crop requires 60 cm of water in 15 days, when the effective rainfall is recorded as 15 cm during that period.

Find, (a) The duty at the head of field. (b) The duty at the head of channel. (c) The head discharge at the head of channel.

Assume total losses as 15%.

Depth of water required=60 mm

Effective rainfall=15 cm

Depth of irrigation water=60-15=45 cm

Δ = 45 cm

B=15 days

$$\Delta = \frac{8.64 \times B}{D} \text{ Duty} = D = \frac{8.64 \times 15}{0.45} = 288 \frac{\text{ha}}{\text{cumec}}$$

(a) So, duty at the head of field=288 ha/cumec. Due to the losses of water the duty at the head of the channel will be reduced.

Here, losses are 15%.

(b) So, the duty at the head of channel = 288×0.85=244.8 ha/cumec (Duty will be reduced due to loss).

Total area under crop=4000×0.7=2800 ha

(c) The discharge at the head of channel=2800/244.8=11.438 cumec

References

1. Ali H (2010) Fundamentals of Irrigation and On-farm Water Management: Volume 1, Springer.
2. Ali H (2010) Practices of Irrigation and On-farm Water Management: Volume 2, Springer.

3. Alizadeh A (2002) Irrigation System Design. (4th Edn Revised), Imam Reza University Press.
4. FAO56 (2000) FAO Irrigation and Drainage Paper No. 56, Crop Evapotranspiration (guidelines for computing crop water requirements).
5. Asawa GL (1999) Elementary Irrigation Engineering. New Age International.
6. Banihabib, ME, Valipour M, Behbahani SMR, (2012) Comparison of Autoregressive Static and Artificial Dynamic Neural Network for the Forecasting of Monthly Inflow of Dez Reservoir. Journal of Environmental Sciences and Technology 13: 1-14.
7. Basak N N (1999) Irrigation Engineering. Tata McGraw-Hill Education.
8. Basak NN (2003) Environmental Engineering. Tata McGraw-Hill Education.
9. Behboudian MH, Singh Z (2010) Water Relations and Irrigation Scheduling in Grapevine. In: J Janick (Ed.). Horticultural Reviews. Volume 27, John Wiley & Sons, Inc., Oxford, UK.
10. Bos MG, Kselik RAL, Allen RG, Molden D (2009) Water Requirements for Irrigation and the Environment. Springer.
11. Calzadilla A, Rehdanz K, Tol RSJ (2011) Water scarcity and the impact of improved irrigation management: a computable general equilibrium analysis. Agricultural Economics 42: 305–323.
12. Camp CR, Lamm FL (2013) Encyclopedia of Environmental Management, Irrigation Systems: Sub-Surface Drip Design, Taylor & Francis.
13. Davis AP (2007) Irrigation Engineering. Read Books.
14. Hillel D, Vlek P (2005) The Sustainability of Irrigation. Advances in Agronomy. Donald Sparks.
15. Howell TA, Meron M (2007) Micro irrigation for Crop Production — Design, Operation, and Management. Developments in Agricultural Engineering. Elsevier.
16. Israelsen OW (1932) Irrigation principles and practices. John Wiley & Sons. University of Minnesota.
17. Khan S (2009) Irrigation Management in a Catchment Context. In: RC Ferrier, A Jenkins (Eds.). Handbook of Catchment Management. Wiley-Blackwell, Oxford, UK.
18. Majumdar DK (2001) Irrigation Water Management: Principles and Practice. PHI Learning Pvt. Ltd.
19. Mazumder SK (1997) Irrigation Engineering. Galgotia Publication.
20. Morillo-Velarde R, Ober ES (2007) Water Use and Irrigation. In: AP Draycott Sugar Beet (Ed.). Sugar Beet. Blackwell Publishing Ltd, Oxford, UK.
21. Murthy CS (2002) Water Resources Engineering: Principles and Practice. New Age International.
22. Newell FH (2008) Principles of Irrigation Engineering. Biblio Bazaar.
23. Punmia (1992) Irrigation and Water Power Engineering. Firewall Media.
24. Rao KL (1979) India's Water Wealth. Orient Blackswan.
25. Sahasrabudhe SR (1962) Irrigation Engineering. Katson Publishing House. The University of Wisconsin – Madison.
26. Sauer T, Havlík P, Schneider UA, Schmid E, Kindermann G et al., (2010) Agriculture and resource availability in a changing world: The role of irrigation. Water Resour. Res., 46, W06503.
27. SCS (1991) National Engineering Handbook, United States Department of Agriculture, Section 15, Irrigation.
28. Sharma RK, Sharma TK (2009) Irrigation Engineering. S. Chand & Company Ltd. Sultan Chand & Company.
29. Tessema B (2007) Irrigation and Drainage Engineering. Adama University, SOE & IT, School of Engineering and Information Technology Department of Civil Engineering and Architectures Surveying Engineering Stream.
30. Valipour M, Banihabib ME, Behbahani SMR (2013) Comparison of the ARMA, ARIMA, and the autoregressive artificial neural network models in forecasting the monthly inflow of Dez dam reservoir. Journal of Hydrology 476: 433-441.
31. Valipour M (2013) Increasing Irrigation Efficiency by Management Strategies: Cutback And Surge Irrigation. ARPN Journal of Agricultural and Biological Science 8(1): 35-43.
32. Valipour M (2013) Necessity of Irrigated and Rainfed Agriculture in the World. Irrigation & Drainage Systems Engineering 9: 1-3.

33. Valipour M (2013) Evolution of Irrigation-Equipped Areas as Share of Cultivated Areas. Irrigation & Drainage Systems Engineering 2(1): 114-115.

34. Valipour M (2013) Use of Surface Water Supply Index to Assessing of Water Resources Management in Colorado and Oregon, US. Advances in Agriculture, Sciences and Engineering Research 3(2): 631-640.

35. Valipour M (2013) Estimation of Surface Water Supply Index Using Snow Water Equivalent. Advances in Agriculture, Sciences and Engineering Research 3 (1): 587-602.

36. Valipour M (2013) Scrutiny of Inflow to the Drains Applicable for Improvement of Soil Environmental Conditions. In: The 1st International Conference on Environmental Crises and its Solutions, Kish Island, Iran.

37. Valipour M (2013) Comparison of Different Drainage Systems Usable for Solution of Environmental Crises in Soil. In: The 1st International Conference on Environmental Crises and its Solutions, Kish Island, Iran.

38. Valipour M, Mousavi SM, Valipour R, Rezaei E, (2013) A New Approach for Environmental Crises and its Solutions by Computer Modeling. In: The 1st International Conference on Environmental Crises and its Solutions, Kish Island, Iran.

39. Valipour M, Banihabib ME, Behbahani SMR (2012) Monthly Inflow Forecasting Using Autoregressive Artificial Neural Network. Journal of Applied Sciences 12(20): 2139-2147.

40. Valipour M, Banihabib ME, Behbahani SMR (2012) Parameters Estimate of Autoregressive Moving Average and Autoregressive Integrated Moving Average Models and Compare Their Ability for Inflow Forecasting. Journal of Mathematics and Statistics 8(3): 330-338.

41. Valipour M (2012) Critical Areas of Iran for Agriculture Water Management According to the Annual Rainfall. European Journal of Scientific Research 84(4): 600-608.

42. Valipour M, Montazar AA (2012) Optimize of all Effective Infiltration Parameters in Furrow Irrigation Using Visual Basic and Genetic Algorithm Programming. Australian Journal of Basic and Applied Sciences 6(6): 132-137.

43. Valipour M, Montazar AA (2012) Sensitive Analysis of Optimized Infiltration Parameters in SWDC model. Advances in Environmental Biology 6 (9): 2574-2581.

44. Valipour M (2012) Comparison of Surface Irrigation Simulation Models: Full Hydrodynamic, Zero Inertia, Kinematic Wave. Journal of Agricultural Science 4 (12): 68-74.

45. Valipour M (2012) Sprinkle and Trickle Irrigation System Design Using Tapered Pipes for Pressure Loss Adjusting. Journal of Agricultural Science 4 (12): 125-133.

46. Valipour M (2012) Hydro-Module Determination for Vanaei Village in Eslam Abad Gharb, Iran. ARPN Journal of Agricultural and Biological Science 7 (12): 968-976.

47. Valipour M, Montazar AA (2012) An Evaluation of SWDC and WinSRFR Models to Optimize of Infiltration Parameters in Furrow Irrigation. American Journal of Scientific Research 69: 128-142.

48. Valipour M (2012) Number of Required Observation Data for Rainfall Forecasting According to the Climate Conditions. American Journal of Scientific Research 74: 79-86.

49. Valipour M, Mousavi SM, Valipour R, Rezaei E (2012) Air, Water, and Soil Pollution Study in Industrial Units Using Environmental Flow Diagram. Journal of Basic and Applied Scientific Research 2(12): 12365-12372.

50. Valipour M (2012) Scrutiny of Pressure Loss, Friction Slope, Inflow Velocity, Velocity Head, and Reynolds Number in Center Pivot. International Journal of Advanced Scientific and Technical Research 2 (5): 703-711.

51. Valipour M (2012) Ability of Box-Jenkins Models to Estimate of Reference Potential Evapotranspiration (A Case Study: Mehrabad Synoptic Station, Tehran, Iran). IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) 1 (5): 1-11.

52. Valipour M (2012) Effect of Drainage Parameters Change on Amount of Drain Discharge in Subsurface Drainage Systems. IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) 1 (4): 10-18.

53. Valipour M (2012) A Comparison between Horizontal and Vertical Drainage Systems (Include Pipe Drainage, Open Ditch Drainage, and Pumped Wells) in Anisotropic Soils. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 4 (1): 7-12.

54. Valipour M, Mousavi SM, Valipour R, Rezaei E (2012) SHCP: Soil Heat Calculator Program. IOSR Journal of Applied Physics (IOSR-JAP) 2 (3): 44-50.

55. Valipour M (2012) Determining possible optimal values of required flow, nozzle diameter, and wetted area for linear traveling laterals. The International Journal of Engineering and Science (IJES) 1 (1): 37-43.

56. Verhoef A, Egea G (2013) Soil water and its management. In: PJ Gregory, S Nortcliff (Eds.). Soil Conditions and Plant Growth. Blackwell Publishing Ltd, Oxford.

57. Walker WR, Prestwich C, Spofford T (2006) Development of the revised USDA–NRCS intake families for surface irrigation. Agricultural Water Management 85 (1-2): 157–164.

58. Valipour M (2014) Comparative evaluation of radiation-based methods for estimation of reference evapotranspiration. Journal of Hydrologic Engineering. Accepted.

59. Valipour M (2014) Drainage, waterlogging, and salinity. Archives of Agronomy and Soil Science. doi: 10.1080/03650340.2014.905676

60. Valipour M (2013) Need to update of irrigation and water resources information according to the progresses of agricultural knowledge. Agrotechnology. S10:e001. doi: 10.4172/2168-9881.S10-e001

61. Valipour M, Mousavi SM, Valipour R, Rezaei E, (2013) Deal with environmental challenges in civil and energy engineering projects using a new technology. Journal of Civil & Environmental Engineering S4:127. doi: 10.4172/2165-784X.1000127

62. Valipour M (2014) Future of the area equipped for irrigation. Archives of Agronomy and Soil Science. doi: 10.1080/03650340.2014.905675

63. Valipour M (2014) Importance of solar radiation, temperature, relative humidity, and wind speed for calculation of reference evapotranspiration. Archives of Agronomy and Soil Science. doi: 10.1080/03650340.2014.925107

64. Valipour M (2014) Temperature analysis of reference evapotranspiration models. Meteorological Applications. doi: 10.1002/met.1465

65. Valipour M (2014) Handbook of Hydraulic Engineering Problems. OMICS.

66. Valipour M (2014) Handbook of Hydrologic Engineering Problems. OMICS.

67. Valipour M (2014) Future of agricultural water management in Americas. Journal of Agricultural Research 54(2):245-268.

68. Valipour M (2014) Land use policy and agricultural water management of the previous half of century in Africa. Applied Water Science. doi: 10.1007/s13201-014-0199-1

69. Valipour M (2014) Handbook of Water Engineering Problems. OMICS.

70. Valipour M (2014) Future of agricultural water management in Europe based on socioeconomic indices. Acta Advances in Agricultural Sciences 2(7):1-18.

71. Valipour M (2014) Application of new mass transfer formulae for computation of evapotranspiration. Journal of Applied Water Engineering and Research 2(1):33-46.

72. Valipour M (2014) Use of average data of 181 synoptic stations for estimation of reference crop evapotranspiration by temperature-based methods. Water Resources Management. doi: 10.1007/s11269-014-0741-9

73. Valipour M (2014) Study of different climatic conditions to assess the role of solar radiation in reference crop evapotranspiration equations. Archives of Agronomy and Soil Science. doi: 10.1080/03650340.2014.941823

74. Valipour M (2014) Comparison of mass transfer-based models to predict reference crop evapotranspiration Meteorological Applications. Accepted.

75. Valipour M (2014) Analysis of potential evapotranspiration using limited weather data. Applied Water Science. Accepted.

76. Valipour M (2014) Pressure on renewable water resources by irrigation to 2060. Acta Advances in Agricultural Sciences 2(8).

77. Walker WR (2011) Encyclopedia of Water Science, Second Edition. Irrigation, Surface. Taylor & Francis.