University of Al Mustansiriyah
Faculty of Engineering
Civil Engineering Department
Third Stage

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Irrigation and Drainage Engineering

Chapter Four
Infiltration of water into Soil

Chapter - 4

Infiltration of water into soils

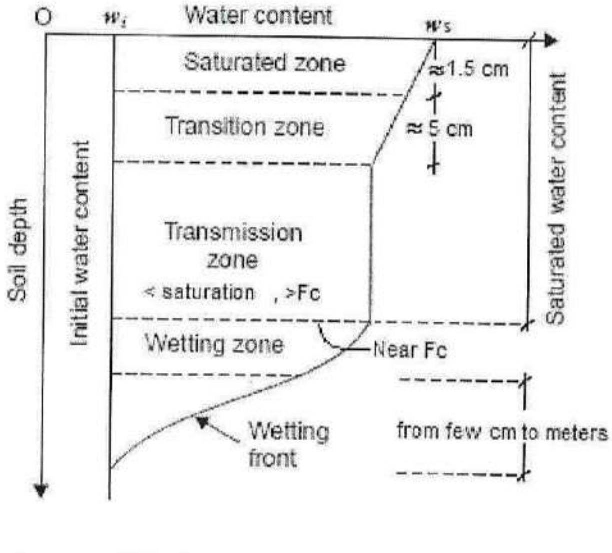
الارتشاح خلال التربة

(الارتشاح (الغائض

Infiltration: is the flow of water into ground through soil surface vertically. Water entering produces a typical soil moisture profile shown in figure below.

التشرب

Intake: water entering through soil surface in any direction (not necessary in vertical direction)

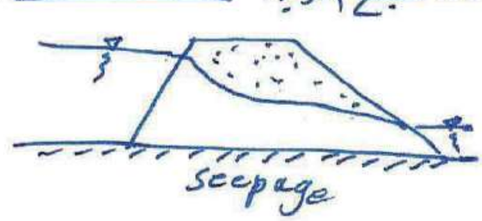


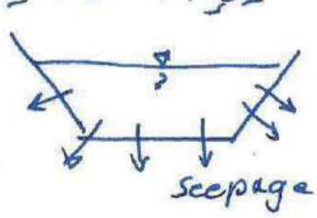
Soil-moisture profile during ponded infiltration

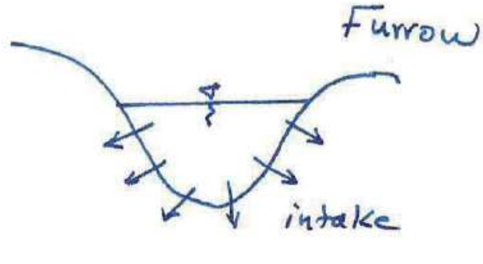
التسرب

Seepage: is a phenomenon of water movement into or out of earthern body that usually saturated, like seepage from earth canals or through earth dams.

Percolation: التغلغل يتحرك للأسفل ولا يشترط تشبع التربة.







Permeability: النفاذية

is the ability of saturated soil to allow the movement of water through it. It was considered as a evident property, not as in infiltration which is affected by several factors for pattern & characteristic of infiltration.

Two forces effects on infiltration:

1. Gravity force
2. Capillary force (with less effect)

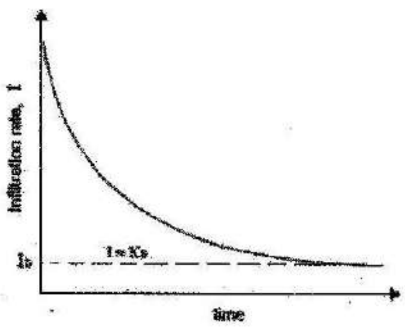
The infiltration plays an important role in the design of irrigation system. The infiltration characteristics restrict the application depth of irrigation (sprinkler type) related to surface runoff.

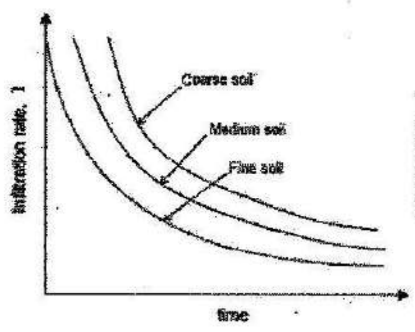
Factors affecting the Infiltration:

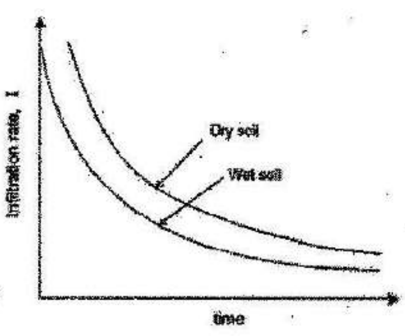
1. Soil texture.
2. Initial moisture content of the soil.
3. type of crop planted.
4. Method of irrigation.
5. Irrigation depth.
6. Time of application of irrigation depth.
7. Temperature (with less effects).

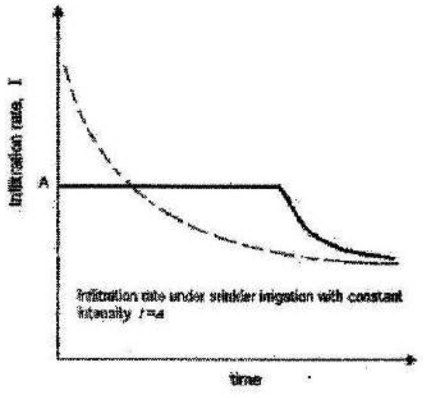
Infiltration capacity: is the max. rate at which a given soil at a given time can absorb the water and termed as I_b ; $I = I_b$ when $i_s \geq I_b$, $I = i_s$ when $i_s \leq I_b$ } for long time

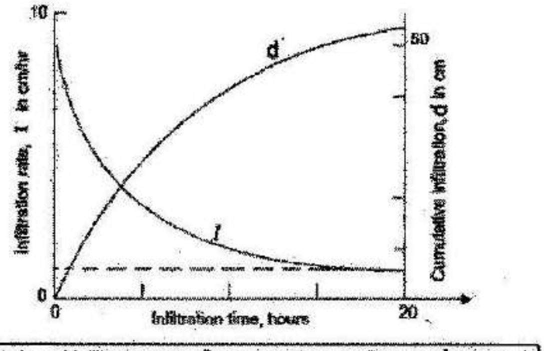
i_s = sprinkler intensity شدة الرش











Variation of infiltration rate, I and cumulative infiltration, d with time

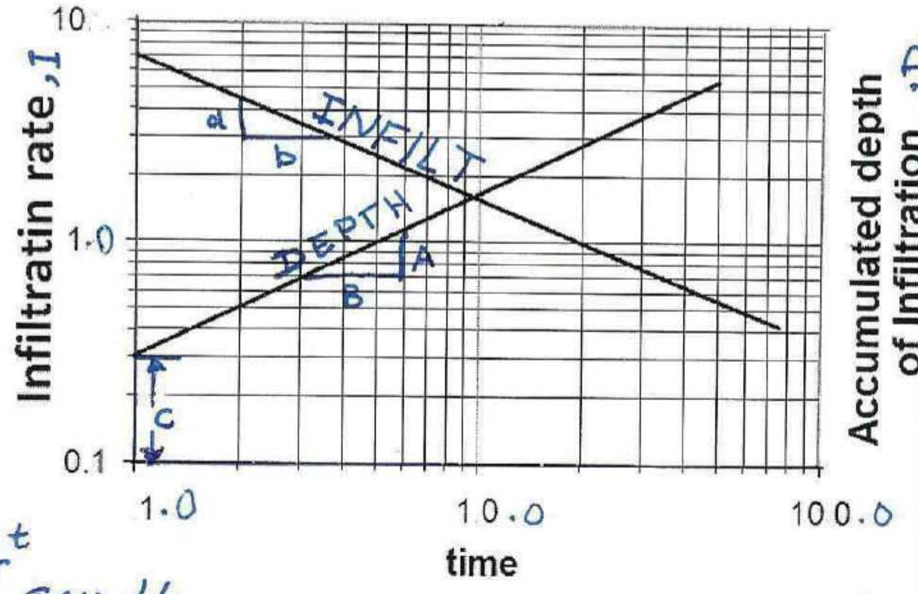
Hint: The infiltration rate decreases as time increases that is due to decreasing in hydraulic gradient as well as blocked of voids by water under countinously entering of water into soil. As time increases $I \rightarrow P$ which is close to hydraulic conductivity K_s ($P \approx K_s$).

Infiltration equations

From field measurements the relationship between I & t is usually exponential and takes the form $y = ax^b$. If this form is plotted on log-log paper, the relation seems to be linear (straight line), since

$$\log(y) = \log(a) + b\log(x)$$

$\Rightarrow \tilde{y} = A + b\tilde{x}$, while is represented by linear plot.



$m = \frac{A}{B}$

$n = \frac{a}{b}$

$n = m - 1$

A, B, a and b can directly measured by ruler; or

$m = \frac{\log(D_2/D_1)}{\log(t_2/t_1)}$

$n = m - 1$

$$D = \int_0^t I(t)\,dt \qquad (4.1)$$

and thus; $I = \frac{dD}{dt}$ (4.2)

if $D = ct^m \Rightarrow I = Kt^n$ $\qquad 0 < m < 1$ (+)

where $K = c.m$ and $n = m - 1$ $\qquad -1 < n < 0$ (−)

why m positive, while n negative?

C: represents initial soil moisture.
m: represents soil properties.

The first mathematical form of equation disribing infiltration rate is Horton (1933).

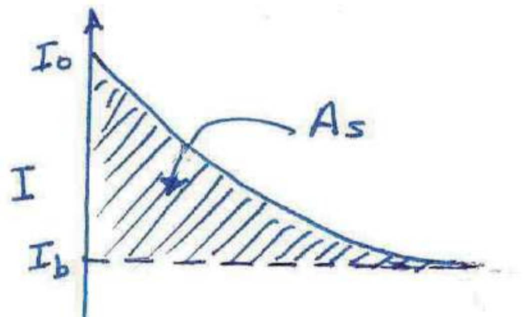
1. <u>Horton equation:</u>

$$I = I_b + (I_o - I_b)\, e^{-kt} \quad \text{-------}(4.3)$$

I: infiltration rate at any time.
I_b: constant infiltration rate (base infiltration)
I_o: initial infiltration rate (at t=0).
K: constant depends on soil and vegetation.
t: time from begining of water application.
K: Can be estimated by:

$$K = \frac{I_o - I_b}{A_s} \quad , \text{-------}(4.4)$$

As: is a shaded area shown in figure below.



<u>example</u>: The infiltration rate was observed to be 80 cm/hr and decreased to a constant rate equal 10 cm/hr after 2.5 hr. The total infiltration depth (accumulated) during 2.5 hr is 40 cm. establish the Horton equation:

<u>Solution</u>: $I_o = 80$ cm/hr, $I_b = 10$ cm, t = 2.5 hr

Area under whole curve = Acc. depth
Area shaded (As) = Total area − $I_b * 2.5$
$= 40 - 2.5(10) = 15$ cm

$$A_s = \frac{I_o - I_b}{K} \;;\; 15 = \frac{80-10}{K} \Rightarrow K = 4.67\ hr^{-1}$$

$$\Rightarrow I = 10 + 70\, e^{-4.67t} \quad ; t\,(hr) \;;\; I\,(cm/hr).$$

H.W

Assuming $I_o = 10\,mm/hr$, $I_b = 5\,mm/hr$, $K = 0.95\,hr^{-1}$

Calculate the total infiltration depth for time = 6 hrs.

(2) Philip equation

$$D = \alpha t^{1/2} + \beta t \quad \text{------------} \quad (4.5)$$

This equation is gouted analytically and hence α, and β have physical meaning (soil & moisture initially).

Using least square method for errors to find α and β;

S = Sum of Errors squared.

$$S = \sum_{i=1}^{n} \left[D_i - \alpha t_i^{1/2} - \beta t_i \right]^2$$

$$\left.\begin{aligned} \frac{\partial S}{\partial \alpha} = 0 &\Longrightarrow \alpha \sum_i t_i + \beta \sum_i t_i^{3/2} = \sum D_i t_i^{1/2} \\ \frac{\partial S}{\partial \beta} = 0 &\Longrightarrow \alpha \sum_i t_i^{1/2} + \beta \sum_i t_i^2 = \sum D_i t_i \end{aligned}\right\} \text{solve for } \alpha \text{ and } \beta;$$

$$\alpha = \frac{\sum_i D_i t_i^{1/2} - \beta \sum_i t_i^{3/2}}{\sum t} \quad \text{------} \quad (4.6)$$

نحتاج ال

$\sum t$

$\sum t^2$

$\sum t^{1/2}$

$\sum t^{3/2}$

$$\beta = \frac{\dfrac{\sum_i D_i t_i}{\sum_i t_i^2} - \dfrac{\left[\sum_i t_i^{1/2}\right]^2}{(\sum_i t_i)(\sum_i t_i^2)}}{1 - \dfrac{(\sum_i t_i^{1/2})(\sum_i t_i^{3/2})}{(\sum_i t_i)(\sum_i t_i^2)}} \quad \text{------} \quad (4.7)$$

ملاحظة:

إن إيجاد المعاملات α و β توفيقياً (توفيق المنحنيات) أو بطريقة المربعات الصغرى لا يعطي أبعاد المعادلة الى تصنيف المعادلات الوصفية لبد أنه تم إيجادها تحليلياً.

example:

For a given data obtained from field test of infiltration:

$t_{acc.}$ min	2	7	30	60	80
$D_{acc.}$ mm	4.5	9	20	30	35

Find D at t = 120 min

Solution

$I = \alpha t^{1/2} + \beta t \Rightarrow D = \alpha(\frac{2}{3}) t^{1.5} + (\frac{1}{2})\beta t^2$

$\Sigma t = 179$, $\Sigma t^{1/2} = 26.23$ $\Sigma t^{3/2} = 1365.97$ $\Sigma t^2 = 10953$

$\Sigma D_i t_i^{1/2} = 685.15$ $\Sigma D_i t_i = 5272$

$\beta = 0.49$, $\alpha = 0.089$

$I = 0.089 t^{1/2} + 0.49 t$

$D = 0.0593 t^{1.5} + 0.0445 t^2$

$= 718$ mm $= 71.8$ cm.

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③ Kostiakov equation (معادلة كوستياكوف) مهمة جداً

It is an empirical equation established to describe the infiltration phenomenon in soils.

$D = ct^m$ ——— (4.8)

$I = \frac{dD}{dt} = cm\, t^{m-1} = Kt^n$ (4.9)

I = Infiltration rate

n, K = constant so as c & m for accumulated depth D.

$K = cm$, $n = m-1$, as explained, previously.

equation (4.9) does not describe the infiltration well when the time became large, because whenever t increase largly I drop to zero. It must be approach to Ks.

Thus, this equation was modified to the form

$$I = Kt^n + P \quad (\text{where } P \approxeq K_s) \quad \text{—— (4.10)}$$

and

$$D = Ct^m + P \cdot t \quad \text{—— (4.11)}$$

However, eq. (4.11) is more accurate than eq. (4.9) (theoretically speaking), but it has three constants need to estimate.

Inspite of this shortcoming, eq. (4.10) and consequently eq. (4.9) c&n desribe the infiltration well in first few hours where the application of irrigation process are fall in it. Kostiakov equation is simple in estimating the constents and therefor it is of wide use in irrigation system.

Field measurements of Infiltration قياس الرشح حقلياً

A simple steel cylinder of 25 cm diam and 40 cm length with thickness of wall greater than 1.5 mm and less than 2 mm. It is of open ends and inserted in soil about 15 cm and filled with water 10 cm.

The measurements of depth in cylinder (Infiltrometer) were recorded at the end of time intervals as:

5 min, 10 min, 20 min, 30 min, 45 min, 60 min, 90 min, 120 min.

and thereafter the records were done every hour.

The depth between two successive readings should be less than 20 mm. In case of adding water during measurements the level before adding must recorded ... and soon until the infiltration rate become steady (3–5 hrs). The test can be stopped if the accumulated depth reaches 150 mm.

ملاحظة: يمكن الاستعانة باستمارة فحص النظامية لتسجيل
الحسابات (انظر الصفحة التالية).

CYLINDER INFLTROMETER TEST

Location: ______________ Observer: ______________ Date: ______________

Soil type: ______________ Crop: ______________ Condition: ______________

Moisture holding capacity: ______________

Notes: ______________

Watch	Differe.	Accum. -min-	Gage	Differe.	Accum.	Watch	Differe.	Accum. - min -	Gage	Differe.	Accum.
10 : 05		0	15.30		0						
	2			0.20							
10 : 07		2	15.10		0.20						
	3			0.10							
10 : 10		5	15.00		0.30						
	20			0.20							
10 : 30		25	14.80		0.50						
	30			0.10							
11 : 00		55	14.70		0.60						
	13			0.10							
11 : 13		68	14.60		0.70						
	12			0.10							
11 : 25		80	14.50		0.80						
	25			0.10							
11 : 50		105	14.40		0.90						

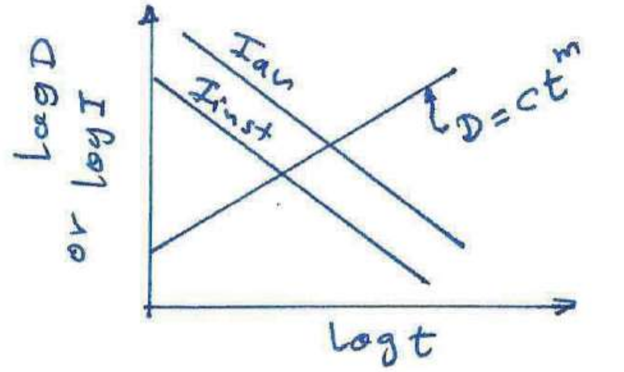
Prepared by Dr. Rasul M. Khalaf

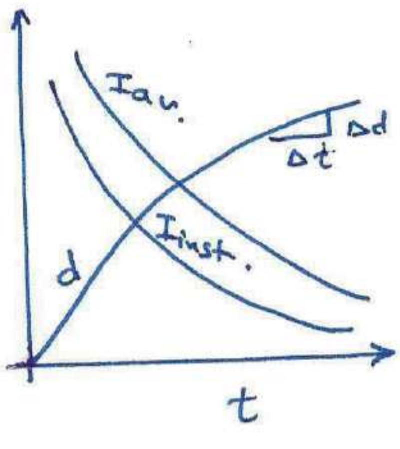
Nov. 1994

$I_{inst} = K t^{n}$ from Kostiakov eq.

$$I_{av} = \frac{D}{t} = \frac{c t^{m}}{t} = c t^{m-1} = \frac{K}{m} t^{n}$$

Now I_{av} greater or smaller than I_{inst}??





How to define I_b with time t_b كيفية تعيين الارتشاح الأساس

(USDA) [US Department of Agriculture] defined the base infiltration rate as the value of infiltration rate curve when change in infiltration rate during "one hour" does not exceed 10%. معدل الارتشاح الأساس هو تلك القيمة على منحنى الارتشاح التي عندها يكون التغير في معدل الارتشاح خلال ساعة لا يزيد عن 10%.

① define t_b

within 1 hr = 60 min according to definitions.

$$\Delta I = 0.1\, I \quad \text{------} (4.12)$$

$$\frac{\Delta I}{\Delta t} \approx \frac{dI}{dt} = \frac{d(Kt^{n})}{dt} = K n t^{n-1}$$

$$\Delta I = K n t^{n-1} \Delta t$$

$$\therefore \; K n t^{n-1} \Delta t = 0.1\,(K t^{n}) \quad \text{---} (4.13)$$

subs. $\Delta t = 1\text{ hr} = 60\text{ min}$, $t = t_b$

$$t_b = |600 n| \text{ min.} \quad \text{-----} (4.14)$$

One can use linear regression to find c, m in eq. (4.11)

ويمكن استخدام الرسم على ورق لوغاريتمي ثم رسم خط توفيقي ومعايرة المعادلة بالنظر والقياس.

$\boxed{D = ct^m}$ → this is non-Linear equation

Transform to Linear equation by Logarthmic Mapping

$X = \log(t) \quad Y = \log D$

حل معادلة كوستياكوف ما لطريقة

الا حصائية (طريقة المربعات الصغرى).

$\Rightarrow y = a + bx$

$$b = \frac{\Sigma(xy) - \frac{1}{n}(\Sigma x)(\Sigma y)}{\Sigma x^2 - \frac{1}{n}(\Sigma x)^2} \quad ---- (4.15)$$

$$a = \frac{1}{n}(\Sigma y - b\Sigma x) \quad ---- (4.16)$$

$C = 10^a$, $m = b$

example:

From test data of infiltration D @ t=15 min equals to 2.5 cm and D @ t=100 min equals to 8 cm. Determine

(1) Base infiltration rate
(2) Time required to accumulate 15 cm depth.
(3) Infiltration rate at time = 3 hr estimated by (mm/hr).

solution $D = ct^m$; $25_{mm} = c(15_{min})^m \Rightarrow C = \frac{25}{15^m}$

$80_{mm} = \frac{25}{15^m}(100)^m \Rightarrow \frac{80}{25} = \left(\frac{100}{15}\right)^m \Rightarrow m = 0.613$

$\therefore D = 4.75\, t^{0.613}$ $\qquad C = 4.75$

$I = 0.63(4.75)\, t^{(0.613-1)}$

or $I = 2.91\, t^{-0.387}$

$t_b = |600(-0.387)| = 232.2$ min

$I_b = 2.91(232.2)^{-0.387} = 0.353$ mm/hr

$D = 4.75\,(t)^{0.613}$

$150 = 4.75\, t^{0.613} \Rightarrow t = 4.65$ hr

$I = 2.91\, t^{-0.387}$

$= 2.91\,(3 * 60)^{-0.387} \Longrightarrow I = 0.39$ mm/hr

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Irrigation and Drainage Engineering

Chapter Five
Surface Irrigation : Concept & Mechanism

Chapter – 5

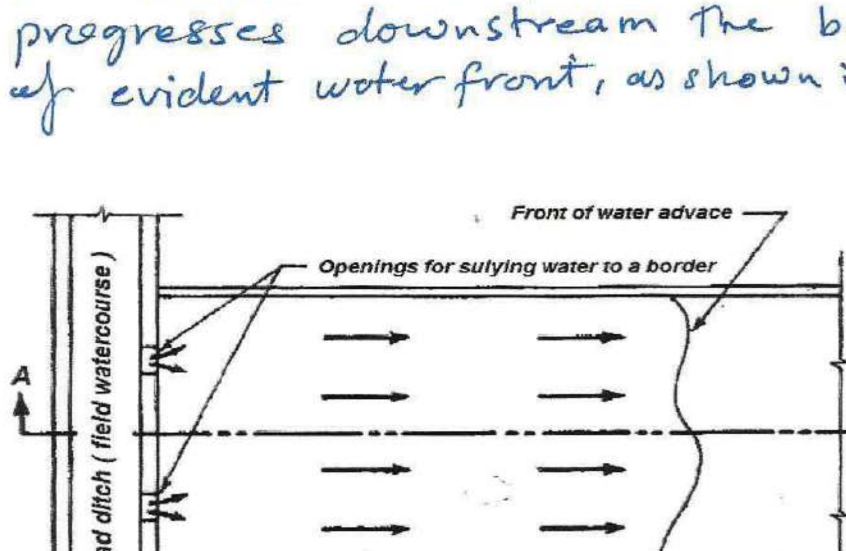
Surface Irrigation – Concept & Mechanism

الري السطحي - المفاهيم والآلية

For the three types of irrigation, border, furrow and basin, the water was leave to move as shallow surface flow over graded area when irrigation depth, supplied from head ditch or pipe, was applied at upstream of the run of border or furrow ----

في الري السطحي بأنواعه الثلاث الشريطي والمروز والأحواض يترك الماء يتحرك بصورة جريان سطحي على تربة مدرجة حيث يزود الماء أعلى النهاية العليا للشريط أو المرز بواسطة قناة صدرية أو انبوب .

For border irrigation, the flow moves rapidly over the width where its slope is almost horizontal. The water progresses downstream the border as surface wave of evident water front, as shown in figure below.

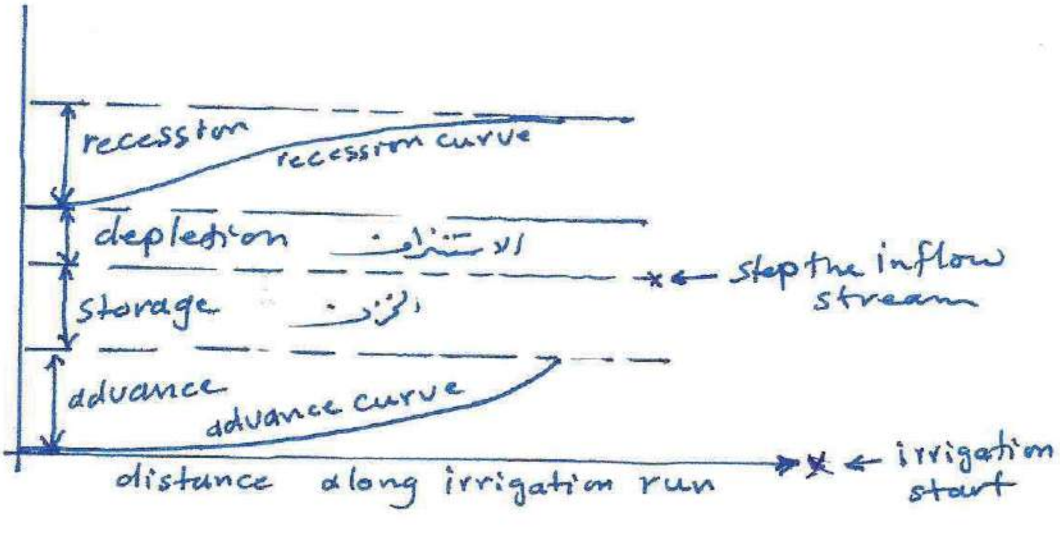


Water movement over surface and susurface of soil in border irrigation

During the water movement over soil surface, some of water infiltrated through a soil with a high rate in the beginning and decreasing slightly with time and distance.

Inflow stream Constant with time ⟹ * depth increases with time.
* the flow velocity decreases with time and distance (Why?).

When the front of water wave reaches the the downstream end of the run (border or furrow), the phase of advance is finished. In the advance phase end, when the water arrives the downstream end of the run, the water begins to flow out as surface runoff whenever the end is opened, or as surface storage when the end is closed (blocked end). The inflow stream is stopped and phase from arrival of water to D/S end till stopping the inflow stream is called storage phase. As time increased, the infiltration process depleted the storage water over the soil surface and the recession phase started while the depth at U/S run becomes zero. The depletion phase is fall between storage phase and recession phase. Not all phases are necessary revealed simultansouly. Some of phases like storage phase-



The advance phase plays very important role in the design of Irrigation system (surface irrigation). It is mandatory to exist in surface irrigation system. It is
وجوده حتمي في نظم الري السطحي .
an important factor effects the efficiency and adquacy, as well as the uniformity of irrigation مهم ويؤثر على كفاءة الإرواء وكفاية الإرواء وتناسق الري .

1. Irrigation Efficieny (IE) كفاءة الإرواء

All irrigation system produce losses by deep percolation and surface runoff and in sprinkler irrigation another losses by evaporation may be involved. Thus, the irrigation depth should be applied in a way that it must be greater than the net depth which so-called (Gross depth dg)

$$dg = dn + \text{farm losses} + LR - \text{rainfall} \quad ----(5.1)$$

dn: net depth of irrigation
farm losses = runoff + deep percolation losses
LR = leaching requirement متطلبات غسل التربة من الاملاح
rainfall : الامطار

and hence;

$$IE = \frac{dn}{dg} \quad \text{———————} (5.2)$$

dn can be calculated by assuming linear or nonlinear distribution of infiltration depth, whereas,

$$dn = \frac{\sum d_i l_i}{\sum l_i} \quad \text{———————} (5.3)$$

المتوسط الحسابي لعمق كل طول تغذية

$$dg * Area = Q_{in} * time \quad (vol.in = vol.out) \Rightarrow$$

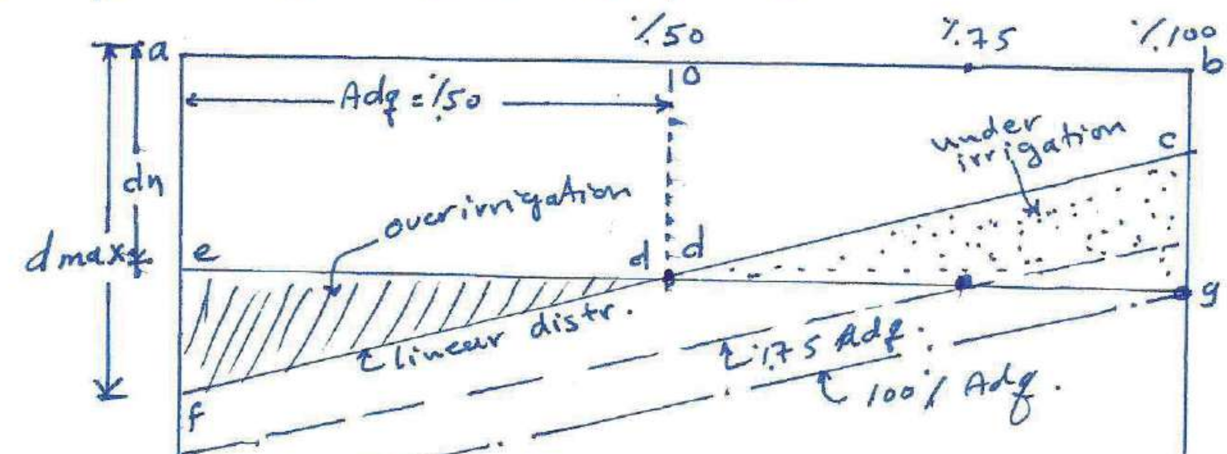
$$dg = \frac{Q_{in} * time}{Area} \quad \text{———————} (5.3)$$

2. Adequacy of irrigation كفاية الإرواء

The irrigation water does not distribute equally over the field run. At u/s end the infiltration depth becomes greater than at D/S end. However, if the root zone was provided by depth equal to the net depth, in averaging sense, half of field recieved less than dn, and other half recieved greater than dn, i.e, 50% of the field area is under irrigation عجز أرواء and 50% of the field is over irrigation فرط أرواء.

الكفاية Adequacy: is the percent of area (or irrigation run if soil is homogenous and the slope of the irrigation is constant) that recieved equal and greater than dn.

هي نسبة المساحة المروية (وترادف استناداً طول المجاري اذا كانت التربة متجانسة وميل الري ثابت) التي تستلم عمقاً مساوياً أو أكبر من العمق الصافي.



od: represents dn

slope of the line cf represents the uniformity

يمثل ميل الخط cf درجة التناسق، ومقداره مقياس قلة منافذ التغلغل الحاصلة بالمثلث edf وقلة التسرب في العمق المكافئ المثلث cdg. وعليه يكون التناسق أفضل

The question remains in situation: Is increase of adequacy givevs economical benefit? هل زيادة الكفاية لها فائدة اقتصادية

* Scarcity of water → decreasing in Adq.
* Balance between production & water cost.

⇒ A new irrigation called deficit irrigation was appeared later to get high production

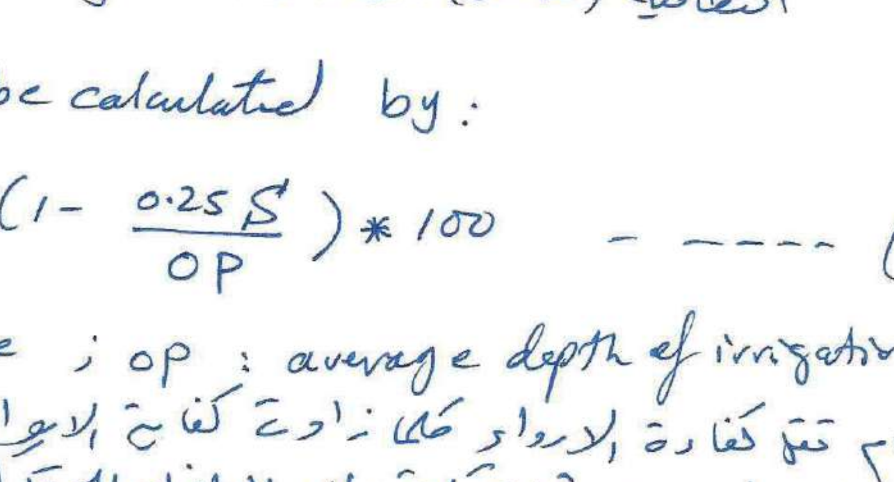
③ uniformity انتظامية (تناسق) الارواء

It can be calculated by:

$$\% U_c = \left(1 - \frac{0.25\, S}{OP}\right) * 100 \quad ----- (5.4)$$

S: slope ; OP : average depth of irrigation water

بشكل عام تقل كفاءة الارواء كلما زادت كفاية الارواء بثبات تناسق الارواء. عند ثبات كمية الماء الداخلة للحقل (الحوض) تزداد الكفاية والكفاءة بزيادة تناسق الارواء.



4. Water conveyance efficiency (E_c) كفاءة النقل

$$E_c = \frac{Q_g}{Q_{total}} \quad ------ (5.5)$$

Q_g ; amount of water at farm gate

Q_{total} ; amount of water at the source.

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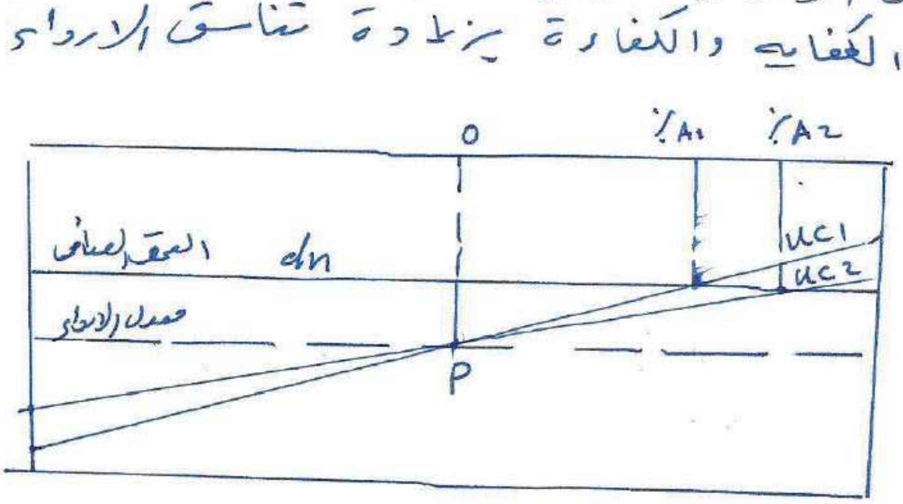
S: slope ; op: average depth of irrigation water

بشكل عام تقل كفاءة الارواء كلما زادت كفاية الارواء بثبات تناسق الارواء. عند ثبات كمية الماء الداخلة للحقل (الحيز) تزداد الكفاية والكفاءة بزيادة تناسق الارواء.



4. Water conveyance efficiency (Ec) كفاءة النقل

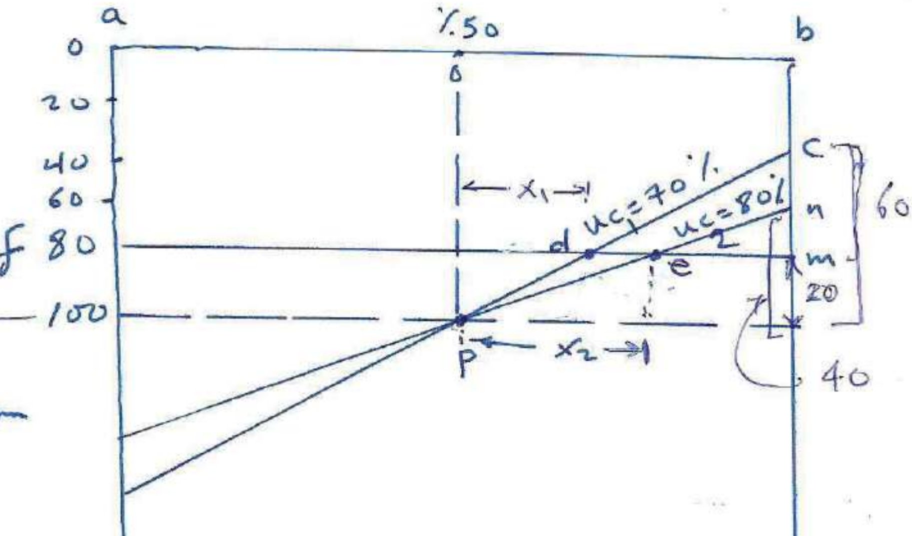
$$Ec = \frac{Q_g}{Q_{total}} \qquad ----- (5.5)$$

Q_g ; amount of water at farm gate
Q_{total} ; amount of water at the source.

Example:

Calculate irrigation efficiency and Adequacy when uniformity coefficient (Christansen coeff.) increased from 70% to 80% - If available water depth (RAW) is 80 mm and the average depth of irrigation water is 100 mm.

Solution



$$uc = \left(1 - \frac{0.25\,S'}{OP}\right) * 100$$

$uc_1 = 70\%$

$S' = 120$

$$S' = \frac{\Delta y}{\Delta x}$$

$$120 = \frac{\Delta y}{50\%} \Rightarrow \Delta y = 60\ \text{mm}$$
c-m

$uc_2 = 80\%$

$S' = 80 \Rightarrow \Delta y = 40\ \text{mm}$
(n-m)

$uc_1 = 70\%$

$$\frac{60}{50} = \frac{100-80}{x_1} \Rightarrow x_1 = 16.6\% \text{ or } \left(\frac{cm}{50} = \frac{20}{x_1}\right) \Rightarrow \frac{40}{50} = \frac{20}{x_1}$$

$$Adq_{(1)} = 50 + 16.6 \simeq 67\%$$

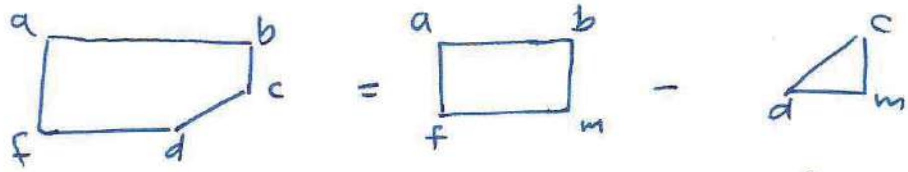
$uc_2 = 80\%$

$$\frac{40}{50} = \frac{100-80}{x_2} \Rightarrow x_2 = 25\% \text{ or } \left(\frac{nm}{50} = \frac{20}{x_2}\right)$$

$$Adq_{(2)} = 50 + 25 = 75\%$$

$$\Delta Adq = 75 - 67 = 8\%$$

when $UC_1 = 70\%$, the irrigated area is abcdf.

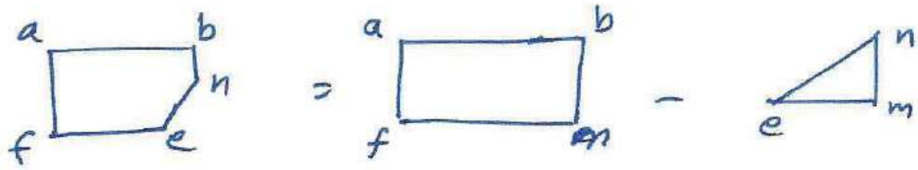


$$= 80 * \frac{100}{100} - \frac{\frac{(100-67)}{100} * 40}{2}$$

$$= 73.4\ \%\ mm$$

$$IE = \frac{73.4}{100} = 73.4\ \%$$

when $UC_2 = 80\%$



$$= 80 \times \frac{100}{100} - \frac{\frac{100-75}{100} * 20}{2}$$

$$= 77.5\ mm$$

$$IE = \frac{77.5}{100} = 77.5\%$$

$$\Delta IE = 77.5 - 73.4 = 4.1\ \%$$

H.W *3

If you know that the adequacy of irrigation (Adq = 80%) for a farm irrigated at allowable depletion (AD) of 50% of water content. In order to have Adq = 100%, the farm should be irrigated at AD = 40% of its water content. Assume the uniformity of irrigation UC & average applied depth OP are constants. Express the irrigation efficiency IE in both cases, also find the uniformity coeff. of irrigation.

Water Balance Concept مفهوم الموازنة المائية

Many mathematical models are available to define the position of water advance front in terms of time over soil surface and how the infiltrated depth distributed. As well as defining the recession curve and may be to adjust the uniformity and adequacy.

In the below one of the models considered as simple was taken into account buit on mass conservation or more specifically the volumetric water balance method. It can be used for graded border, level border as well as furrows & basin.

By Continuity equation :- بواسطة معادلة الاتصال

$$Q \cdot t = V_f + V_i \quad \text{for } t \leq T_r \qquad \text{------- } (5.6)$$

Q = discharge (inflow) of irrigation run التيار الداخل لمجاري الري

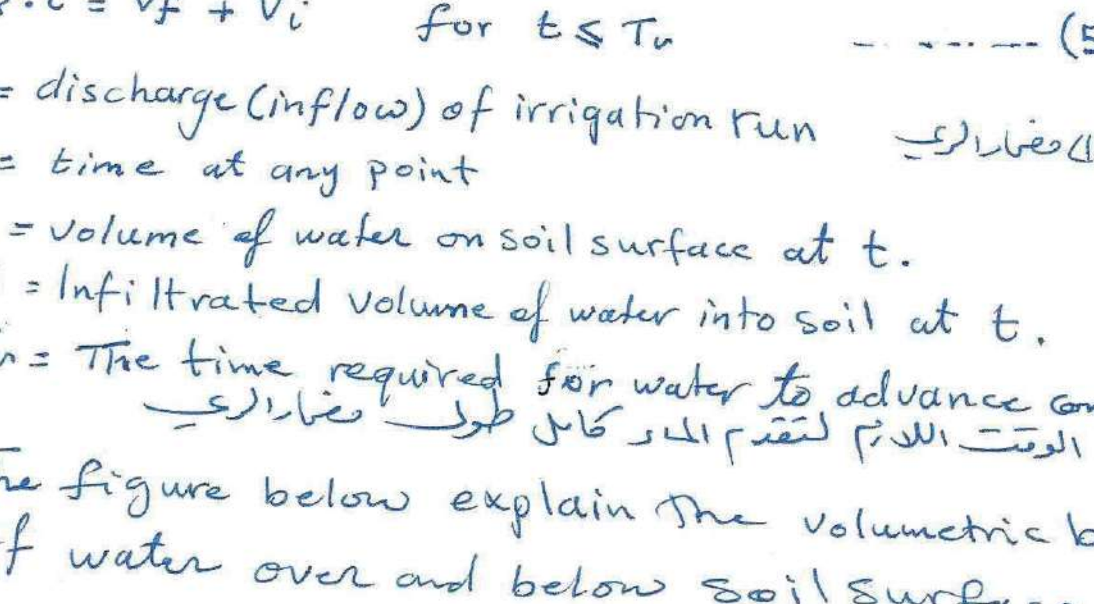
t = time at any point

V_f = volume of water on soil surface at t.

V_i = Infiltrated volume of water into soil at t.

T_r = The time required for water to advance complete run. الوقت اللازم لتقدم الماء كامل طول مجاري الري

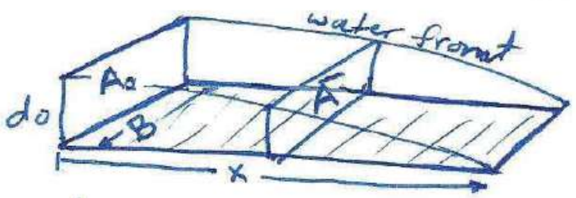
The figure below explain the volumetric balance of water over and below soil surface.



Major elements in a volumetric water balance model for surface irrigation

The depth of flow (over soil surface) changes with distance; it is in max. value at u/s of run and be zero at water front end. Hence, the cross-sectional area of surface flow decreases with increasing distance. Therefor, the volume can be calculated by Area integral over the distance x at time t ;-

$$V = \int_0^{X(t)} A(s,t)\,ds = \bar{A}x = 0.77 A_o x \quad \text{------}(5.7)$$



x = the advance distance

$A(s,t)$ = cross-sectional area of surface flow at $x=s$ at $(t \leq t_x)$

S = distance from u/s run of irrigation , طول من مدخل الخط

t = time from begining of irrigation الزمن من بدء الإرواء

A_o = cross-sectional area at u/s run of irrigation.

$\bar{A}$ = average cross-sectional area over distance x.

A_o can be calculated by Manning equation:

$$Q = \frac{1}{n} A_o R_o^{2/3} S^{1/2}$$

For border: $R \cong d_o$

$$d_o = 100\,(nq)^{0.6} / S^{0.3} \quad \text{------}(5.8)$$

d_o in cm & $q = Q/B$ = m³/s/m (discharge per unit width)

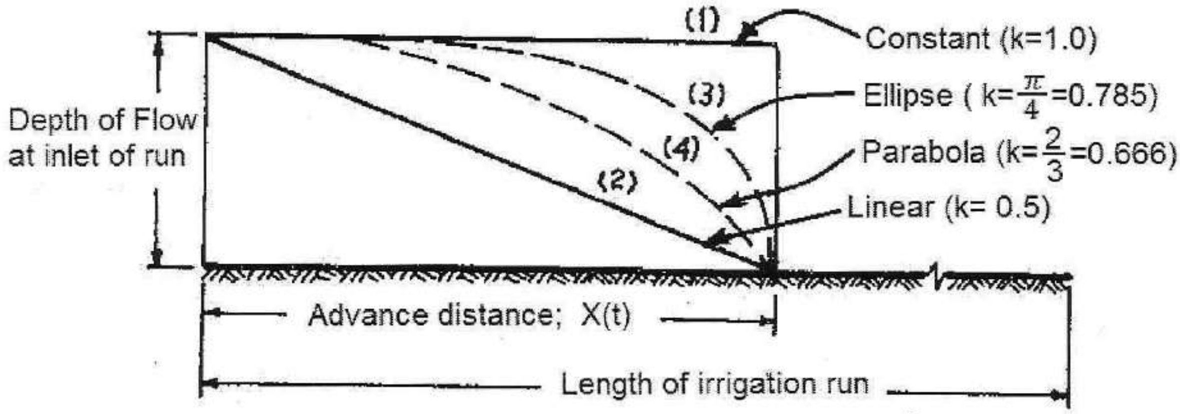
For furrow:

$$Q = \frac{1}{n} A_o R_o^{2/3} S^{1/2} \quad \text{------}(5.9)$$

Note that, $\bar{A} = K A_o$ (5.10)

K = depends on geometry of longitudinal section of surface flow.

All experiments reveals that K ranged from 0.5 to 1.0
If triangular shape was assumed K = 0.5 & if rectangular shape was held K = 1.0 (constant), as shown in figure.



Longitudinal geometery of surface flow

From field experiments ; $K = 0.75 - 0.8$. In case of information Lack ; the value of $K = 0.77$.

Volume of infiltrated water can be calculated as:

$$V_i = B \int_0^{X(t)} D(s, t_x - t_s)\, ds \qquad (5.11)$$

t_x = time of distance x .
s = distance from u/s inlet of run .
t_s = time of advance distance s .
D = function of infiltration .

Same considerations for surface volume are taken for infiltration volume ; i-e;

$$V_i = B . F . D(0, t_x)\, X$$

where F: shape factor for subsurface pattern.
Thus; eq(5.6) becomes

$$Q.t = 0.77\, A_o x + B F D(0, t_x)\, X \qquad (5.12)$$

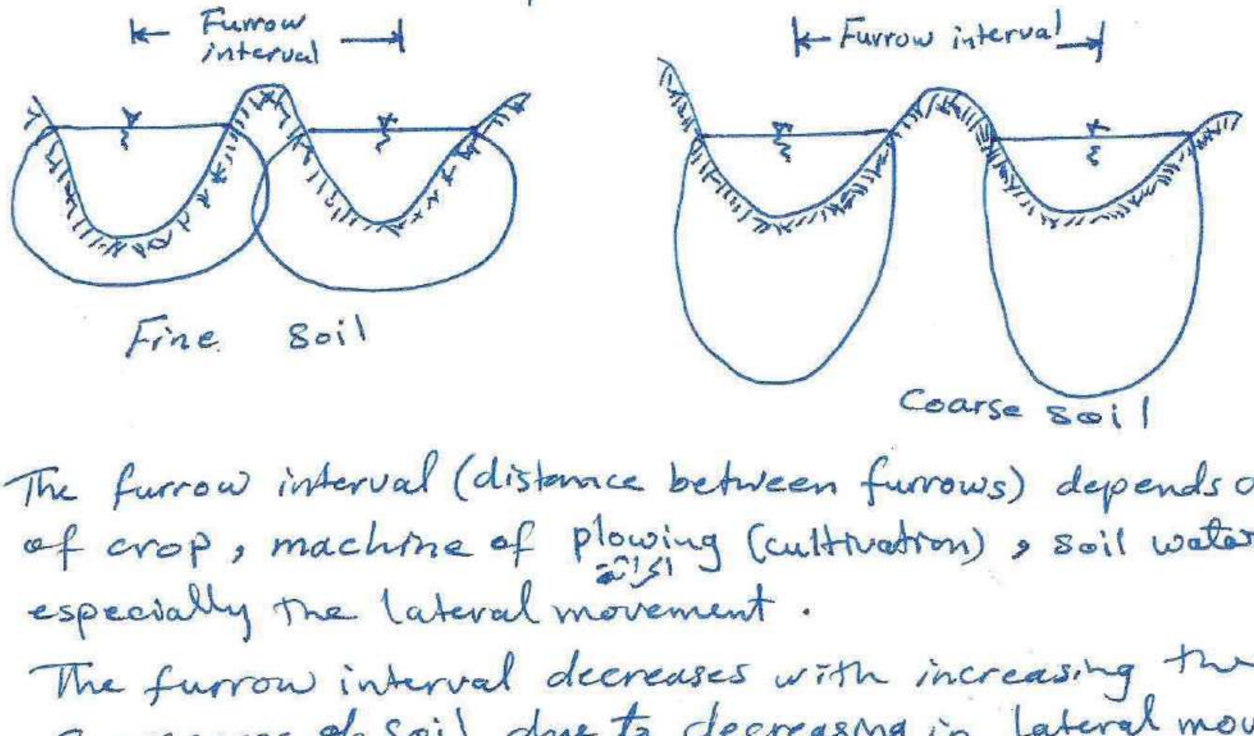
The field works results agreed that the advance phase can be approximated by logarithmic function:

$$x = a t^{b} \qquad (5.13)$$

and a & b were found by similar method of determing constants in infiltration function.

Furrow Irrigation: ري المروز

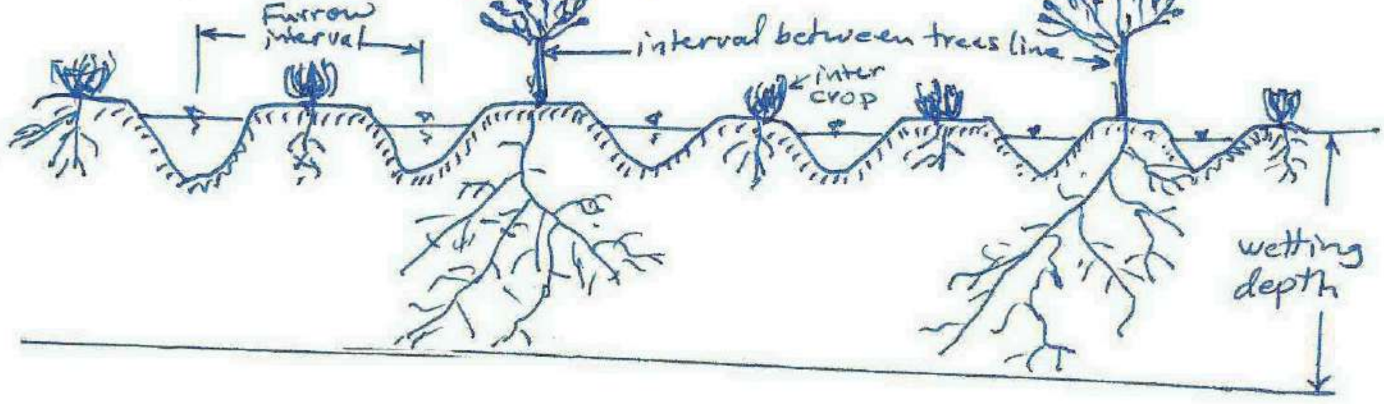
Furrows are ditches or small canals of constant slope in a flow direction. This method is used for all crops that plantted in lines such as vegetables (tomatoes, okra, spinach .. etc) and cotton, corn, Potatoes



The furrow interval (distance between furrows) depends on type of crop, machine of plowing (cultivation) حراثة, soil water movement especially the lateral movement.

The furrow interval decreases with increasing the coarseness of soil due to decreasing in lateral movement of water, therefor furrow interval should not be exceeds 50 cm in coarse soil and 1.2 m in medium and greater in fine soil. Whenever wetting depth decreases the interval is consequently decreases.

Interval Of furrow is from 30-40cm (Lettuce خس, Onion بصل, Carrot جزر) and increased by 60-90 cm for potatoes, corn and cotton). However trees need more than one furrow for wetting purposes.



The water supply by furrow to the soil included a method differs from flood water in border irrigation. The width of furrow is from 20-40cm and depth is 10-25 cm. While the flow depth is maximum at U/s inlet of furrow to minimum at end of furrow. The researches revealed that the intake varied linearly with wetted perimeter of furrum. The slope should not exceed the limits because the flow velocity may be reach the scour velocity and causing an erosion in soil. It is preferable to maintain the slope less than 2%.

Advantages:

1. less discharges
2. part of field area is covered by water, the services are excuted well.
3. less loss in area (ditches and ridges do not exist).

disadvatages:

1. Salt accumulation at top of furrow
2. high surface runoff.
3. Needs to many Labor workers as well as operating & maintenance.
4. The discharge control with high precision.
5. The pplied depth is not be able for less than 50 mm.

Basin Irrigation: الري الحوضي

The basin irrigation is the simplest method of surface irrigation, therefore it is frequently use in crop irrigation. It includes the dividing the farm into Level areas (مساحات مستوية، او لوح) nearly square in shape, surrounded by dikes or Levees (ridges) دكات adequate to accumulate the water inside the basin (prevent water escaping, i-e, Prevent surface runoff). The area ranged from $1\,m^2$ to some square meter for irrigation of vegetable, 7.5 hectars for rice crop or crop plannted in heavy clay.

A large quantity of water is delivered into basin to cover the most area in short time, and thereafter the water discharge is stopped. The water infiltrated into soil in a finite time. It is suitable for heavy soil (low permeability) and for Level area (or less changes in topography)

disadvanteges:

1. Leveling works is required with high accuracy.
2. The watercourses & ditches, dikes, hinders (تعيق) the works of Agr. machines.
3. The construction requirements & the labours have much needs compared with border irrigation.

Example-1

The advence time for $x = 50m$ is 20 min, for another 50 m distance is 35 min, Estimate the advance time required for third 50 meters from border.

sol.
$$X = a\,t^{b}$$

$$50 = a\,(20)^{b} \quad —(1)$$
$$100 = a\,(50)^{b} \quad —(2)$$

م: لاحظ أن الزمن والمسافة تحسب دائماً من البداية

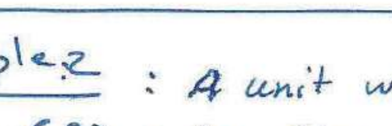
Solve two equations yields

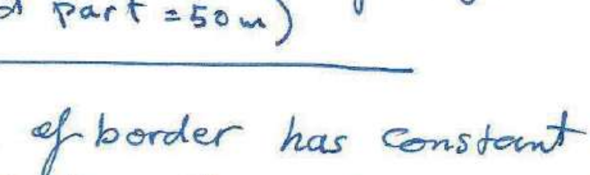
$$a = 6.42\,,\quad b = 0.69 \Rightarrow X = 6.42\,t^{0.69}$$

$$150 = 6.42\,(t)^{0.69} \Longrightarrow t = 96 \text{ min from begining of irrigation.}$$

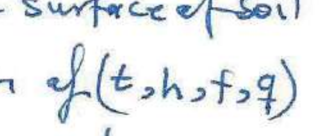
(41 min for the third part = 50 m)

Example 2 : A unit width of border has constant infiltration rate (f), the flow depth is uniform = h over surface of soil. Express the advance distance x as a function of (t, h, f, q) where q is a unit discharge & t the advance time. Also fined The distance at $t = 40$ min, if $q = 7$ l/s/m, $h = 10$ cm, and $f = 15$ mm/hr.





Solution: from water balance principle :-



$$q \cdot dt = h \cdot dx + f \cdot dt \cdot x$$

$$(q - f x)\,dt = h \cdot dx \quad \text{or} \quad dt = \left(\frac{h}{q - f x}\right) dx \Rightarrow$$

$$\int_0^t dt = \int_0^x \frac{h}{(q - f x)}\,dx$$

$$t = \frac{h}{-f} \ln (q - f x) \Big|_0^x = -\frac{h}{f}\left[\ln q - \ln (q - f x)\right] = \frac{h}{f}\left[\ln\left(\frac{q - f x}{q}\right)\right]$$

$$\Rightarrow x = \frac{q}{f}\left(1 - e^{-ft/h}\right) \;;\; \text{for } t = 40 \quad X = 159.9 \text{ m}$$

انتبه الى الوحدات (ft/h) يجب أن تكون بلا وحدات.

$\left(\frac{-2.5t}{1000}\right)$

وتكون $1680 = (q/f)$

Example-3

If the infiltrated depth in the U/s run is 48 mm when the water front distance is 160 m, but when the water front reach 240 m the infiltrated depth is 72 mm. Find the infiltrated depth at 100 m from begining of the run, when the advance water front reached 300 m. The infiltration function is $\underset{mm}{D} = 6\,\underset{min}{t}^{1/2}$).

solution:

1. Find advance equation from time of infiltration:

* the time of water advance 160 m is same time of infiltration depth of 48 mm; thus;

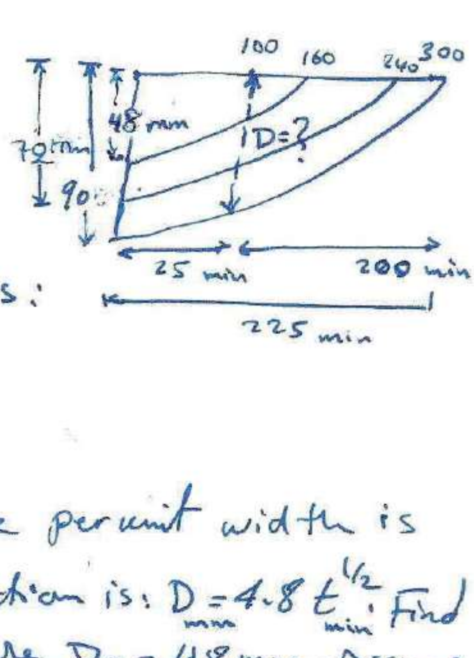
$t = \left(\frac{48}{6}\right)^2 = 64\,min$

* Same rule applied for $x = 240\,m$ and $D = 72\,mm$; yields

$t = \left(\frac{72}{6}\right)^2 = 144\,min.$

$\Rightarrow \quad X = a(t)^b$

$\left.\begin{matrix} 160 = a(64)^b \\ 240 = a(144)^b \end{matrix}\right\} \Rightarrow X = 20\,t^{1/2}$



2. at $x = 100 \Rightarrow t = 25\,min$

at $x = 300 \Rightarrow t = 225\,min$

The time of water remains on point $x = 100$ is:

$225 - 25 = 200\,min$

$D = 6(200)^{1/2} = 84.85\,mm.$

Example 4 : For irrigation run the discharge per unit width is $q = 3.9\,l/s/m$, $d_o = 8\,cm$, infiltration function is: $\underset{mm}{D} = 4.8\,\underset{min}{t}^{1/2}$. Find max. distance of advance water front where $D_o = 48\,mm$. Assume that shape of infiltration pattern is parabola.

Sol: max. distance = length of run $\Rightarrow$ t of D_o is t_a زمن الإرواء

$t = \left(\frac{48}{4.8}\right)^2 = 100\,min \Rightarrow$ Apply eq. (5.12) water balance principle

for $Q = 0.0234\,\frac{m^3/min}{m}$, $A_o = 0.08\,m^2$, $B = 1.0\,m$, $F = 2/3$, $D(0, t_x) = 0.048\,m$

$\Rightarrow X = 250\,m$ لاحظ أننا قمنا بتحويل الوحدات لغرض التجانس

H-W #4

① Irrigation run has length 300m and the water advance front cover this reach by 120 min. IF the shape of infiltrated depths was assumed a triangle, and the infiltration function is considered as $\underset{mm}{D} = 4.2\,\underset{min}{t}^{1/2}$. Find the advance water function? $\left(\text{Ans: } X = \dfrac{t^{2.41}}{341.7}\right)$

② A Level border having length 200m, was supplied by discharge equal to 8 m³/hr/m for two hrs, then the water reached to the D/S end of the border within 100 min. If the infiltration rate is assumed constant and equal to 24 mm/hr. Calculate the irrigation uniformity (U_c), assume the Linear distribution for infiltrated depths and no surface runoff occurred.

(Ans: $U_c = 87.5\%$)

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Third Stage

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Dr. Rasul M. Khalaf

Irrigation and Drainage Engineering

Chapter Six
Consumptive Use and Water Requirements

Chapter six

Consumptive use & water Requirements

"الاستهلاك النباتي والاحتياجات المائية"

الاستهلاك المائي — التبخر-نتح

Consumptive use (crop evapotranspiration): is water consumed by plant for purpose of growth for specified time and for transpirated and evaporated water.

هو الماء المستهلك من قبل النبات لاغراض النمو والنتح والتبخر. ويختلف من نبات لآخر بل هو يختلف لنفس النبات مع اختلاف اطوار النمو.

Consumptive is necessary for calculating the water requirements for a farm. It depends on (1) temperature (2) daylight hours (3) humidity (4) wind movement (5) type of crop (6) stage of growth of crop and (7) soil moisture depletion.

Measurements of crop cosumptive use

(1) Field plot ; small area $(2\times2)\,m^2$ and performing measurements of rainfall + water used (irrigation water) − surfece losses = consumptive use

(2) By Lysimeters ; field method $\Rightarrow$ tank $(15\times15\times3)\,m$.

Crop evapotranspiration = Rainfall + Irrigation water − percolation.

Consumptive use = evapotranspiration + water used in plant growth = crop evapotranspiration

E_T = Crop evapotranspiration mm/day.

E_{To} = Reference evapotranspiration mm/day. يحصل عليه من دائرة الأنواء الجوية

K = Crop coefficient (depends on crop type & growth phase).

$$E_T = K\,E_{To} \qquad \text{--------- (6.1)}$$

$$\text{Farm efficiency of irrigation} = \frac{\text{consumptive use}}{\text{consumptive use} + \text{percolation} + \text{runoff}}$$

③ By formulae of consumptive use, such as:

1. Blaney - Criddle
2. Thornthwait
3. Penman
4. Hargreaves, class A pan evaporation method

Blaney - Criddle method

E_o = monthly consumptive use factor (potential evapotranspiration)

$$E_o = T^{F°}\left(\frac{P}{100}\right) \quad \text{———} \quad (6.2)$$

inch/month

P = percentage of length of daytime hours of one month / length of daytime hours in one year

$$E_o = P\left[\frac{1.8T^{c°}+32}{40}\right]$$

mm/month

$$E_o = P\,(0.46\,T_{c°} + 8.14) \quad \text{———} \quad (6.3) \quad \text{in SI-units}$$

mm/month

$\mathcal{U}$ = consumptive use

$$\boxed{\mathcal{U} = K_c E_o} \quad \text{———} \quad (6.4)$$

K_c = crop coeff. (From table)

prof. Najeeb Kharrufa corrected Blaney - Criddle in a way suitable for Iraq as;

$$E_o = K'\,P\,(0.46\,T_{c°} + 8.14) \quad \text{———} \quad (6.3a)$$

and $K' = 0.0311\,c° + 0.24$

معادلة أ.د. نجيب خرفوفة (رحمه الله) .
التي عدّل بموجبها معادلة بلاني-كردل

$\mathcal{U} = K_c E_o$

For K_c values of N. Kharuffa see table in next page.

Cu = Consumptive for season of growth.

$$Cu = \sum_{i=1} u_i \text{ ——— } (6\text{-}5)$$

Crop-Water Coefficient, k_c , and Root Zone Depth *

by

Professor N. Kharruffa

	Crop	R.Z. mms	Month											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov	Dec
حنطة	wheat	800	1.2	1.2	1.0	0.5	...	...	...	...	...	...	0.4	0.8
شعير	Barely	800	1.2	1.2	0.8	0.3	...	...	...	...	...	...	0.4	0.3
بنجر سكري	Sugarbeet	800	1.2	1.2	1.2	1.1	0.7	...	...	...	...	0.5	0.7	1.0
كتان	Flax	1200	1.2	1.3	1.1	0.7	...	...	...	...	...	0.5	0.7	1.0
برسيم	Berseem	800	0.6	0.7	1.0	0.8	0.2	...	...	...	...	0.4	1.1	1.2
جت	Alfalfa	1200	0.5	0.8	1.0	1.0	1.1	1.1	1.1	1.0	0.9	0.9	0.9	0.9
رز	Rice	800	...	...	1.1	1.2	1.3	1.3	1.2	0.9	0.5	...	...	...
قطن	Cotton	1000	...	...	0.6	1.0	1.1	1.2	1.2	1.2	1.0	...	...	...
دوار الشمس	Sunflower	1000	...	...	...	0.7	0.9	1.1	1.2	1.2	0.9	...	...	...
ذرة صفراء	Yellow corn	800	...	...	...	...	...	...	1.0	1.0	0.8	0.5	0.2	...
ذرة بيضاء	White corn	700	...	...	...	...	...	...	1.0	0.9	0.7	0.4	...	...
[illegible]	Greengram	700	...	...	...	...	...	0.5	0.8	1.1	0.6	...	...	...
خضروات	Vegetables	600	0.5	0.6	0.8	0.8	0.8	0.9	1.0	0.9	0.7	0.7	0.5	0.5
بساتين فاكهة	Orchards	1500	0.5	0.6	0.8	0.8	0.8	0.9	1.0	0.9	0.7	0.7	0.5	0.5

* These coefficients are to be used only with the corrected Blaney-Criddle formula as follows :

$$E_o = k' f$$

Example: Determine the seasonal consumptive use of wheat;

	Jan	feb	march	apr.
T °C:	15	16	20	31
P :	7.0	7.4	7.6	7.9

Solution:

$$E_o = k' P (0.46T + 8.14) = (0.0311\, C^\circ + 0.24)(0.46\, C^\circ + 8.14) P$$

	Jan.	Feb.	Mar.	Apr.	
$E_o =$	74.38	84.60	113.60	152.54	mm
$U = K_c \cdot E_o \Rightarrow U =$	89.26	101.52	113.60	76.27	mm

$Cu = \sum u_i = 380.65$ mm for wheat season.

Average monthly consumptive use = ?
Average daily consumptive use = ?
Peak monthly consumptive use = ?

Water Requirements الاحتياجات المائية

P_e : المطر الفعال هو جزء المطر الذي شارك في رطوبة التربة المجهزة للنبات

* Consumptive Irrigation Requirement (CIR)

$$CIR = Cu - Pe \quad \text{------} \quad (6.6)$$

If ($P = P_K - P_{runoff}$)

If $P > 7.5$ cm/month $\Rightarrow Pe = 0.8P - 2.5$ | cm/month.

If $P < 7.5$ cm/month $\Rightarrow Pe = 0.6P - 1.0$ | cm/month.

If $P < 1$ cm/month $\Rightarrow Pe = 0$ (Pe : effective rainfall)
(P_K : Peak rainfall)

* Net Irrigation Requirement (NIR)

$$NIR = CIR + Le = Cu - Pe + Le \quad \text{------} \quad (6.7)$$

Le : is leaching requirement.

* Field Irrigation Requirement (FIR)

$$FIR = NIR + Losses \quad \text{------} \quad (6.8)$$

$$FIR = Cu - Pe + Le + Losses$$
$$= Cu - Pe + Le + Ea\,(Cu - Pe)$$

Ea : application efficiency ranged (60% - 80%) ⇒ sand → H. clay.

Ex: using data given below in first four columns, Determine the irrigation depth for each month (take IE = 60%.)

(1) Month	(2) Kc	(3) pan Evapor. mm	(4) Pe mm	(5) $u = (2) \times (3)$	mm $d_g = \frac{d_n}{IE} = \frac{(5)-(4)}{0.60}$
Nov.	0.2	118	6	23.6	29.3
Dec.	0.36	96	16	34.5	30.93
Jan.	0.75	90	20	67.5	79.17
Feb.	0.9	105	15	94.5	132.5

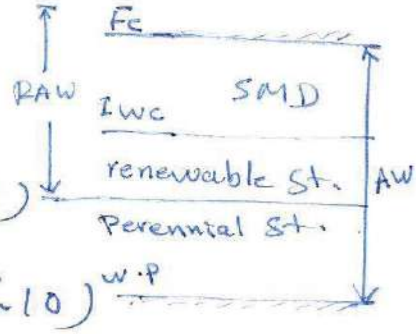
Net depth : is the depth of water applied and stored in root zone. (It is only available for plant growth).

For full irrigation $d_n = SMD$ dn الماء المضاف هو كامل العجز المائي

For uncomplete irrigation $d_n < SMD$ dn الماء المضاف هو أقل من العجز الكلي

$$RAW = AW * AD * RZ$$

Note $RAW \geq SMD$



$$II_{max} = \frac{RAW}{Cu} \qquad (6.9)$$

$$II = \frac{d_n}{Cu} = \frac{RAW - SMD}{Cu} \qquad (6.10)$$

II = Irrigation interval -

Not that!

$d_g = d_n +$ farm losses + L.R. − eff. rainfall

If no iformation about eff. rainfall take eff rainfall = 50% Bulk rainfall

example:

Cu = 2.8 mm/day. Determine the irrigation interval (II) and the depth of water to be applied whenever Soil moisture available is ① 25% ② 50% ③ 75% ④ 0% of max depth of availabe water in R.Z which equal 80 mm and IE = 65%

sol: $II = \frac{d_n}{Cu} = \frac{(1-0.25)80}{2.8} = 21.4 \text{ days} \approx 21 \text{ days}$

$IE = \frac{d_n}{d_g} \Rightarrow d_g = \frac{(1-0.25)80}{0.65} = 92.3 \text{ mm}$

and so on

Deficit :	25%	50%	75%	0%
II(day) :	21	14	7	28
dg(mm) :	93	62	31	124

For given Area of farm all depths can be converted to volume and this volume with time assingment $\Rightarrow Q.t = d * A$.

example:

$Fc = 38\%$, $PWP = 18\%$, $RZ = 90cm$, $IWc = 26\%$, $AD = 50\%$, $Cu = 4 mm/day$ on 20^{th} Jan. morning. At 25^{th} Jan., eff. rainfall = 10 mm. On 28^{th} Jan. (evening), gross depth was applied in order to have full irrigation, assume 10% of net depth was gone as runoff, Find ① dg ② IE ③ initial water content at 31^{th} Jan. evening in mm.

Sol:

ص on 20^{th} Jan:

$$SMD = (0.38 - 0.26) * 90 * 10 = 108 \ mm$$

م on 25^{th} Jan: داخلة ضمنها (20^{th}, 21^{th}, 22^{th}, 23^{th}, 24^{th} evening)

$$SMD = 108 + 4.0 \frac{mm}{day} * 5 day - 10 = 118 \ mm$$

م on 28^{th} Jan. (25^{th}, 26^{th}, 27^{th}, 28^{th})

$$SMD = 118 + 4.0 \frac{mm}{day} * 4 = 134 \ mm$$

full irrigation $\Rightarrow dn = SMD = 134 \ mm$

$$dg = dn + \frac{10}{100} dn = 134 + 0.1(134) = 147.4 mm$$

$$IE = \frac{dn}{dg} = \frac{134}{147.4} = 90.9\%$$

on 31^{th} Jan. (29^{th}, 30^{th}, 31^{st} evening)

$$SMD = 4 \frac{mm}{day} * (3) = 12 \ mm$$

$$I.Wc = F.c - SMD$$

$$= 0.38(90) - 1.2 = 33 \ cm$$

ex :

Given: given crop evapotranspiration = 7 mm/day R.Z = 90 cm, Fc = 35%, PWP = 15%, initial soil water content 28% [all by volume]. AD = 40%, water is applied with gross depth = 69 mm, runoff losses = 25% of the applied depth. Find ① water content at 6 days after irrigation ② IE ?

Sol.

SMD (before irrigation) $= (Fc - W.c) * Rz * 10$

$= (0.35 - 0.28) * 90 * 10 = 63$ mm

$d_g = d_n + LR + \text{Farm losses} - \text{Rainfall}$ (LR = 0, Rainfall = 0)

$69 = d_n + \frac{25}{100}(69) \Rightarrow d_n = 52$ mm

SMD (after irrigation) $= 63 - 52 = 11$ mm

$IE = \frac{52}{69} \times 100 = 75.4\%$

SMD (after 6 days of irrigation $= 11 + 6 * 7 \frac{mm}{dy} = 53$ mm

$\% \ SMD = \frac{53}{900} * 100 = 5.9\%$

Initial water content (Wc) = Fc − SMD

$= 0.35 - 5.9 = 29.1\%$

H.W # 5

Given a crop of Cu = 10 mm/day, Rz = 1 m Fc = 38%, PWP = 20%, initial water content before irrigation = 30%, AD = 50%. Gross depth applied = 75 mm, water losses = 20% of applied depth. Find ① IE ② Percentage of water content 10 days after irrigation ③ SMD after 12 days after irrigation if eff. rainfall = 10 mm.

Ex: Given a discharge of $5\ m^3/s$ diverted from Canal irrigation of conveyance efficiency $CE = 85\%$ and

كفاءة النقل خلال القناة من مصدر المشروع .

Irrigation efficiency is $IE = 90\%$, and applied to a farm of total area 1500 Mishara (Donum) for a period of 24 hrs. Calculate the gross & net depth applied to the farm. (Assume 80% of area is planted).

افرض ٨٠٪ من الاجمالي فقط تستثمر للاستزراع والباقي ٢٠٪ قنوات وممرات وسداد.

Sol.

$$CE = \frac{Q_{gross}}{Q_{total\ (from\ source)}} = \frac{Q_g}{Q_{total}} \quad —— (6.11)$$

$$\Rightarrow Q_g = CE * Q_{total} = 0.85 * 5 = 4.25\ m^3/s.$$

$$Q_g \cdot t = d_g \cdot A$$

$$4.25*24*60*60 = d_g\ (1500*2500)*0.8$$

$$4.25 \times 86400 = 3 \times 10^6\ d_g \Rightarrow d_g = 0.1224\ m = 122.4\ mm$$

say 123 mm

$$IE = \frac{d_n}{d_g} \Rightarrow d_n = 0.9 \times 123 = 111\ mm \quad ■$$

Ex: Given discharge 900 l/s applied to a farm of net area 100 Donum once per week. $C_u = 20$ mm/day, farm losses is 10% of net depth. Find time of irrigation.

Sol:

$$Q_g \cdot t = d_g \cdot A \qquad d_g = d_n + \frac{10}{100} d_n$$

$$\frac{900}{1000} \frac{m^3}{sec} * t = d_g \cdot (100*2500)*1.0$$

$$0.9 \frac{m^3}{s} * t = \left(20 \frac{mm}{day} * 7\ \cancel{days}\right) * \frac{1.10}{1000 \frac{mm}{m}} * 250000\ m^2$$

$$t = \frac{38500\ m^3}{0.9\ m^3/s} = 11.88\ hrs \quad ■$$

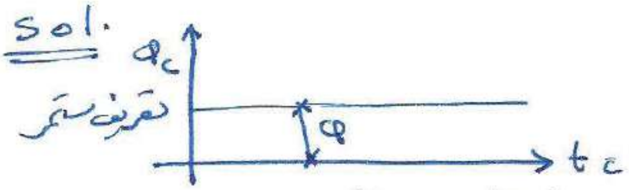
H.W 6: 250 l/s discharge applied for total area of 250 Donums (assume 80% of area is net), water losses by runoff through application is 20 l/s, $C_u = 12$ mm/day. Find net depth stored in soil after the end of one day (24 hr) of irrigation time.

$\boxed{\text{Answer: 28 mm.}}$

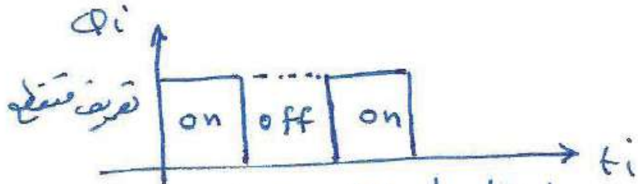
example: (for continous & intermittent discharge)
مثال حول التصريف المستمر والمتقطع

15 m³/s of water applied for 15 hrs to irrigate a net area of 1500 Donums, Pan evaporation $E_p = 5$ mm/day, coefficient of crop is $K_p = 1.2$, water is applied once every 3 days. Find IE, Continous discharge.

sol.



continous discharge



intermitted discharge

نفضل التشغيل المتقطع على المستمر بسبب التنظيم في توزيع المياه (المراشنة أو المناوبة) وأيضاً بسبب أعمال الصيانة .

$$Q_g \cdot t = d_g \cdot A \qquad (6.12)$$

$$15 \frac{m^3}{s} * 15 * 60 * 60 = d_g \cdot 12500 * 2500$$

$$d_g = 0.026 m = 26 mm.$$

[illegible]

$$C_u = K_p E_p = 1.2 * 5 = 6 \text{ mm/day}.$$

$IE = \frac{d_n}{d_g}$; d_n is assumed = SMD (SMD = 6 × 3 = 18 mm)

$$IE = 18/26 = 69.23\%$$

$$Q_c \cdot t_c = Q_i t_i \qquad (6.13)$$

Note that $Q_c < Q_i$ since $t_c > t_i$

$$Q_c (3 * 24) = 15 * 15 \Rightarrow Q_c = 3.13 \text{ m}^3/\text{sec}$$

Example

A net depth of 120 mm was applied to total area 60 ha and the applied discharge is 180 l/s continous type. IE = 85%. What must be the time of irrigation.

sol. $IE = \frac{Q_n}{Q_g} \Rightarrow Q_n = 180 * \frac{80}{100} = 144$ l/s

$Q_n \cdot t = d_n \cdot A$ (assume An = 80 total area)

$$\frac{144}{1000} * 3600 * t(hr) = \frac{120}{1000} * 60 \times 10^4 * 0.85$$

$$t = 118 hr.$$

example:

A Valume of water equal to $3.5 \times 10^6\ m^3$ was required to irrigate a farm every 10 days. Find a discharge in (m^3/s) if water is applied according to:

ⓐ once day every 10 days
ⓑ 3 days once every 10 days
ⓒ 5 days every 10 days
ⓓ 12 hrs between day & another
ⓔ Continuously

sol:

ⓐ $$Q = \frac{V}{T} = \frac{3.5 \times 10^6}{1\left(\frac{10}{10}\right) \times 24 \times 3600} = 40.5\ m^3/sec.$$

ⓑ $$Q = \frac{3.5 \times 10^6}{3\left(\frac{10}{10}\right) \times 24 \times 3600} = 13.5\ m^3/sec.$$

ⓒ $$Q = \frac{3.5 \times 10^6}{5\left(\frac{10}{10}\right) \times 24 \times 3600} = 8.1\ m^3/sec$$

ⓓ $$Q = \frac{3.5 \times 10^6}{\left(\frac{12}{24}\right)\left(\frac{10}{2}\right) \times 24 \times 3600} = 16.2\ m^3/sec$$

ⓔ $$Q = \frac{3.5 \times 10^6}{10\left(\frac{10}{10}\right) \times 24 \times 3600} = 4.05\ m^3/sec.$$

أي أن التعريف = $\dfrac{\text{الحجم المطبق}}{\text{عدد أيام السقي بالفترة (عدد مرات فترات الأيام)} \times ٢٤ \times ٣٦٠٠ \text{ ثانية}}$

Q*: What about 24 hrs, every Five days? $20.25\ m^3/sec$

Irrigation Scheduling — جدولة الري

It is an organizing process of irrigation and calculating the amounts of water added during a specified period that may be month, or two months or even agricultural season, and achievement of water budget for plant consumptive use + the remaining water in Root Zone.

هي عملية تنظيم الري وحسابات المياه المضافة خلال مدة معينة قد تكون شهر أو شهرين أو حتى موسم زراعي كامل مع موازنة الاستهلاك المائي + الماء المتبقي في المنطقة الجذرية (التربة).

There is two methods for scheduling:-

1- Constant net depth of irrigation with variable irrigation interval - عمق ماء صافي مع فاصلة ري متغيرة

2- Variable net depth of irrigation with constant irrigation interval. عمق ماء صافي متغير مقابل فاصلة ري ثابتة

Note that the water budget is:

Irrigation depth + effective rainfall = Consumptive use + Farm losses + water stored in R.Z

$I = \sum_i dn_i$

$$\boxed{I + Pe = Cu + Loss + \text{water in RZ}} \quad \text{------} \quad (6.14)$$

$$\text{water in RZ} = WC\big|_{@\text{ end of water Budget}} - WC\big|_{@\text{ begining of water Budget}}$$

الماء المخزون في المنطقة الجذرية = المحتوى الرطوبي في نهاية الموازنة - المحتوى الرطوبي في البداية.

Example: An irrigation project of $Q_g = 8.4\ m^3/s$, net area = 6000 ha, I.w.c. on 1st march = 27% (by vol.), f.c. = 36%, PWP = 21% (all by vol.). AD = 40%, IE = 60%, Cu = 4.8 mm/day, R.Z. = 600 mm. Effective rainfall = 31 mm/month. Schedule the irrigation using both methods.

Sol:

$dn = RAW = (0.36 - 0.21) * 0.4 * 600 = 36\ mm$

لاعتبار الخسائر نطرح المطر التي تزيد الاستهلاك المائي.

$Cu = 4.8\ \frac{mm}{day} - \frac{31\ mm}{month} \cdot \frac{1\ month}{31\ day} = 3.8\ mm/day$

SMD before irrigation $= \frac{36 - 27}{100} * 600 = 54\ mm$

Conti →

① constant net depth

① Date day-month	② d_n mm	③ SMD mm before irrigation	④ SMD mm after irrigation	⑤ Note
1-3 (+5)	36	54	54-36=18	water can be depleted 18 mm; no. of days $= \frac{18}{3.8} = 4.7 \simeq 5$; no. of days $= \frac{② - ④}{cu}$
6-3 (+9)	36	$18+5\times3.8 = 37$	37-36=1	no. of days $= \frac{36-1}{3.8} = 9$ days
15-3 (+10)	36	$1+9(3.8) = 36$	36-36=0	$II = \frac{36-0}{3.8} = 10$ days
25-3	36	$0+10(3.8) = 38$	38-36=2	$II = \frac{36-2}{3.8} = 9$ days; تتوقف هنا لاننا سنذهب الى شهر ٤

ⓐ 31-3 $SMD = 2 + 7\times3.8 = 29$ mm

نتوقف لغاية 1-4 لضمان دخول 31-3 ع الحساب (أي 7 يوم)

$I.W.C. = \left(\frac{36}{100} \times 600\right) - 29 = 187$ mm

$I = \Sigma d_n = 36 * 4 = 144$ mm

$\Sigma Cu = 3.8 * 31 = 118$ mm

$I + Pe = Cu +$ soil moisture at end of budget $-$ soil moisture at begining of budget

$144 + 0 = 118 + 187 - \frac{27}{100} * 600$ (162 mm)

$144 = 144$ o.k.

② Constant Interval

$II_{max} = \frac{36}{3.8} = 9.5$ days RAW = 36 mm

$\simeq 9$ or 10 days say 9 days

II = 9 days ; Cu = 3.8 mm/day ; SMD on 1st march = 54 mm

$d_n = SMD = 54$ mm [on 1st march] ري كامل

Date	d_n mm	SMD before irrigation	SMD after irrigation
1-3	54	54	0 ← ري كامل
10-3	34	$0+9\times3.8=34$	34-34=0
19-3	34	$0+9\times3.8=34$	34-34=0
28-3	34	$0+9*3.8=34$	34-34=0

31-3 ; $SMD = 0 + 4 * 3.8 = 15$ mm ; $WC = F.C. - SMD = 0.36 * 600 - 15 = 201$ mm

$\Sigma d_n = 54 + 3(34) = 156$ mm

$\Sigma cu = 31\times3.8 = 118$ mm [$156 = 118 + (201 - 162)$]

Example

schedule the irrigation, calculate the water budget for october and NOV. by using the two methods. Fc=39% pwp=17%, AD=40%, RZ=90 cm, Soil moisture content on 1st oct. (morning) = 25% (all by vol.), Cu=5 $\frac{mm}{day}$ in Oct. and 3.5 $\frac{mm}{day}$ in NOV.

Sol:

① constant dn

$dn = RAW = (0.39-0.17)*0.4*900 = 79.2 \approx 80$ m

$SMD(1^{st}$ oct. Morning$) = (0.39 - \underbrace{0.25}_{\text{initial moisture}})*900 = 126$ mm

date	dn	SMD befor	SMD after	Interval (II)
1-10	80	126	126-80=46	$\frac{80-46}{5} = 6.8 \approx 7$ days
8-10	80	46+5*7=81	81-80=1	$\frac{80-1}{5} = 15.8 \approx 16$ days
24-10	80	1+16*5=81	81-80=1	=16 days
31-10	—	1+8*5=41	—	$\frac{80-41}{3.5} \approx 11$ days
12-11	80	41+11*3.5 ≈ 80	80-80=0	$\frac{80-0}{3.5} = 23$ days
30-11	—	0+19*3.5 = 66.5 ≈ 67 mm		

W.C. @31NOV. $= (0.39*900) - 67 = 284$ mm

$I = \Sigma di = 4(80) = 320$ mm

$\Sigma Cu = 31*5 + 30*3.5 = 260$ mm

$I + Pe = Cu +$ water storage (59)

$320 = 260 + [284 - (0.25*900)]$

320 ≈ 319 o.k check

② constant interval

$II_{max} = \frac{RAW}{Cu} = \frac{80}{5} = 16$ days for oct., $\frac{80}{3.5} = 23$ days for NOV.

II = 16 days [always consider the smallest II]

Now construct the table of Calculations

Cont... →

Date	dn	SMD before	SMD after	
1-10	126	126	0	ريه كامله full irrigation
17-10	80	$0 + 16 \times 5 = 80$	0	
31-10	—	$0 + 15 * 5 = 75$	—	
2-11	$78.5 \approx 79$	$75 + 1 * 3.5 = 79$	0	
18-11	56	$0 + 16 * 3.5 = 56$	0	
30-11 ≡ 1/12 ex.		$0 + 13 * 3.5 = 45.5 \approx 46$	—	

$$I.W.C = (0.39 * 900) - 46 = 305 \text{ mm}$$
at 30 NOV.

$$I = \Sigma dn = 126 + 80 + 79 + 56 = 341 \text{ mm}$$

$$\Sigma Cu = 31 * 5 + 30(3.5) = 260 \text{ mm}$$

$$341 = 260 + [305 - (0.25 * 900)]$$

$$341 \approx 340 \quad \underline{\underline{\text{o.k}}}$$

بسبب تقريب ½ ملم ← ١ ملم

2-11 is [illegible] SMD ٢

H.W # 7: Given a project of total area = 50 Donums, net discharge = 0.05 m^3/s, F.C = 40%, PWP = 22%, all by volume, R.Z. = 1 m, AD = 50%, Cu = 5 $\frac{mm}{day}$ for May, Cu = 7 $\frac{mm}{day}$ for June, Cu = 8 $\frac{mm}{day}$ for July, Cu = 10 $\frac{mm}{day}$ for August. Complete irrigation is performed at 10^{th} May (morning). Schedule the irrigation starting from 1^{st} of June to End of August by using constant dn method.

المقنن المائي

Water duty (W.Du): It is an area irrigated by unit continous discharge over entire period (Base)

$$W.Du = \frac{A}{Q} \quad hec/1\,cumecs \text{ ------ } (6.15)$$

$(cumecs = m^3/sec)$

يعرف المقنن المائي بأنه مقدار مساحة المروية لتصريف مقداره $1\ m^3/sec$

Water duty depends on:

1. Type of plant 2. Type of soil 3. temperature
4. Salt concentration in the soil.

عادة كمية الماء المجهزة لا تعطى بشكل مستمر بل متقطعة (على شكل ريات)
وفي النهاية يكون حجم الماء في الحالتين المستمرة والمتقطعة هو نفسه .

Base period (B):

The period from first watering to last watering

first watering — Base period — last watering

وهذه الفترة تختلف قليلا عن الفترة الأكثر من الإنبات إلى الحصاد ويمكن القول أنه نفسه .

Delta (Δ):

It is the total depth of water during base period

$$\Delta = \frac{\text{total quantity of water } (hec.m)}{\text{total area of land } (hec)} \text{ ---- } (6.16)$$

$$\text{Quantity of water} = 1\ \frac{m^3}{sec} \cdot B \text{ days} * \frac{24\ hr}{day} * 60 * 60\ \frac{sec}{hr}$$

$$= 8.64 \times 10^4\ B$$

$$\text{but Quantity of water} = W.Du * 10^4 * \Delta$$

$$\Rightarrow W.Du * 10^4 = 8.64 \times 10^4\ B$$

$$\Rightarrow W.Du = \frac{8.64\ B_{(day)}}{\Delta_{(m)}} \text{ ------ } (6.17)$$

يحسب المقنن المائي لأي كل متطلبات مائية شهرية تكفي لارواء
المزرعة لأي أشهر أشتراكهم او أشهر حاجة للماء .

Example: Find the delta of a crop if the water duty is 1800 hec/cumecs and the base period is 130 days. What would be the WDu if the delta is increased by 20% and base period is reduced by 10 days?

Sol.

(a) $\Delta = \dfrac{8.64\,B}{W.Du} = \dfrac{8.64\,(130)}{1800} = 0.624\,m$

(b) $\Delta = 1.20\,(0.624) = 0.75\,m$

$B = 120$ days

$WDu = \dfrac{8.64 \times 120}{0.75} = 1382$ hec/cumecs

Example:

Given; $Cu = 12$ mm/day; irrigation time (continous) is 1 day, $IE = 95\%$, total area $= 10$ hec. Find WDu?

Sol: $d_n = SMD = 12\,\dfrac{mm}{day} * 1\,day = 12\,mm$

$Q_n . t = d_n . A \Rightarrow Q_n * 24 * 3600 = \dfrac{12}{1000} * A \times 10^4 * 0.8$

for $A = 10$ hec. $\Rightarrow Q_n = \frac{1}{90}$ l/s

$Q_g = \dfrac{1/90}{0.95} = \dfrac{10}{855}$ l/s $\quad \left[Q_g = \dfrac{Q_n}{IE} \right]$

$W.Du = \dfrac{A}{Q_g} = \dfrac{10}{10/855} = 855$ hac/cumecs

example:

Given W.Du = 2000 mishara/cumecs, CE = 75%
total area = 1000 mishara. Find the discharge at the head of the canal (Q_{total})?

$$\%CE = \frac{Q_g}{Q_T} \times 100 \quad ; \quad W.Du = \frac{A_g}{Q_g} \Rightarrow 2000 = \frac{1000}{Q_g}$$

$$\Rightarrow Q_g = 0.5\ m^3/sec \Rightarrow Q_T = \frac{Q_g}{CE} = \frac{0.5}{0.75} = 0.67\ m^3/s$$

example: Discharge is applied to farm = 180 l/s once per week. Total area = 60 hec., FC = 40%, initial water content just before irrigation = 32%, RZ = 1 m, water loss = 20% of net depth.
Find W.Du measured in Donum/cumecs?

Sol:

$$d_n = SMD = \left(\frac{40-32}{100}\right) * 1000 = 80\ mm \ \text{(before irrigation)}$$

$$d_g = d_n + \text{losses} + \cancel{LR} - \text{eff.} \cancel{\text{rainfall}}$$

$$d_g = 80 + \frac{20}{100}\,80 = 96\ mm$$

التصريف المقطع هو تصريف متناوب (متقطع) لذا يجب تحويله الى تصريف مستمر قبل استخدامه في المعادلات

$$Q_i t_i = Q_c \cdot t_c$$

t_i تدعى

$$q_g \cdot t_i = d_g\, A \leftarrow$$ لذا نبدأ من هذه المعادلة

$$\frac{180}{1000} * 3600\, t_i = \frac{96}{1000} * 60 * 10000$$

$$t_i = 88\ hr = 3.67\ days$$

$$Q_i\, t_i = Q_c \cdot t_c$$

$$180 \cdot 88 = Q_c * (7 * 24) \Rightarrow Q_c = 94.28\ l/s$$

$$W.Du = \frac{60 * 4 \times 0.8}{\frac{94.28}{1000}\ m^3/sec} = 2036\ \text{Donums/cumecs}$$

مشارة = دونم

الهكتار = ٤× دونم