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Irrigation and Drainage

Lecture No: 56 Drainage Case Study

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AGRICULTURAL AND FOOD ENGINEERING DEPARTMENT

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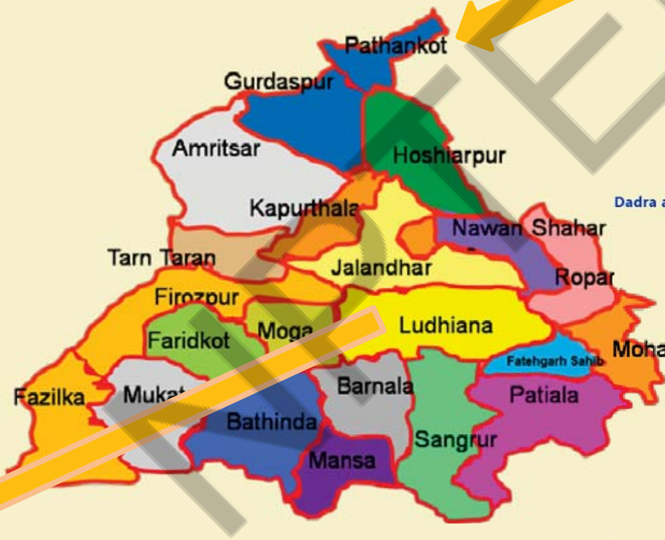
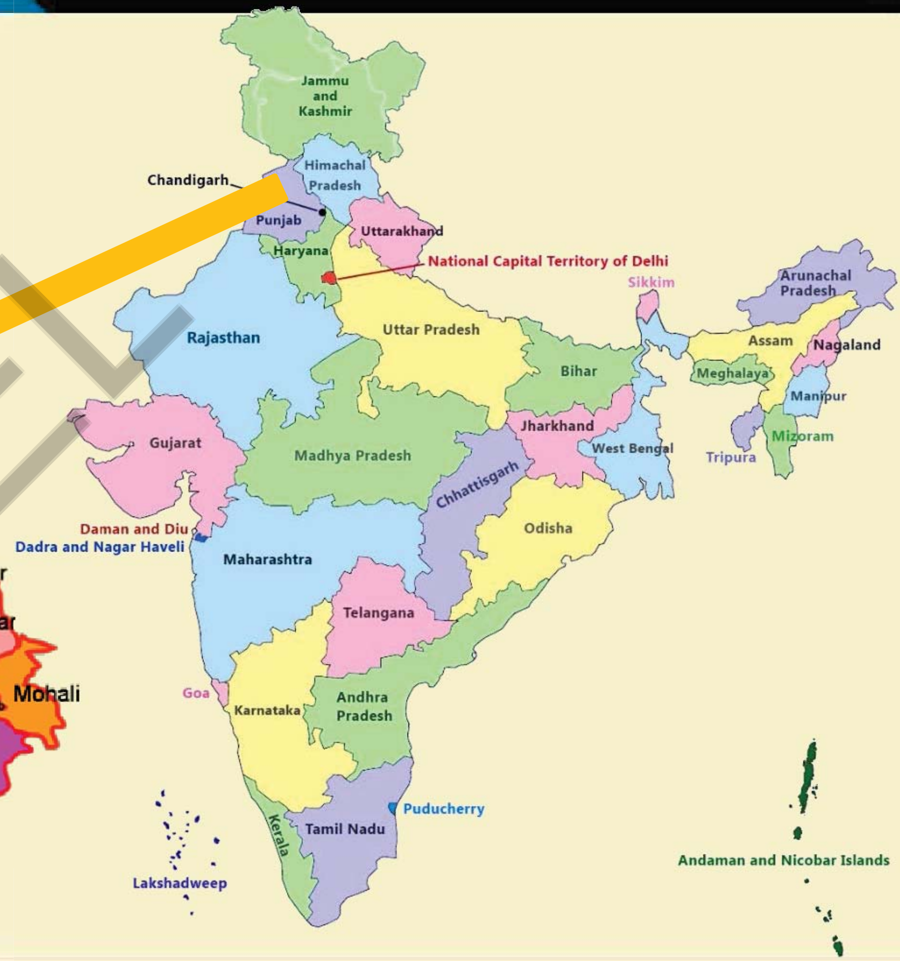
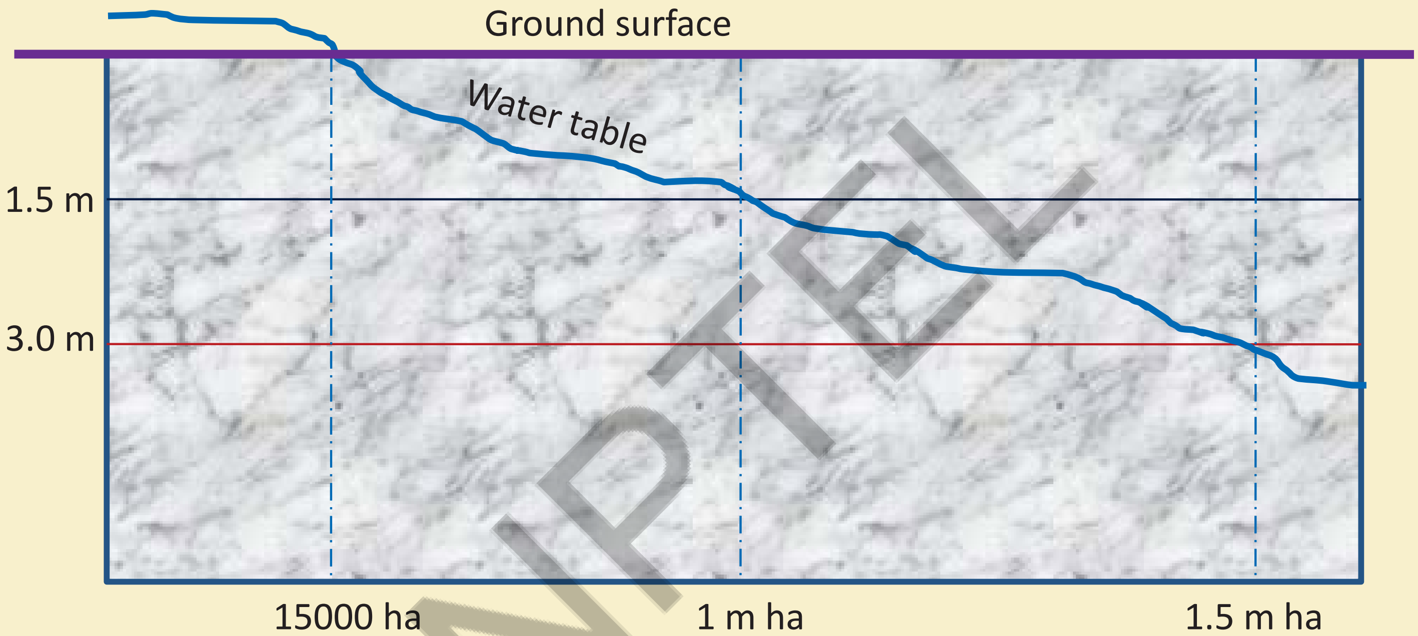
Drainage & Reclamation of the Low-Lying Area of Punjab Agricultural University Farm, Ludhiana





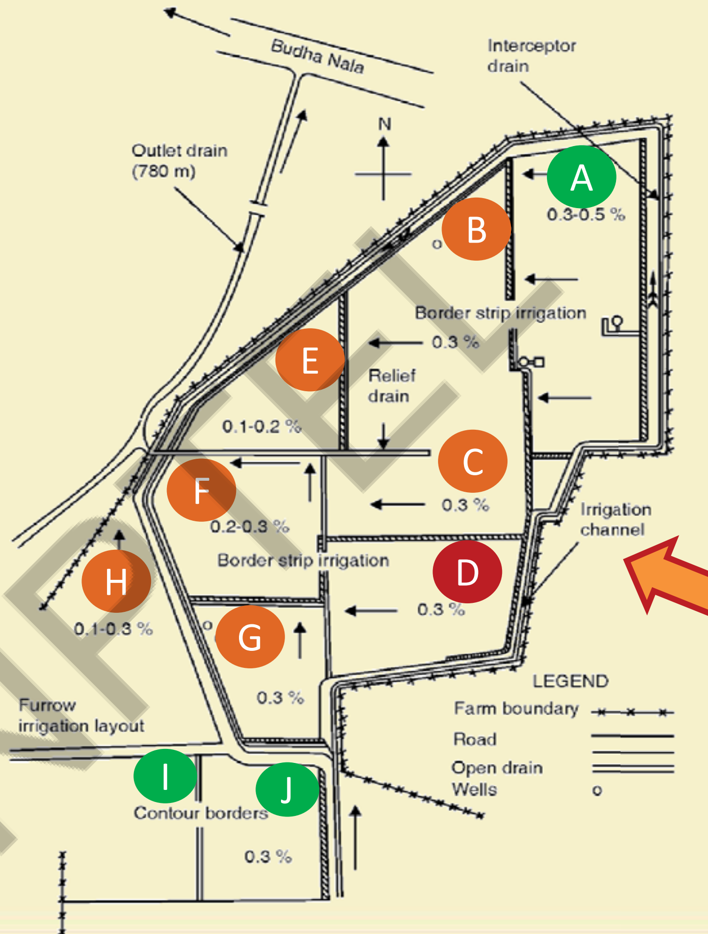
Problem Statement



- ✓ Punjab state
- ✓ A favorable salt balance must be maintained in an area, if irrigated agriculture is to be sustained

PAU Agricultural Farm

- ✓ Area - 30 ha (low-lying land)
- ✓ 10 plots : A, B, C, D, E, F, G, H, I, J
  - o D plot: Acute salt problem
  - o E, F, C, G & H : Appreciable amount of salts
  - o E, F & H : Deep rooted tall grass & water table of 30 cm bgl
  - o A, J & I : No salt problem (located in higher area)



Objectives

Accumulation of runoff & seepage water from the higher area & absence of drainage facility were the main problems facing the low-lying area of the PAU farm

- ✓ To develop a **design criteria** for surface & sub-surface drainage & Land reclamation of affected areas of Punjab
- ✓ To evolve **suitable techniques** for investigating the sources of water logging, characteristics of the soil and water quality
- ✓ To develop **techniques & procedures** for reclamation and management of areas having various problems of water logging and salt accumulation

Reconnaissance Survey

- ✓ Earlier land drainage methods
  - o non-conventional drainage system
  - o biological control and pump drainage
  - o could not satisfy the desired technical and economic standards
- ✓ Current Method
  - o Gravity drainage and outlet to Budha nala
- ✓ The farm lowest point is 2.4 m higher than the water surface in Budha nala
  - o Unlikehood of flood water of the Budha nala reaches the low-lying area of the university farm

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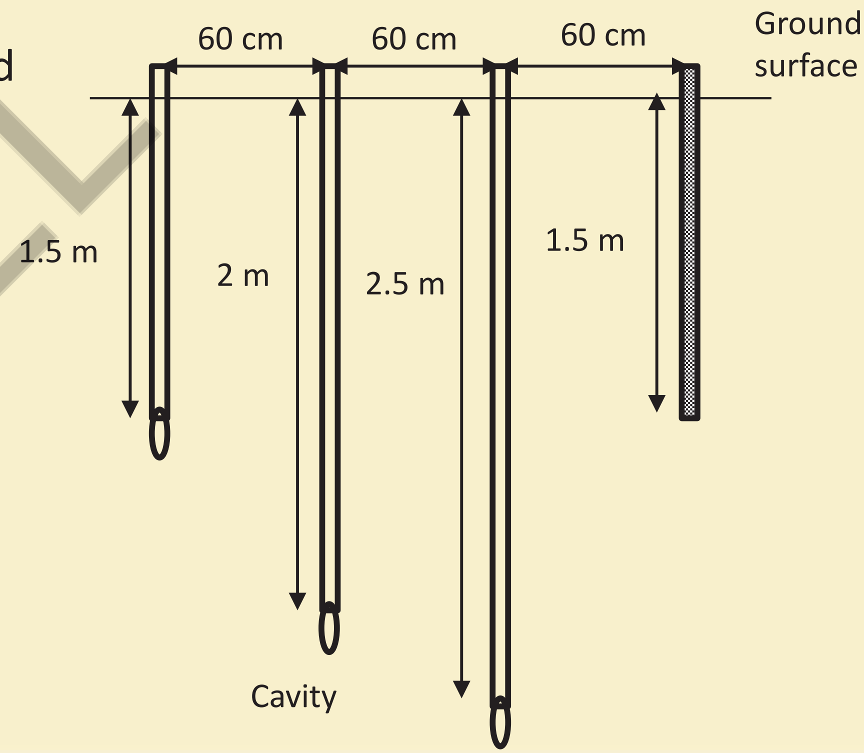
Drainage Surveys & Investigations

- ✓ Topographic map of 30 m x 30 m grid
  - o Contours of 30 cm contour interval
- ✓ Topographic maps used for determining
  - o drainage area
  - o establish grades of drains & field plots
  - o locate & design the drains & associated structures
  - o design the methods of irrigation water application
  - o estimate quantity and cost of work

Ground Water Investigations

- ✓ **First major step** in drainage investigations was to select the drainage method best suited to a particular area based on
  - o Identification of the source
  - o Extent of the water logging problem
- ✓ Position and fluctuation of water table in the study area
  - o Piezometer batteries were installed at the node of 60 m square grid
  - o Three piezometers were installed in each node at 1.5, 2.0 and 2.5 m
  - o Observation well was installed at 1.5 m below the ground surface



Observations

- Depth to water table in piezometer = depth of water in piezometer from the top – pipe length above the ground
- Depth of water table was measured by using **electric depth gauge**
- Daily observations in all piezometer & observation wells
- Weekly observations during rainy season (less fluctuations in water table)
- The observations gives the depth of water table & the direction of the ground water flow
- No artesian pressure was observed

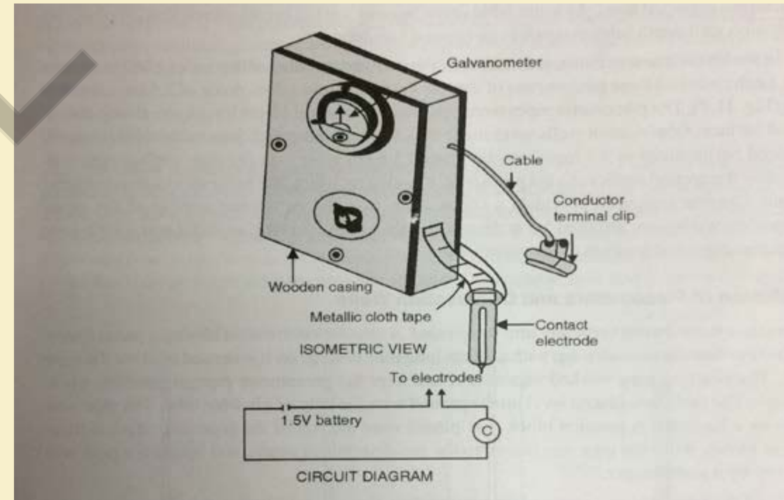


Fig. 11.4. An electrical depth gauge for monitoring water table in an observation well.

Water Table Contour Maps

Lines of equal water table were drawn through the fortnightly average water table elevation, starting from the second fortnight of September 16-30, 1966 and April 16-30 of 1967 (all drains were constructed)

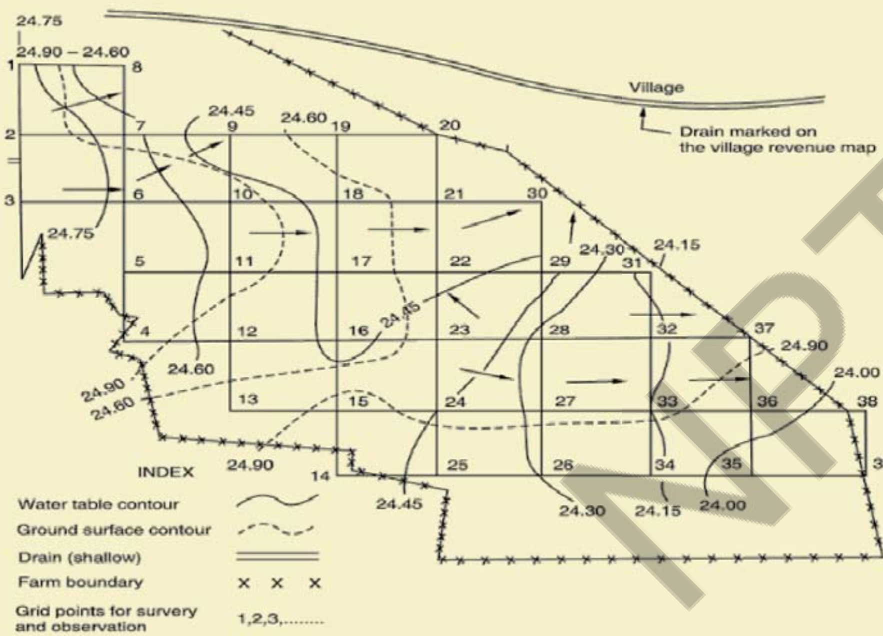


Fig. 11.5. Water table contour map of low-lying area of PAU main farm, Ludhiana prior to the construction of drainage system. Average values for the period September 16–30, 1966.

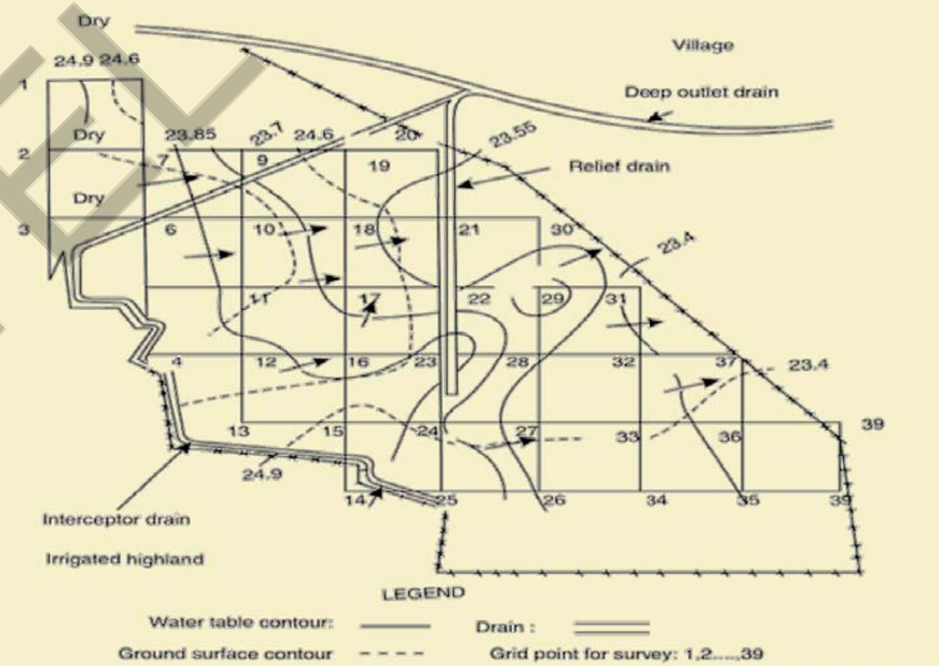


Fig. 11.12. Water table contour map of the low-lying area of PAU, Ludhiana Main Farm after the construction of the drainage system. Average values for the period April 16–30, 1967.

Water Table Isobath Maps

Regions were circumscribed by a depth to water table range of 15 & 30 cm

These maps are useful for identifying the areal extent and the boundary of waterlogged regions

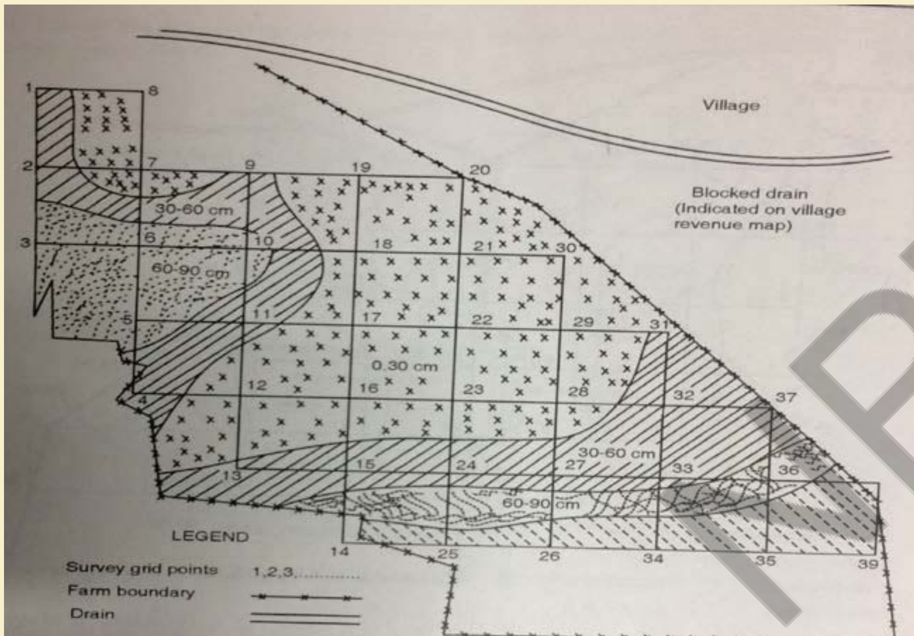


Fig. 11.6. Isobath (depth to water table) map of the low-lying area of PAU Farm before construction of the drainage system. Average values for the period September 16–30, 1966.

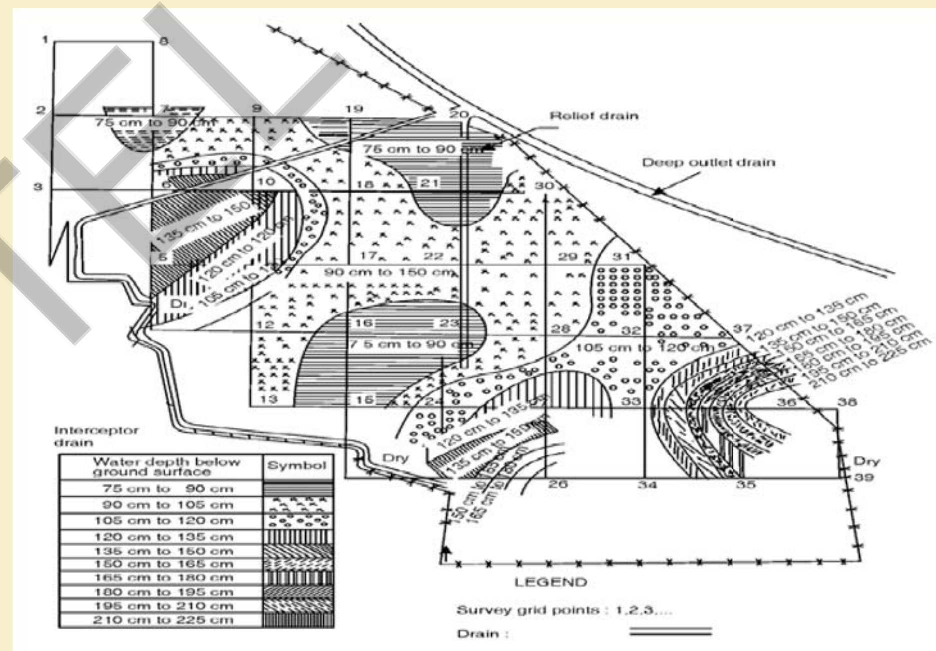


Fig. 11.13. Isobath (depth to water table) map of the low-lying area of PAU Farm, Ludhiana after the installation of the drainage system. Average values for the period April 16–30, 1967.

Observation Well Hydrograph

The hydrographs shows seasonal fluctuation of water table in Fig 11.14; Useful in determining source of ground water

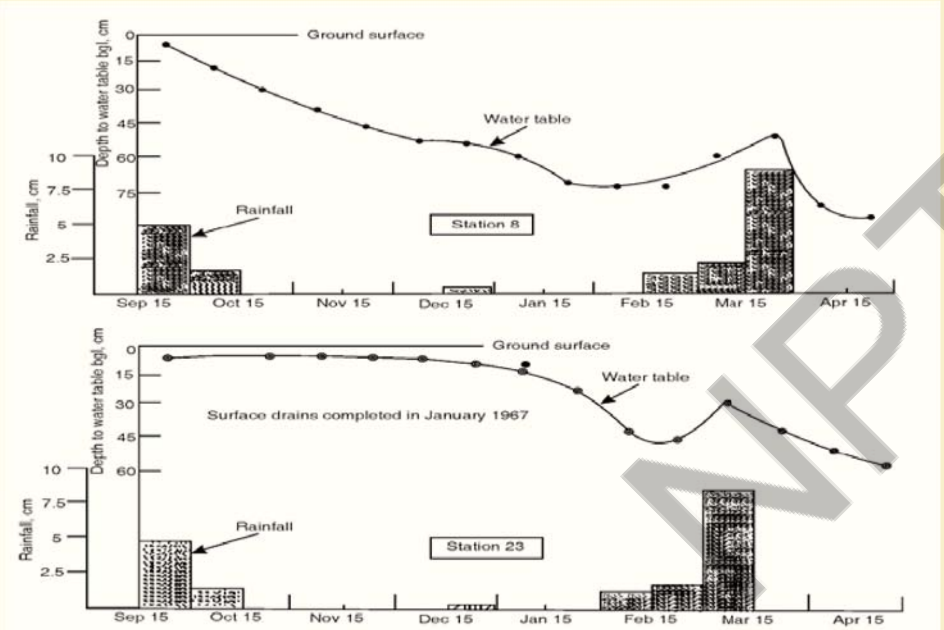


Fig. 11.14. Water table hydrographs at Station Nos 8 and 23 of the low-lying area of PAU Main Farm, Ludhiana for the period, 16 September 1966 to 30 April 1967.

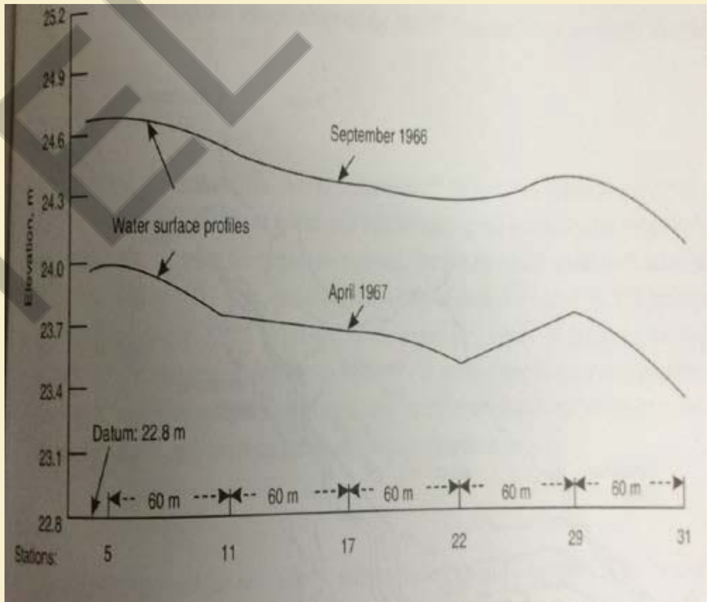


Fig. 11.15. Ground water profile along the line passing through Stations 5, 11, 17, 22, 29 and 31. (PAU Farm low-lying area)

Design of Drainage System

- ✓ Topography & ground water investigation revealed the need of providing a combination of **surface & sub-surface gravity drainage** system to the problem area within the university farm
- ✓ The surface drainage system comprises
  - o **Interceptor drain** along the upper boundary of the farm
  - o **Relief drain** along the middle
  - o **Outlet drain** leading the drainage water to municipal drain

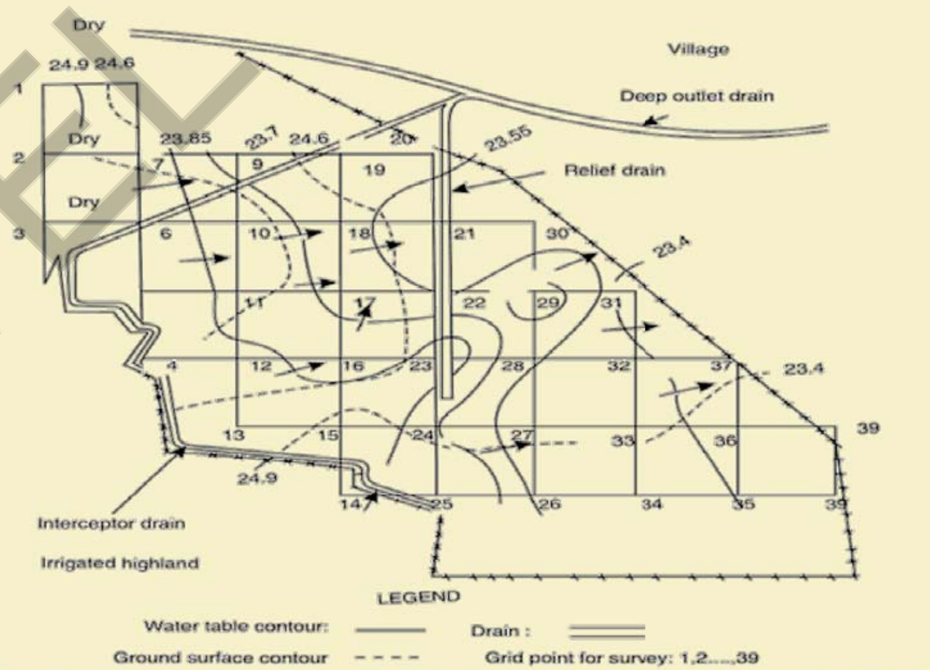


Fig. 11.12. Water table contour map of the low-lying area of PAU, Ludhiana Main Farm after the construction of the drainage system. Average values for the period April 16–30, 1967.

- ✓ The interceptor drain & relief drains were joined at the lowermost point in the farm through a short link drain, which was connected to the outlet drain
- ✓ The bottom box of the out drain were made of brick masonry laid in cement mortar
- ✓ Runoff entering the surface drain was determined by **Rational formula**
- ✓ Velocity of flow in open drain was estimated using **manning formula** & the drains were designed considering unlined open channel design

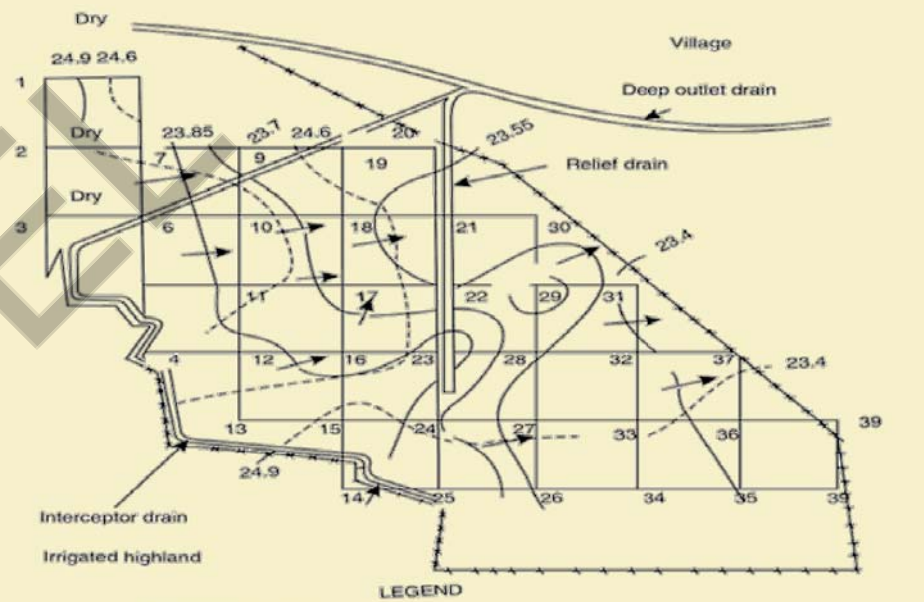


Fig. 11.12. Water table contour map of the low-lying area of PAU, Ludhiana Main Farm after the construction of the drainage system. Average values for the period April 16–30, 1967.

Outlet drain

- ✓ base width of 1.6 m, top width of 8.25 m, depth of 1.6 m, bed slope of 0.2 % & total length of 780 m
- ✓ The bed slope was appropriate to ensure a non-erosive & non-silting mean velocity of flow

Relief drain

- ✓ The relief drain had a total length of 221 m with a bottom width of 0.6 m, top width of 1.6 m & a depth of 0.7 m till the berm
- ✓ It design to carry the combination of peak runoff & sub-surface flow from its watershed

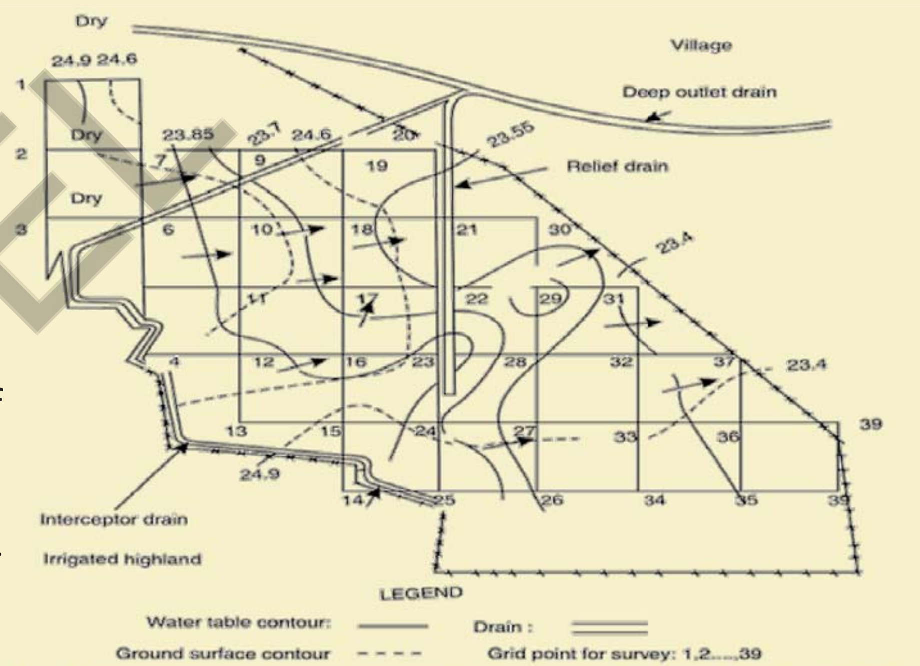


Fig. 11.12. Water table contour map of the low-lying area of PAU, Ludhiana Main Farm after the construction of the drainage system. Average values for the period April 16–30, 1967.

Interceptor drain

- ✓ The interceptor drain was 667 m long; bottom width 1.5-1.8 m, top width 3-4.2 m & depth 1.35-1.8 m

- o The discharge capacity of all the tree types of drains were adequate to carry design discharge

- o The out let drain in addition to benefiting the university farm, solved the problem of waterlogging of the neighboring **Habowal khurd** village & the adjoining farm land

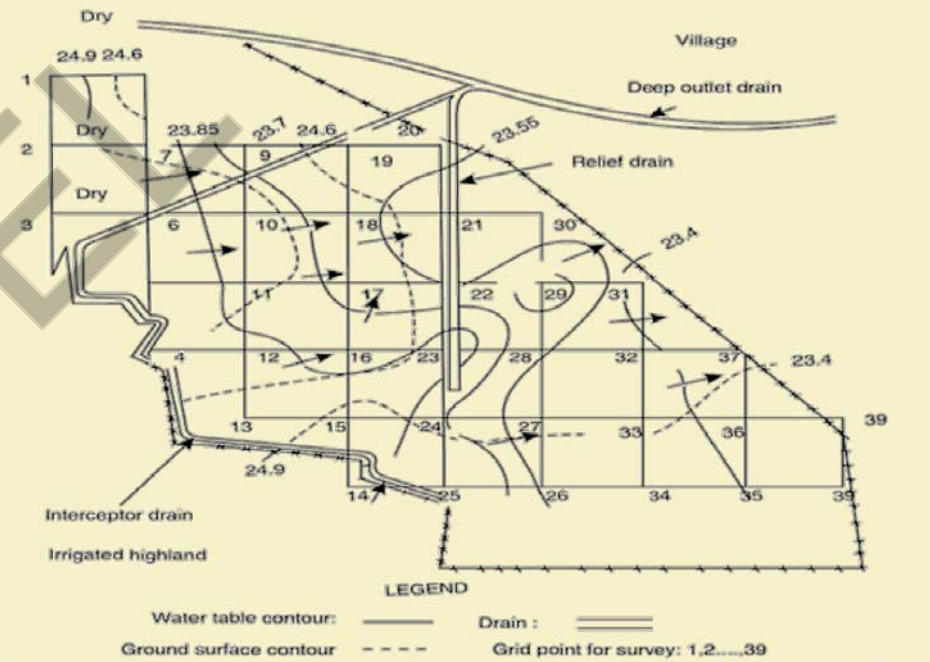


Fig. 11.12. Water table contour map of the low-lying area of PAU, Ludhiana Main Farm after the construction of the drainage system. Average values for the period April 16–30, 1967.

Reclamation & Development of the University farm

- ✓ First deep-rooted grasses in the marshy areas were uprooted
- ✓ Cutting trenches leading to shallow natural drains for draining the standing surface water
- ✓ Land was disc ploughed by using heavy duty(45-50 HP) wheel type tractors. Furrow slice allowed to air dry for few days
- ✓ The higher plot A, I & J – sandy loam soil
- ✓ B, E, C, F, & H – Sticky clay loam soil
- ✓ The field was graded to get a uniform downfield gradient

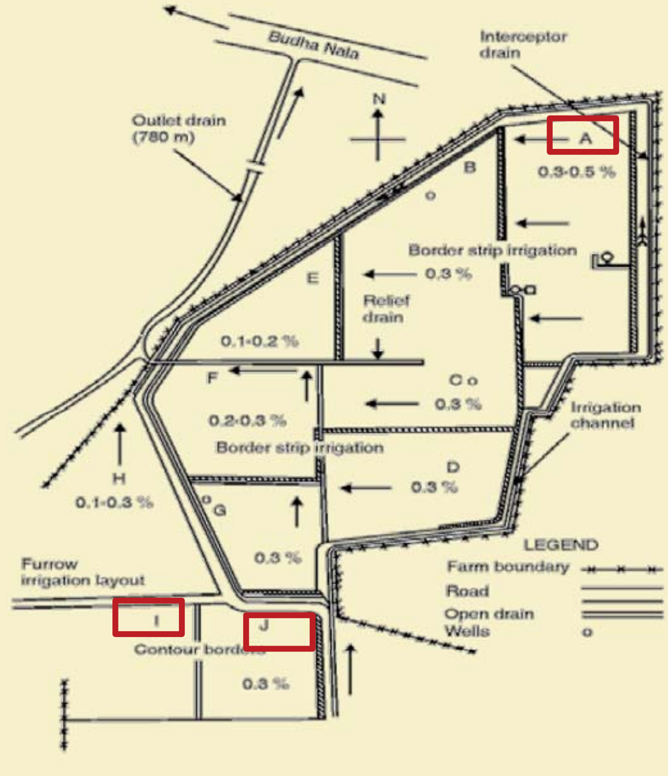


Fig. 11.9. Layout of the drained area of PAU Farm, Ludhiana.

- ✓ Longitudinal slope for different plots were as follows
  - o A plot - 0.3-0.5 %; B, C, D, G & J plot – 0.3 %
  - o H plot – 0.3 %; F plot – 0.2-0.3 %; E plot - 0.1-0.2 %
- ✓ A, B, C, D, E, F & G – Border irrigation (width: 3.5 – 5 m & length: 75- 140 m)
- ✓ H plot – furrow irrigation
- ✓ I & J plot – Contour border strip irrigation (90 m long & 5 m wide)
- ✓ Winter crop (Rabi):
  - ✓ Wheat grown in plots of - A, B, C, G, J & I
  - ✓ Barley crop grown in the plots of - E, F & D

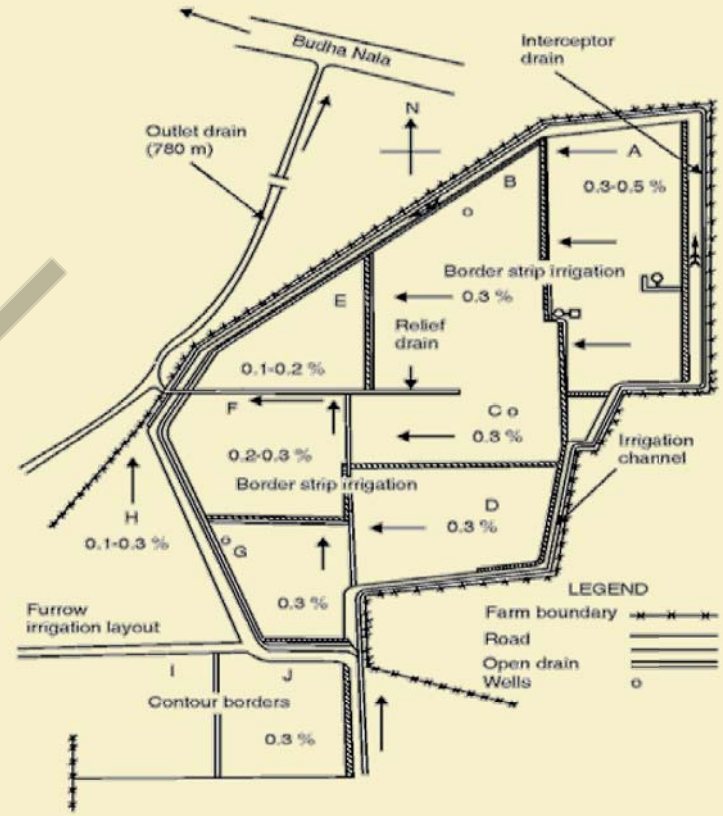


Fig. 11.9. Layout of the drained area of PAU Farm, Ludhiana.

Soil & Water Analysis

Water samples:

- About 60% of water samples have salt concentration (EC) reduced by 7-23 %

Soil sample:

- Soil salinity status were estimated on sample collected from 0-15, 15-30 & 30-60 cm depth
- The EC ranges from 0.18-1.15 dS/m; pH ranges from 8.6-10
- Organic carbon-0.12-0.48 %; available phosphorus -3.6-8.8 Kg/ha
- Calcium carbonate 1-4 %

Texturally, the soil were mostly sandy loam with some of the samples being loamy sand & sand

Conclusions

- ✓ A surface drainage system comprising **an interceptor drain** along the upper boundary of the farm, **a relief drain** along the middle & a suitable **outlet drain** leading the drainage water to the outlet point in the municipal drain were the main feature of the drainage system
- ✓ Constriction of outlet drain with the cooperation of farmers of the **neighboring villages was highly beneficial** as it improved the drainage situation of a large area, even beyond the PAU research farm
- ✓ Water table control was feasible even with an **open drainage network**, properly designed and strategically laid out.
- ✓ **Border strip and furrow irrigation are compatible with a surface drainage system** when shallow drainage channel are provided at the lower end of the field
- ✓ Improve irrigation system on a properly graded land results in **increased water application efficiency**

Thank You!!

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Irrigation and Drainage

Lecture No: 57 ENDRAIN MODEL

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Why we use Drainage model?

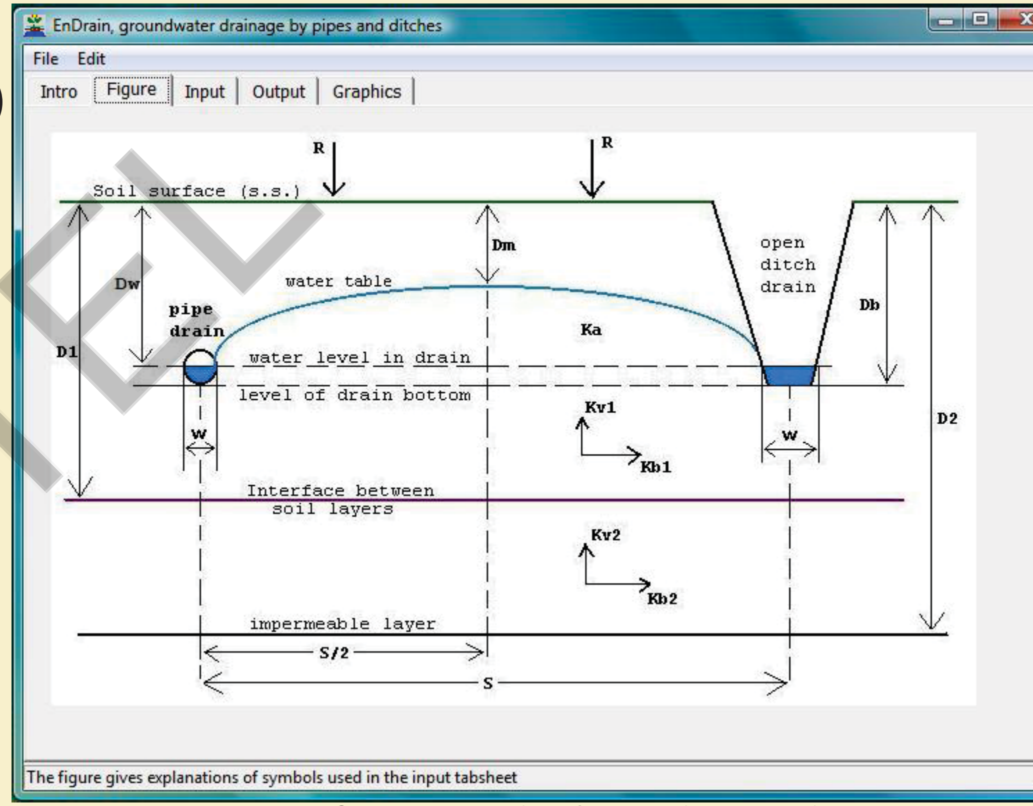
- ✓ The estimation of drain spacing is still a challenging task for many drainage designs.
  - ✓ Too wide drain spacing: water table may rise to the root zone
  - ✓ Too close drain spacing: needless construction costs are incurred
- ✓ The optimal drain spacing can be estimated with the help of models
  - ✓ midpoint water table height
- ✓ Computer models are available to estimate optimal **drain spacing** or **equivalent depth** for installation of artificial drainage system

EnDrain Model

- ✓ Developed by **Prof. Oosterbaan** (Netherlands, 1994)
- ✓ Deduced from energy balance of groundwater flow
- ✓ Computes
  - ✓ Drain spacing
  - ✓ Shape of water-table
  - ✓ Drainage discharge
  - ✓ Head losses

The model is available for free at

https://www.waterlog.info/endrain.htm



EnDrain program for open ditch and pipe drain

EnDrain

- ✓ Applied for reclamation (remediation, rehabilitation, restoration) of saline soils
- ✓ The traditional concepts based on the Darcy and water balance or mass conservation equations are also considered along with the energy balance
- ✓ Allows for the presence of three soil layers with different hydraulic conductivity and permeability
- ✓ The last two layers can also have different horizontal and vertical hydraulic conductivity

Assumptions:

1. Steady state fluxes, i.e. no water and associated energy is stored
2. Vertically two-dimensional flow, i.e. the flow pattern repeats itself in parallel vertical planes
3. Horizontal component of the flow is constant in a vertical cross-section
4. Soil's hydraulic conductivity is constant from place to place

R: Time average recharge or discharge (m/day)

D1: Bottom depth of 1st layer below s.s. (m)

D2: Bottom depth of 2nd layer below s.s. (m)

Dw: Depth water level in drain below s.s. (m)

Db: Depth of drain bottom below s.s (m)

W: Max. width of water body in the drain

Ka: Hydraulic permeability, above drain level (m/day)

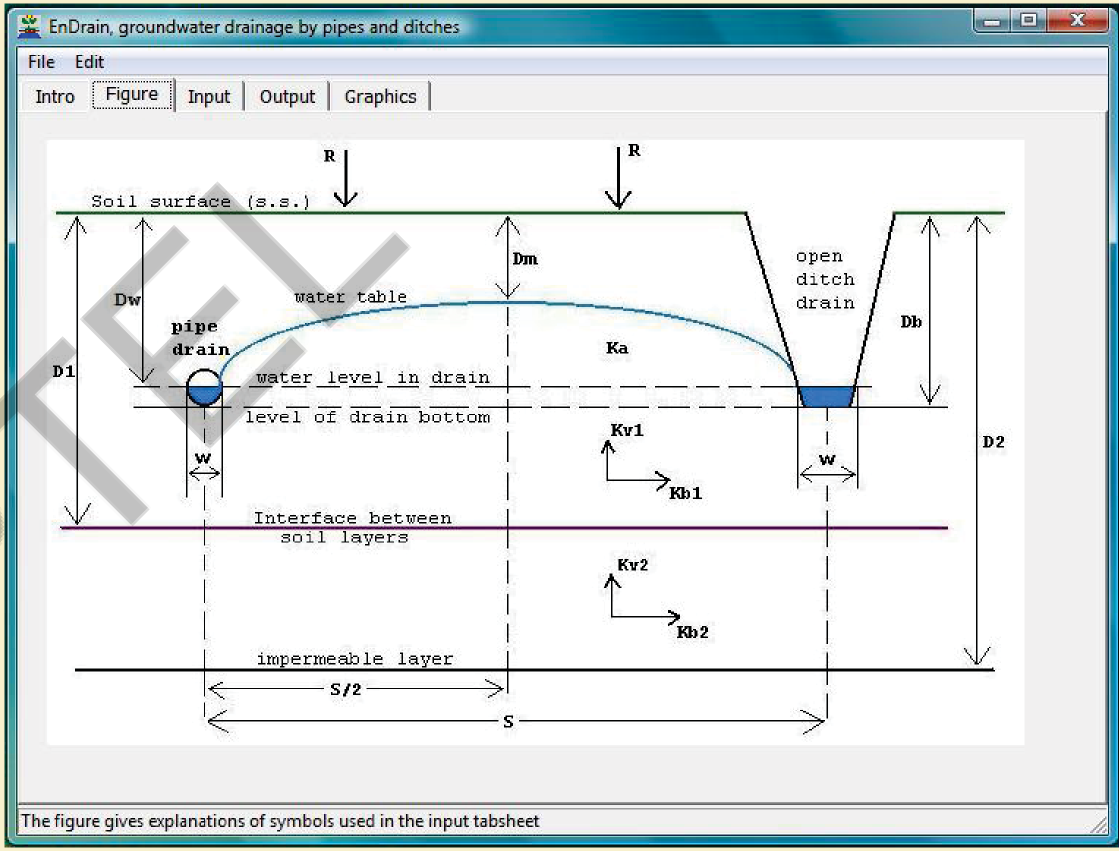
Kb1: Horizontal permeability, 1st soil layer (m/day)

Kv1: Vertical permeability, 1st soil layer (m/day)

Kb2: Horizontal permeability, 2nd soil layer (m/day)

Kv2: Vertical permeability, 2nd soil layer (m/day)

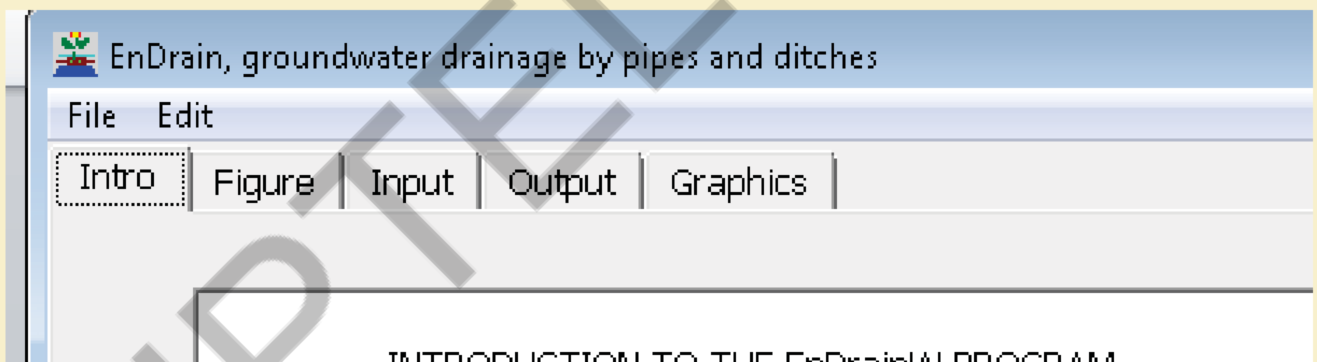
Dm: Depth water-table midway between drains (m)



EnDrain Model

Endrain model consist of five tabsheets

1. **Intro**
2. **Figure**
3. **Input**
4. **Output**
5. **Graphics**



EnDrain Model

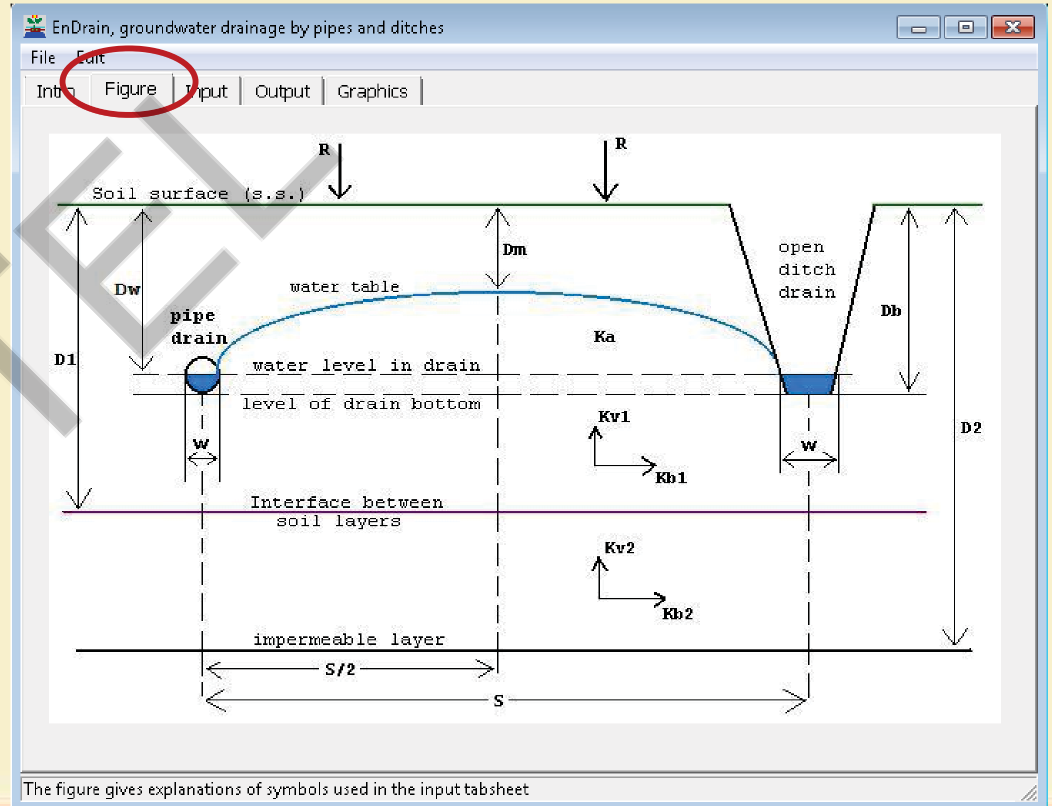
1. Intro sheet :

- ✓ Brief introduction to the EnDrain program
- ✓ Link to various related help materials for reference purpose

EnDrain Model

2. Figure sheet:

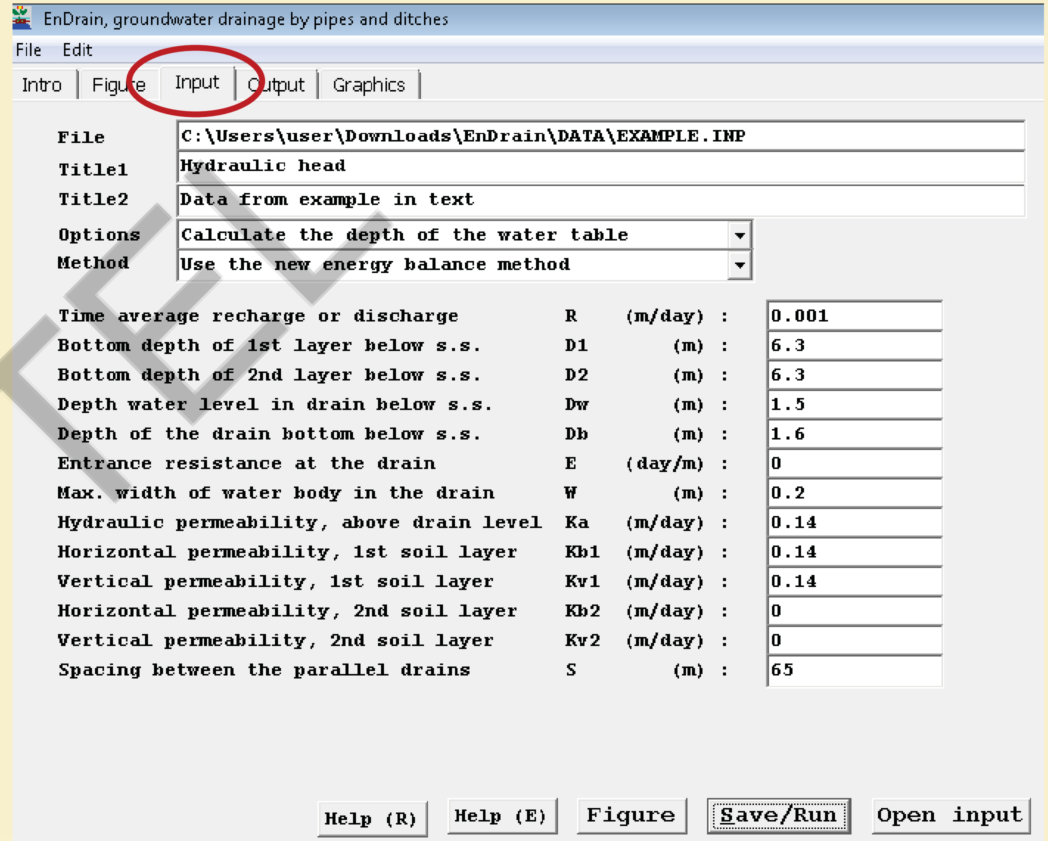
- ✓ Pipe and open drainage system
- ✓ Explanation of symbols used in the input tab sheet



EnDrain Model

3. Input sheet:

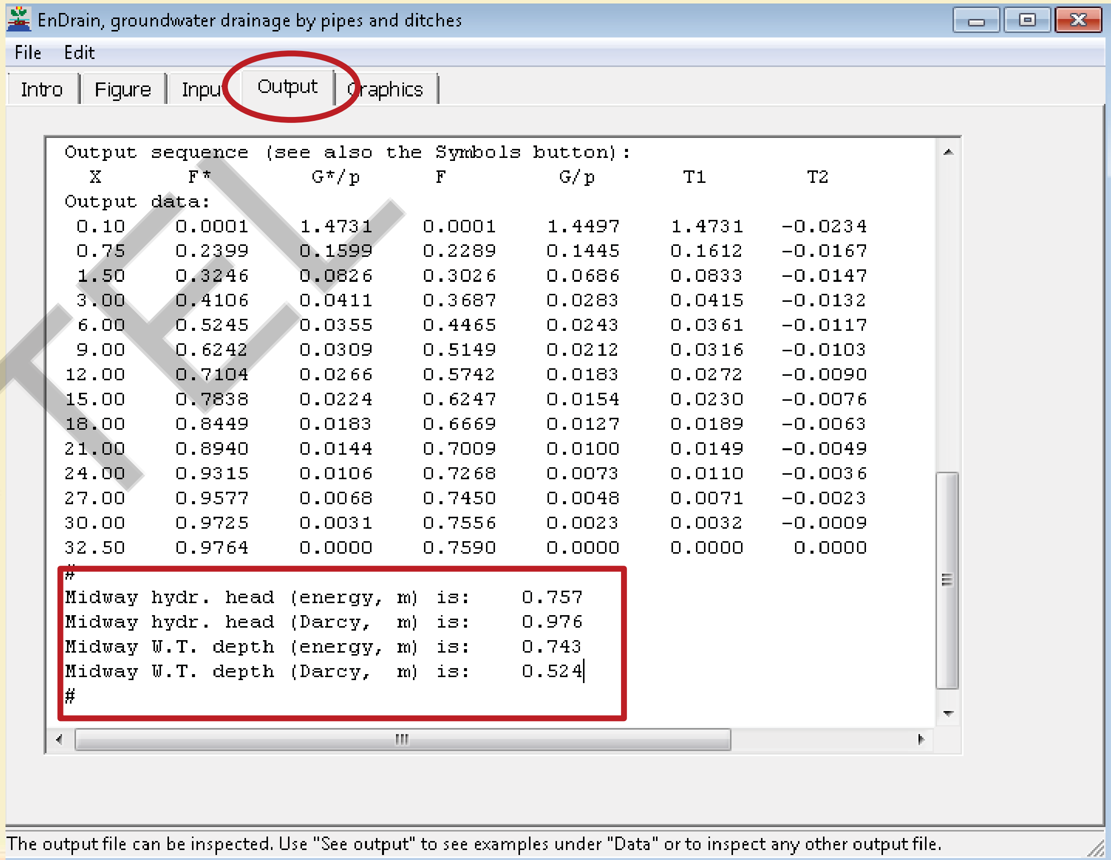
- ✓ Different variables and drainage parameters are provided with units
- ✓ Figure shows an example of the different parameters provided for running the Endrain model



EnDrain Model

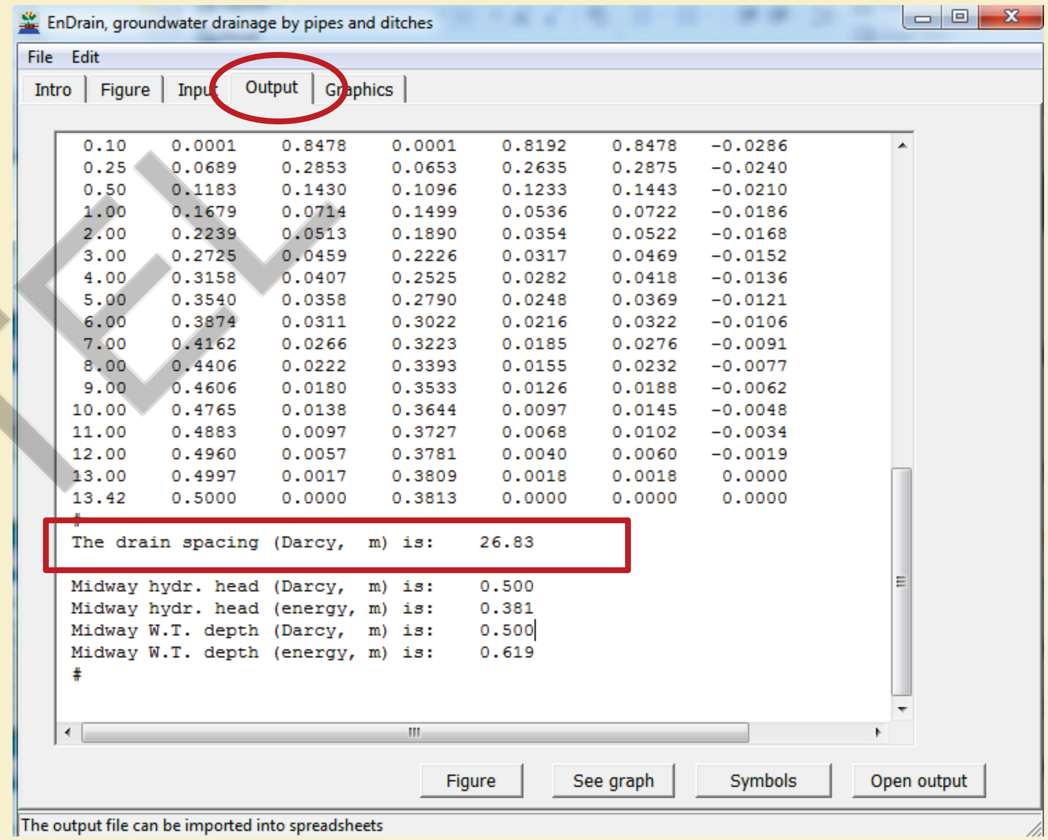
4. Output sheet

- ✓ Figure shows the output of the previous example
- ✓ Hydraulic head and the water table head calculated with both Darcy and Energy equation
  - ✓ X = distance from drain (m)
  - ✓ p = small increment of X (m)
  - ✓ F* = hydraulic head (m, Darcy)
  - ✓ G*/p = gradient of F* (m/m)
  - ✓ F = hydraulic head (m, energy balance)
  - ✓ G/p = gradient of F (m/m) {Note: G/p=T1+T2}
  - ✓ T1 = energy loss/p (m/m)
  - ✓ T2 = correction for energy input/p (m/m)



EnDrain Model

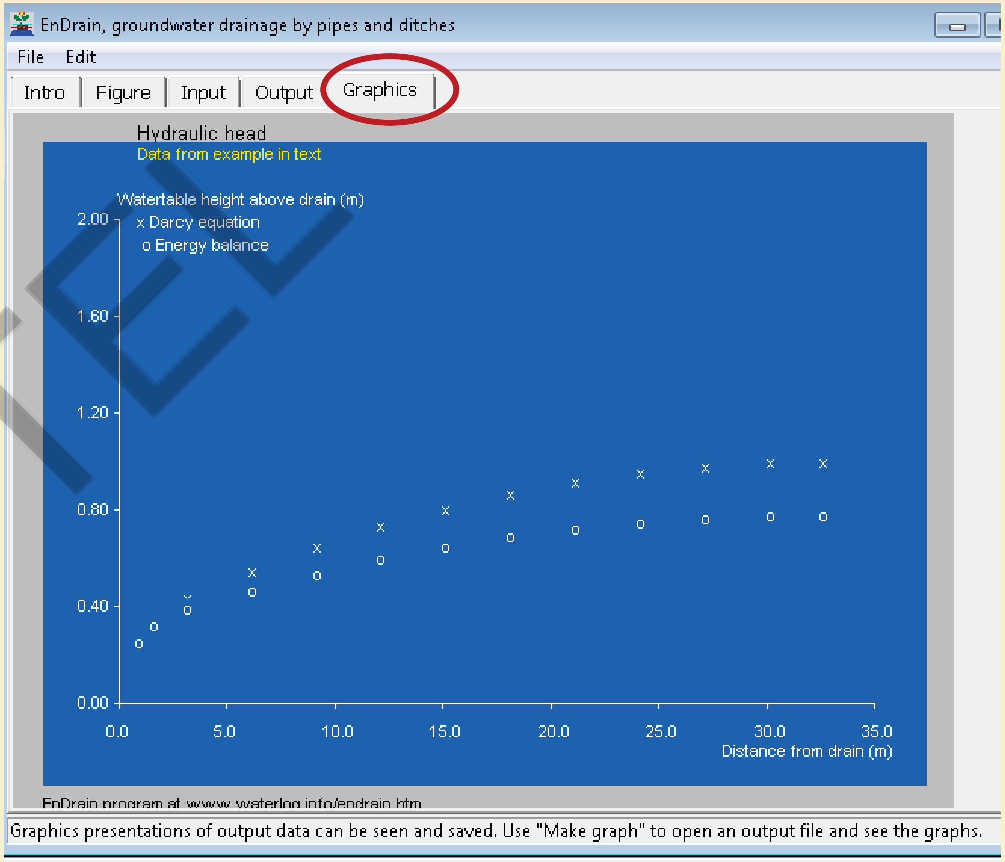
- ✓ **For calculating the drain spacing**
  - ✓ Similar procedure is followed as the previous example except at the input tab we select the option for drain spacing calculation
  - ✓ EnDrain model suggests a drain spacing of **26.83 m**



EnDrain Model

5. Graph sheet consist of

- ✓ The curve of the water-table
- ✓ The depth of the water table diminishes with the distance from the drains.
- ✓ The water table is flat midway between the drains (at half the distance of the drain spacing), elsewhere it is curved.



EnDrain Model

Example 57.1: Tile drain of 5 cm diameter, alluvial soil

Time average recharge or discharge	R (m/day) :	0.0070
Bottom depth of 1st layer below s.s.	D1 (m) :	2.00
Bottom depth of 2nd layer below s.s.	D2 (m) :	2.00
Depth water level in drain below s.s.	Dw (m) :	1.42
Depth of drain bottom below s.s	Db (m) :	1.45
Entrance resistance at the drain	E (day/m) :	0.507
Max. width of water body in the drain	W (m) :	0.050
Hydraulic permeability, above drain level	Ka (m/day) :	0.011
Horizontal permeability, 1st soil layer	Kb1 (m/day) :	0.011
Vertical permeability, 1st soil layer	Kv1 (m/day) :	0.011
Horizontal permeability, 2nd soil layer	Kb2 (m/day) :	0.0000
Vertical permeability, 2nd soil layer	Kv2 (m/day) :	0.0000
Depth water-table midway between drains	Dm (m) :	0.80

EnDrain Model

Example: Output

Output sequence :

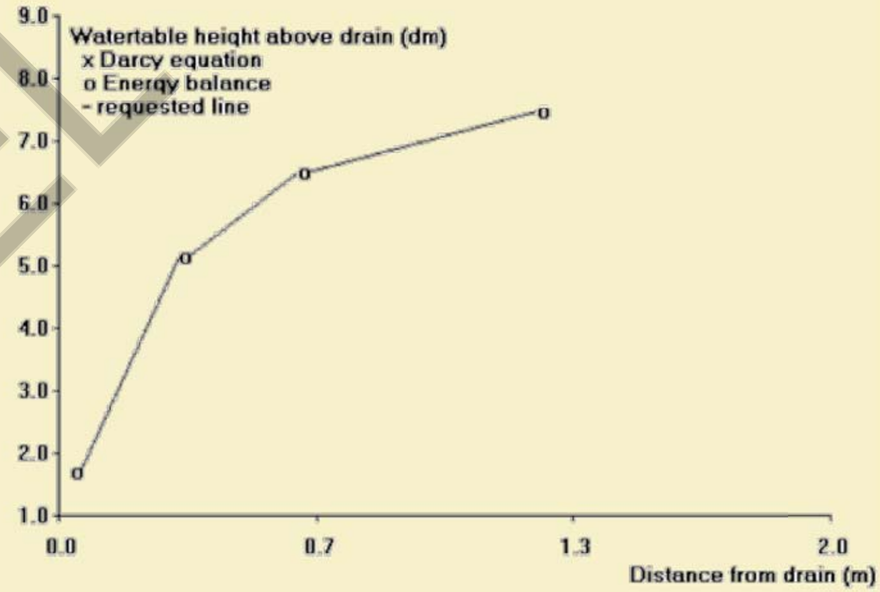
X	F*	G*/p	F	G/p	T1	T2

Output data:

0.03	0.1701	16.1246	0.1650	15.6190	16.1246	-0.5056
0.31	0.5135	0.6037	0.5096	0.6061	0.6061	0.0000
0.62	0.6476	0.3278	0.6442	0.3287	0.3287	0.0278
1.24	0.7451	0.0043	0.7419	0.0043	0.0043	13.1284

#

The drain spacing (energy, m) is: 2.49
Midway hydr. head (energy, m) is: 0.742
Midway hydr. head (Darcy, m) is: 0.745
Midway W.T. depth (energy, m) is: 0.800
Midway W.T. depth (Darcy, m) is: 0.680



Water-table level variation according to energy balance equation

EnDrain Model

Reference:

R.J. Oosterbaan, J. Boonstra and K.V.G.K. Rao, 1996, "The energy balance of groundwater flow". Published in V.P.Singh and B.Kumar (eds.), Subsurface-Water Hydrology, p. 153-160, Vol.2 of Proceedings of the International Conference on Hydrology and Water Resources, New Delhi, India, 1993. Kluwer Academic Publishers, Dordrecht, The Netherlands. ISBN: 978-0-7923-3651-8

Rares HALBAC-COTOARA-ZAMFIR0, 2010, " Calculation of distance between drains between drains using EnDrain Program, Research Journal of Agricultural Science, 42 (3), 2010.

Endrain is available for free at https://www.waterlog.info/endrain.htm

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Irrigation and Drainage

Lecture No: 58 Irrigation Efficiency

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Irrigation Efficiency

- ✓ **Irrigation water loss:**
  - ✓ Spray droplet evaporation, weed water use, soil evaporation, furrow evaporation, leaks in pipelines, seepage and evaporation from irrigation ditches, surface runoff, and deep percolation.
- ✓ Inadequate irrigation application results in crop water stress and yield reduction
- ✓ Excess irrigation application can result in pollution of water resources
- ✓ Efficient use of irrigation water maximizes economic return & water resources sustainability

Irrigation Efficiency

- ✓ **Beneficial use of irrigation water**
  - o Crop evapotranspiration (ET) requirement
  - o Leaching of salt from the soil
- ✓ **Non-beneficial use of irrigation water**
  - o Evaporation from water and soil surface (which does not contribute to crop productivity)
- ✓ **Irrigation efficiency** defined from three points of view
  1. Irrigation system performance
  2. Uniformity of water application
  3. Response of the crop to irrigation

Spatial and temporal scale

Irrigation Efficiency

✓ **Evaluating Irrigation System Performance**

1) Water conveyance efficiency
2) Water application efficiency
3) Soil water storage efficiency
4) Irrigation efficiency
5) Overall irrigation efficiency
6) Effective irrigation efficiency

Irrigation Efficiency

1) Water Conveyance Efficiency (E_C)

The water delivered to the farm or field is usually less than the water diverted from the source. Due to canal seepage loss, canal spills, evaporation losses from canals, and leaks in pipelines.

$$E_C = \frac{V_f}{V_t} \text{x} 100$$

Where, V_f = volume of irrigation water that reaches the farm or field (acre-inch)

V_t = volume of irrigation water diverted from the water source (acre-inch)

Typically, conveyance losses are much lower for pipelines due to reduced evaporation and seepage losses.

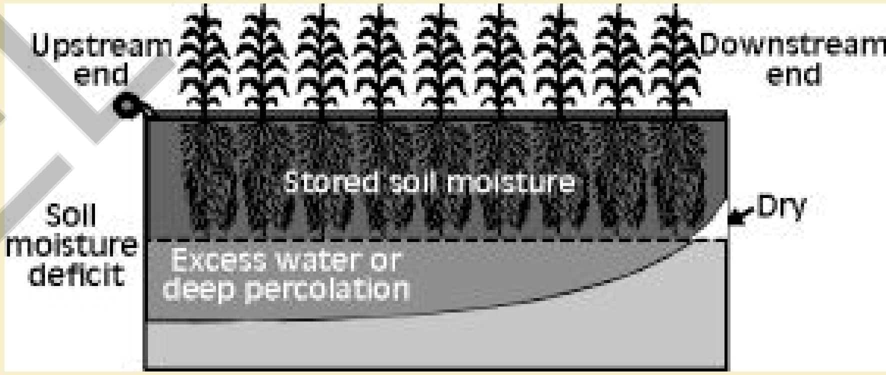
Irrigation Efficiency

2) Water Application Efficiency (E_a)

The objective is to apply the water and store it in the crop root zone to meet the crop water requirement.

$$E_a = \frac{V_s}{V_f} \text{x} 100$$

Where, V_s = volume of irrigation water stored in the root zone (acre-inch); V_f= volume of irrigation water delivered to the farm or field (acre-inch)



Water loss from **sprinkler system (**Wind drift , Evaporation from droplets in the air, crop canopy and soil) and **surface irrigation (**Runoff, Evaporation from furrow channels and soil surface, Percolation)

Irrigation Efficiency

Potential application efficiencies for well designed and well managed irrigation system

Irrigation System	Potential E_a, %	Irrigation System	Potential E_a, %
Sprinkler irrigation		Furrow (tail water reuse)	60-80
LEPA	80-90	Basin	60-75
Linear move	75-85	Precision level basin	65-80
Central pivot	75-85	**Micro irrigation system**	
Solid set	70-85	Micro-point source	85-90
Surface irrigation system		Micro-line source	85-90
Furrow (Surge)	55-75	Subsurface drip Surface	>95
Furrow (Conventional)	45-65	Drip	85-95

Irrigation Efficiency

3) Soil Water Storage Efficiency (E_s)

It indicates how well the system uses the available root zone storage capacity to store water to meet crop needs.

$$E_s = \frac{V_s}{V_{fc} - V_a} \text{x } 100$$

Where, V_s = volume of water stored in the soil root zone from an irrigation event; V_{fc}= volume capacity at field capacity in the crop root zone; V_a = volume of water in the soil root zone prior to an irrigation event

- ✓ Refilling the soil profile to about 90 percent of the field capacity can be a good strategy.
- ✓ Sprinkler and micro-irrigation systems usually supply only sufficient water to satisfy crop ET needs without filling the soil root zone

Irrigation Efficiency

4) Irrigation Efficiency (E_i): Irrigation water may be applied for other beneficial uses.

- ✓ Removal of salts (leaching requirement)
- ✓ Microclimate control (evaporative cooling frost protection)
- ✓ Seedbed preparation
- ✓ Germination of seeds
- ✓ Softening of soil crust
- ✓ Chemigation

When more than ET water used is considered, only beneficial care is considered in (E_i)

$$E_i = \frac{V_b}{V_f} x\ 100$$

Where, V_b = volume of water beneficially used. Water losses that occur as a result of excessive deep percolation, runoff, weed ET, wind drift are not considered as beneficial uses

Irrigation Efficiency

5) Overall Irrigation Efficiency (E_o)

$$E_o = E_c \times E_a \times 100$$

Where, E_c = water conveyance efficiency (fraction); E_a = water application efficiency (fraction)

6) Effective Irrigation Efficiency (E_e)

Reuse of runoff water decreases the amount of water pumped from a source and can improve overall irrigation efficiency.

$$E_e = [E_o + (FR) \times (1.0 - E_o)] \times 100$$

FR = fraction of surface runoff, seepage, and/or deep percolation that is recovered.

Irrigation Uniformity

- ✓ **Non-uniformity in surface irrigation**
  - o Differences in opportunity time for infiltration
  - o Spatial variability of soil-infiltration properties
  - o Non-uniform grades
- ✓ **Non-uniformity in micro-irrigation**
  - o Variations in pressure caused by pipe friction and topography
  - o Variations in hydraulic properties of emitters or emission points
  - o Variations in soil wetting from emission points

Generally, irrigation uniformity is calculated based on the indirect measurements.

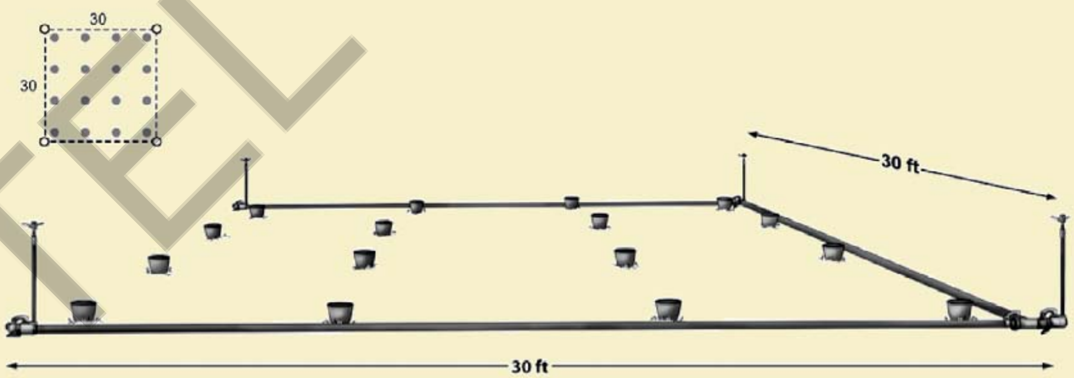
Irrigation Uniformity

1) Christiansen's Uniformity Coefficient (Cu) for Sprinkler Systems

Commonly used to describe uniformity for stationary sprinkler irrigation systems and is based on the catch volumes

$$C_u = [1 - \frac{\Sigma \left| X_i - X_m \right|}{\Sigma X_i}] \times 100$$

Where, X_i -measured depth of water in equally spaced catch cans on a grid arrangement (inch); X_m - mean depth of water of the catch in all cans (inch)

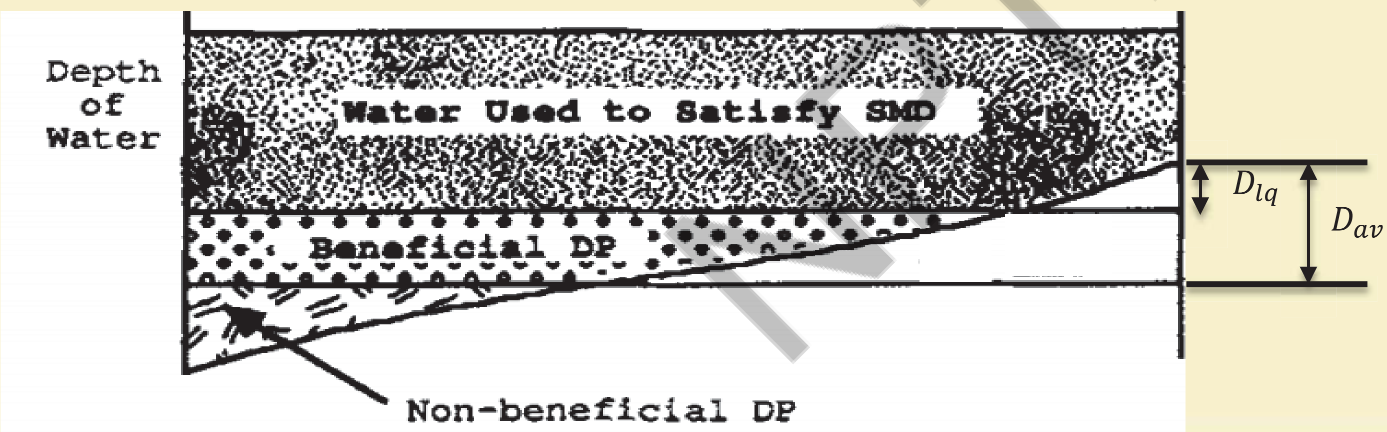


Irrigation Uniformity

2) Low-Quarter Distribution Uniformity (D_u) for Surface Irrigation Systems

$$D_u = \frac{D_{lq}}{D_{av}} \text{x } 100$$

Where, D_{lq} -average depth of water infiltrated in the low one quarter of the field (inch); D_{av} -average depth of water infiltrated over the field (inch)



$D_u < 60\%$, Non-uniform

$D_u \geq 60\%$, Uniform

Irrigation Uniformity

3) Emission Uniformity (E_u) for Micro irrigation Systems

C_u and D_u concepts are impractical for micro irrigation because the entire field does not wet. Uniformity of irrigation water is expressed by emission uniformity (E_u)

$$E_u = [1 - 1.27\, C_{vm} n^{-\frac{1}{2}}] \frac{q_{min}}{q_{avg}} \times 100$$

Where, n = the number of emitters per plant; C_{vm}= manufacturer's coefficient of uniformity; q_{min} = minimum emitter discharge rate at minimum system pressure at minimum system pressure (gpm); q_{avg}= average emitter discharge rate (gpm)

4) Coefficient of Design Uniformity (C_{ud})

$$C_{ud} = [1 - 0.798\, C_{vm} \times n^{-\frac{1}{2}}] \times 100$$

Where, C_{vm} = Manufacturer's coefficient of uniformity ; n = the number of emitters per plant

Crop Response to Irrigation

- ✓ Irrigation system performance and irrigation uniformity parameters discussed previously evaluate the engineering and operational aspects of the irrigation system.
- ✓ The three most commonly used parameters for evaluating the response of the crop to water
  - ✓ Crop water use efficiency
  - ✓ Irrigation water use efficiency
  - ✓ Water use efficiency

1) Crop Water Use Efficiency (CWU_E): $CWU_E = \frac{(Y_i - Y_d)}{(ET_i - ET_D)}$

Where, CWU_E = Crop water use efficiency (Kg/ha-cm); Y_i = Yield of the irrigated crop (Kg/ha); Y_d= Yield of the equivalent rain fed crop (Kg/ha); ET_i= ET for irrigated crop (cm); ET_D= ET for rainfed crop (cm)

Irrigation Uniformity

2) Irrigation Water Use Efficiency (IWUE)

$$IWU_E = \frac{(Y_i - Y_d)}{IR_i}$$ {to characterize crop yield in relation to total depth of water applied}

Where, IR_i= Depth of irrigation water applied for irrigation (cm), which does not account for irrigation application losses

3) Water Use Efficiency (WUE_b)

$$WUE_b = \frac{Y_i}{P_e + IR + \Delta SW}$$

Where, P_e= Effective rainfall (cm); IR = Irrigation applied (cm); ΔSW = Change in soil water content in root zone (cm)

It neglects deep percolation losses, groundwater use, and surface runoff.

Example 58.1:

A stream of 150 lps was delivered from a canal and 110 lps were delivered to the field. An area of 2.2 ha was irrigated in eight hours. The effective depth of root zone was 1.5m. The runoff losses the field was 445 cubic meter. The depth of water penetration varied linearly from 1.5 m at the head end of the field to 1.1m at the tail end. Available moisture holding capacity of the soil is 200 mm per meter depth of soil. Determine ***the Water Conveyance Efficiency, water application efficiency, water storage efficiency,* and *water distribution efficiency***. Irrigation was started at a moisture extraction level of 50%.

Solution:

1) Water Conveyance Efficiency (E_C) = $E_C = \frac{V_f}{V_t}$x100

$= \frac{110}{150}$x100

= 73.33%

2) Water Application Efficiency (E_a)

$$E_a = \frac{V_s}{V_f} \text{x}100$$

$$\text{Water delivered to the plot} = \frac{110 \times 60 \times 60 \times 8}{1000}$$

$= 3168\ m^3$

Runoff = 445 m^3

V_s= 3168-445= 2723 m^3

$$E_a = \frac{2723}{3168} \text{x}100$$

$= 86\%$

3) **Water Storage Efficiency (E_s)**

$$E_s = \frac{V_s}{V_{fc} - V_a} \text{x } 100$$

V_{fc} = 200 × 1.5=300mm

V_a= 300 × 0.5= 150mm

$V_{fc} - V_a$= 150mm =(150 × 2.2 × 10000)/1000=3300 m^3

$$E_s = \frac{2723}{3300} \text{x } 100$$

= 82.52%

4) Water distribution efficiency(DU)

Average depth of water storage in the root zone

$$d = \frac{1.5+1.1}{2} = 1.3 \text{ m}$$

Numerical deviation from depth of penetration

At the head end of the field = (1.5-1.3) = 0.2m

At the tail end of the field = (1.3-1.1)= 0.2 m

Average numerical deviation in depth of water application

$$Y = \frac{0.2+0.2}{2} = 0.2 \text{ m}$$

$$DU = \{1 - (y/d)\} \times 100$$

$$= \{1 - (0.2/1.3)\} \times 100 = 84.62\%$$

Thank You!!

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NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No: 59 Irrigation Economics

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IIT KHARAGPUR

Irrigation Economics

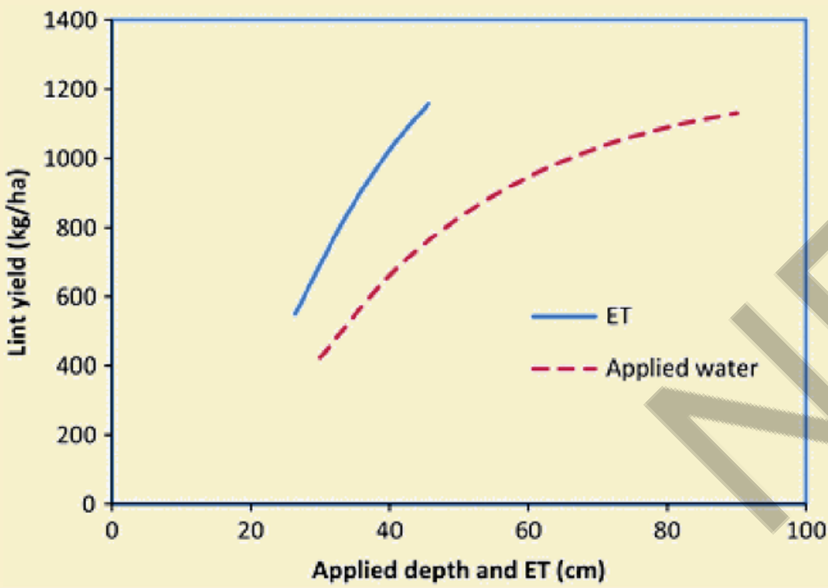
Economics is the fundamental decision criteria in irrigation and drainage engineering

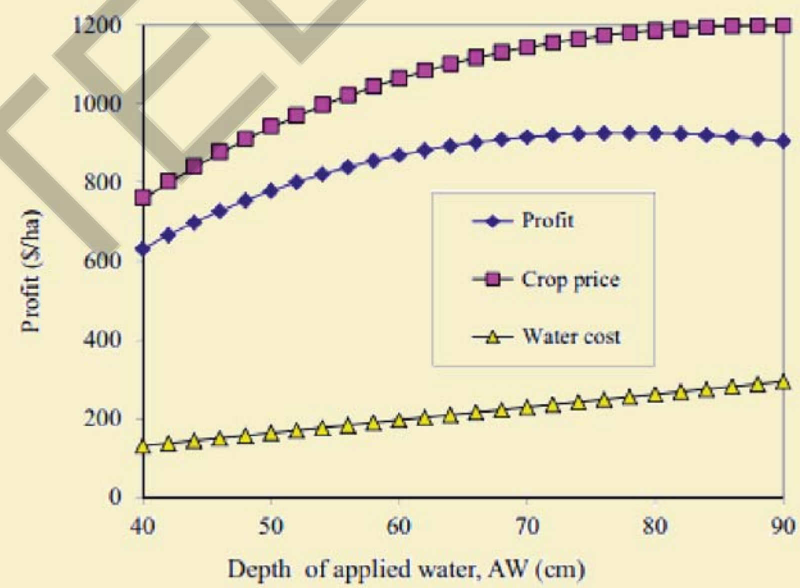
- ✓ Engineering economics analysis uses the **project life** and **expected rate of return** to compute the expected **present and future costs and benefits** of proposed irrigation or drainage system.
- ✓ If the system is profitable at the required rate of return, that the decision is made to invest in the system
- ✓ **Crop water production function** with water and energy cost information enables to calculate optimal depth of water application

Irrigation Economics

Crop water production function

Crop yield = f (water applied during growing season)





Irrigation Economics

Crop Water Production Function(e.g. Grimes and El-Zik,1990)**:**

The Crop Water Production Function for cotton

$$Y_a = -3954 + 1067\,(AW_e)^{0.5} - 54.14(AW_e)$$

Where, Y_a= actual yield per ha, kg/ha; AW_e= depth of applied water used in calculation of yield, cm.

Since, Irrigation (AW) is often supplemented by precipitation,

$$Y_a = -3954 + 1067(AW_e + P_e)^{0.5} - 54.14(AW_e + P_e)$$

The above equations are obtained from the field experiments.

Irrigation Economics

If the experimental irrigation efficiency is 90%, then the relationship between gross depth of irrigation water (AW) applied and AW_e

$$AW = \frac{AW_e}{\frac{[100-(90-\eta)]}{100}} \quad or \qquad AW_e = AW - AW(0.9-\eta)$$

Where, η = the efficiency of actual field irrigation system (fraction); AW= actual gross depth of applied water used to calculate water cost.

Pre-irrigation may be needed to germinate the crop, and most of this water is often wasted as leachate or runoff.

$$AW = \frac{AW_e}{\frac{[100-(90-\eta)]}{100}} + pre\ irrigation \qquad (1)$$

Irrigation Economics

Water cost is normally (but not always) calculated on a volume basis (m^3, ac-ft, ha-cm), if the unit of AW is cm, then the cost of water in \$/ha is

$$WC(\$/_{ha}) = \$/_{m^3} \times 100 \times AW \qquad (2)$$

If only water cost is considered, then profit is calculated as

$$P_r = Y_a \times (\$/_{ha}) - WC(\$/_{ha}) \qquad (3)$$

Where, P_r= benefit or profit, \$/ha

The maximum profit can be found by setting the derivative $\frac{d(P_r)}{d(AW)} = 0$

Example 59.1:

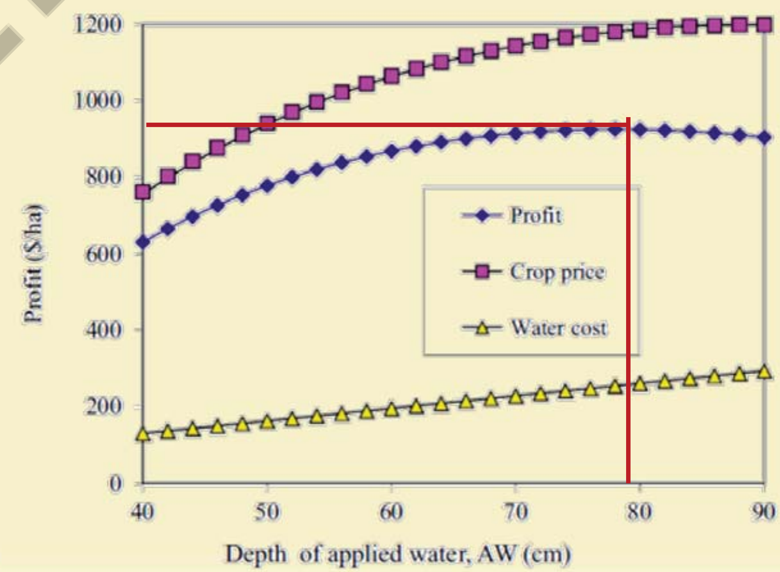
Find the depth of applied water (AW) that results in maximum profit with a drip irrigation system for the cotton CWPF by Grimes and El-Zik (1990). Assume that 7.5 cm of precipitation infiltrates during the growing season. The cost of water is $0.0327/m^3. The selling price of cotton is $0.92/kg. Assume that preirrigation depth is 0 cm and AW = AW$_e$. The drip irrigation system efficiency is 90%.

Solution:

From Grimes and El-Zik (1990),

$$Y_a = -3954 + 1067(AW + 7.5)^{0.5} - 54.14(AW + 7.5), \text{kg/ha}$$

$$P_r = \$0.92 \times [-3954 + 1067(AW + 7.5)^{0.5} - 54.14(AW + 7.5)] - \$0.0327 \times 100 \times AW, \text{\$/ha}$$



Maximum profit is $925/ha, which is found at an applied depth of water AW_e = 79 cm

Example 59.2:

Repeat **Example 59.1**, but use the surface irrigation with 60 cm preirrigation and 60 % efficiency.

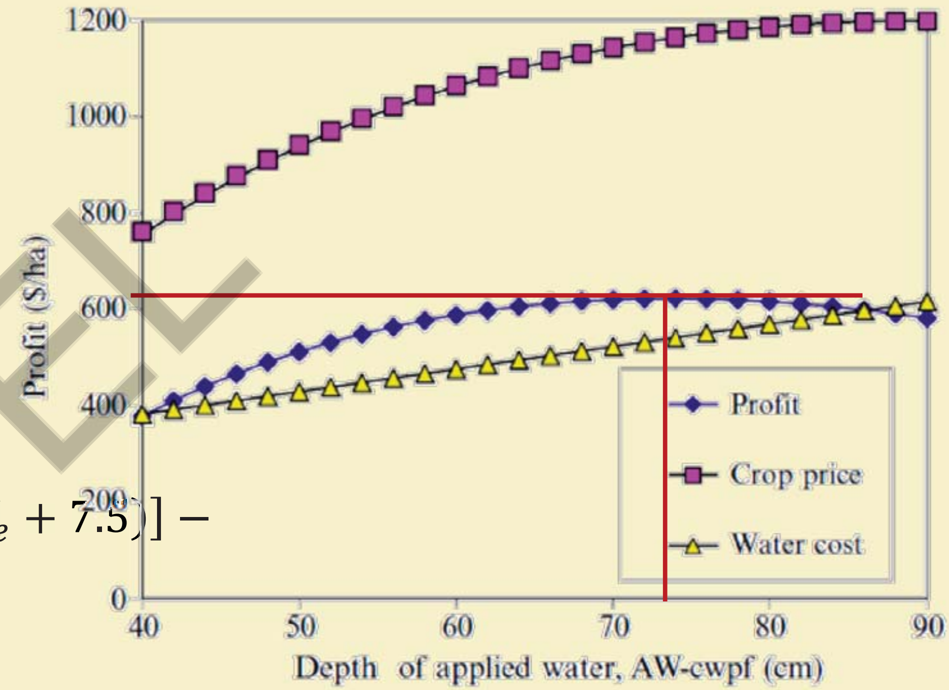
Solution: $AW = \left[\frac{AW_e}{\frac{[100-(90-\eta)]}{100}} + 60\right]$

Profit,

$P_r = \$0.92/kg \times [-3954 + 1067(AW_e + 7.5)^{0.5} - 54.14(AW_e + 7.5)] - WC$

Maximum profit (\$623) is found at AW_e = 74 cm. The gross depth of water that is applied by the irrigation system is:

Depth of water applied (AW) $= \left[\frac{AW_e}{\frac{[100-(90-\eta)]}{100}} + 60\right] = \left[\frac{74}{1-0.3} + 60\right] = 166$ cm



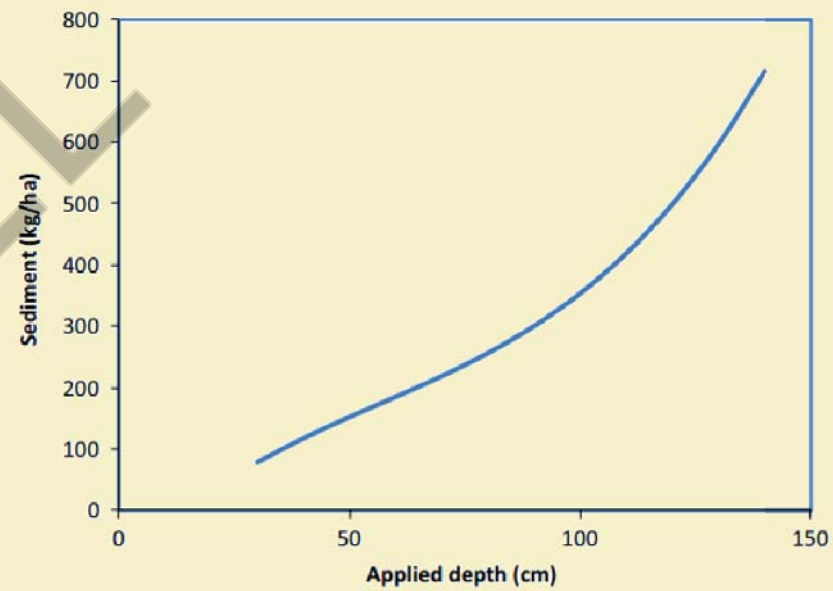
The annual benefit is decreased by approximately \$300/ha from the drip irrigation system analyzed in Example.1

Environmental Cost

Erosion from sloping furrow irrigation systems is used here as an example

$$Sediment\left(\frac{kg}{ha}\right) = 10^3 \times (4.62 \times 10^{-5} i^3 - 7.84 \times 10^{-3} i^2 + 0.77i - 9.44)$$

Where, i= seasonal gross depth of water applied by irrigation system, cm.



The environmental cost (EnvC) on a per hectare basis is

$$EnvC\left(\frac{\$}{ha}\right) = \frac{\$}{kg} \times \frac{kg}{ha}$$

$$Profit, P_r = Y_a \times \left(\frac{\$}{ha}\right) - WC - EnvC$$

Example 59.3:

Repeat **Example 59.2**, but include cost of erosion. The cost of erosion (land degradation and sediment removal from river water) is \$0.2/(kg/ha).

The actual depth of applied water is used to calculate the amount of erosion. For example, the irrigation depth at AW_e = 64 cm is

$$i = \left[\frac{AW_e}{1-(0.9-0.6)}\right] + 60 = \left[\frac{64}{1-(0.3)}\right] + 60 = 151 \text{ cm}$$

$$Sediment\left(\frac{kg}{ha}\right) = 10^3 \times (4.62 \times 10^{-5} \times 151^3 - 7.84 \times 10^{-3} \times 151^2 + 0.77 \times 151 - 9.44) = 429\frac{kg}{ha}$$

$$EnvC\left(\frac{\$}{ha}\right) = 0.2\frac{\$}{kg} \times 429\frac{kg}{ha} = \$86/ha;$$

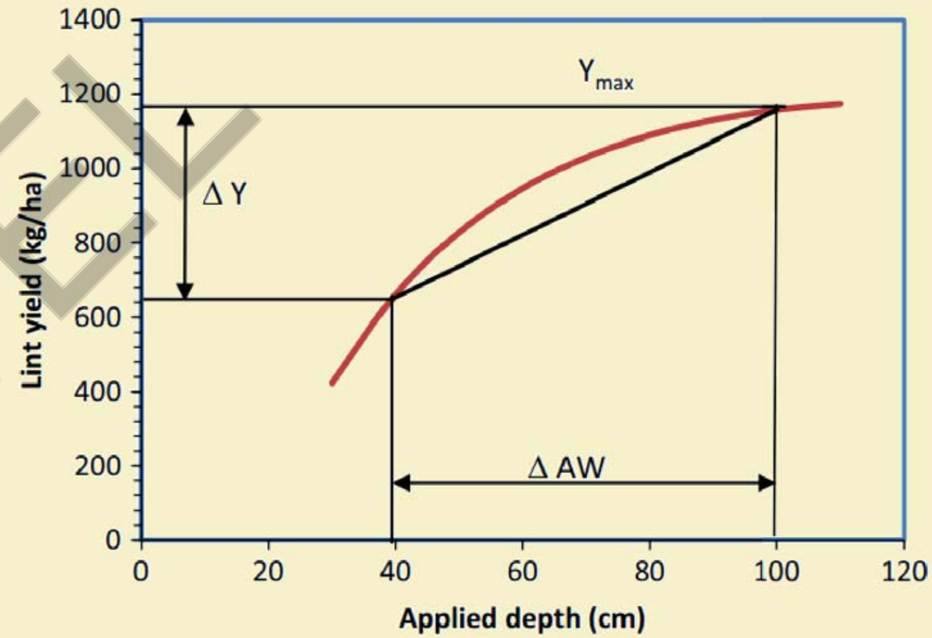
Using above profit equation, maximum profit (\$519/ha) is found at AW_e= 64 cm with I = 151 cm.

This example shows that the optimal economic depth of irrigation is generally reduced when environmental cost of irrigation is considered.

Transferring a CWPF from One Climatic Zone to Another

FAO had published linearized CWPF for several crops

This approach makes the crop water production function more general and applicable to another region with a different water requirement and a different maximum yield.



Linearized crop water production curve

Transferring a CWPF from One Climatic Zone to Another

$$Y_a = y_{max}\left[1 - \frac{\%\Delta Y}{\%\Delta AW}\left(\frac{(AW_{req} - AW_e)}{AW_{req}}\right)\right]$$

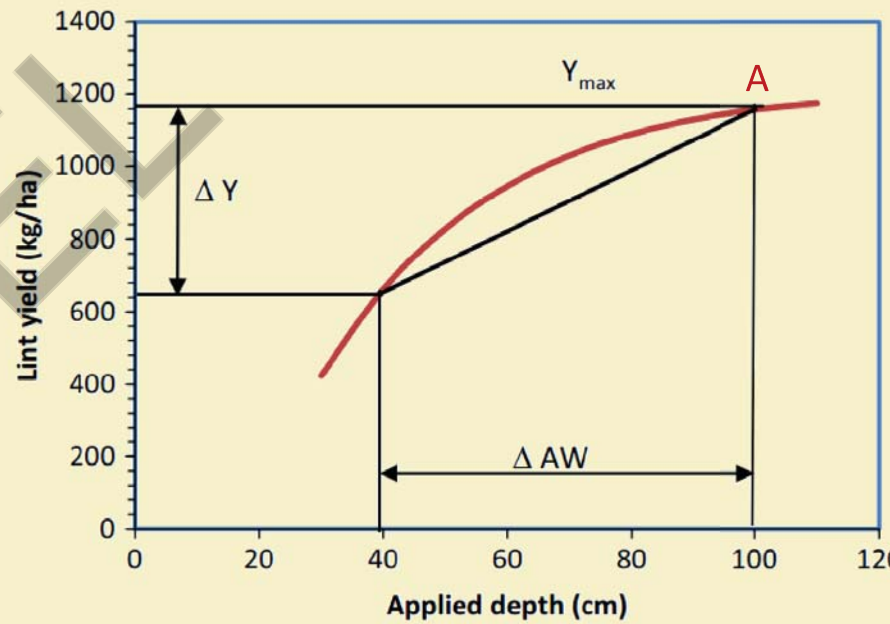
Where, ΔAW= change in applied water (percent or fraction); ΔY= Change in yield (percent or fraction); y_{max}= yield with under no stress, kg/ha; AW_{req}= applied water depth with no yield reduction, cm

Proof

$$Slope\ (m) = \frac{\Delta Y}{\Delta AW}$$

Equation of a line passing through point, A (Aw_{req}, Y_{max})

$$(Y - Y_1) = m(X - X_1)$$



Linearized crop water production curve

$$(Y - Y_{max}) = \frac{\Delta Y}{\Delta AW}(AW_e - AW_{req})$$

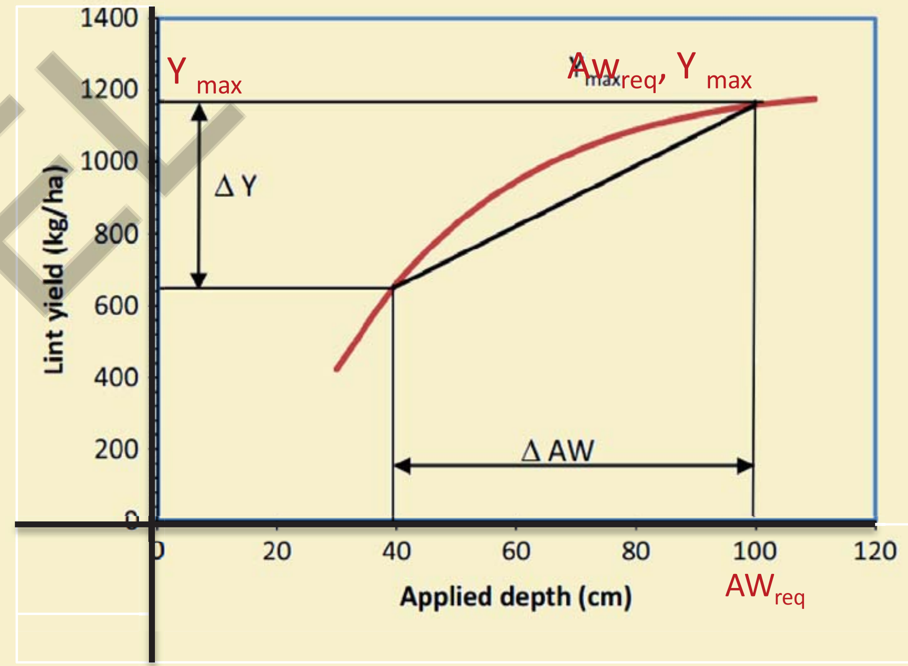
$$Y = Y_{max} + \frac{\Delta Y}{\Delta AW}(AW_e - AW_{req}) \text{ or}$$

$$Y = Y_{max} - \frac{\Delta Y}{\Delta AW}(AW_{req} - AW_e)$$

$$= Y_{max}\left[1 - \frac{\Delta Y}{\Delta AW}\left(\frac{AW_{req} - AW_e}{Y_{max}}\right)\right]$$

$$Y = Y_{max}\left[1 - \frac{\frac{\Delta Y}{y_{max}}}{\frac{\Delta AW}{AW_{req}} \times AW_{req}}(AW_{req} - AW_e)\right]$$

$$Y = Y_{max}\left[1 - \frac{\%\Delta Y}{\%\Delta AW}\left(\frac{AW_{req} - AW_e}{AW_{req}}\right)\right]$$



Linearized crop water production curve

Example 59.4:

Calculate cotton yield. The required depth of applied water in a region is 100 cm, actual applied water depth is 80 cm, and the maximum yield is 1180 kg/ha.

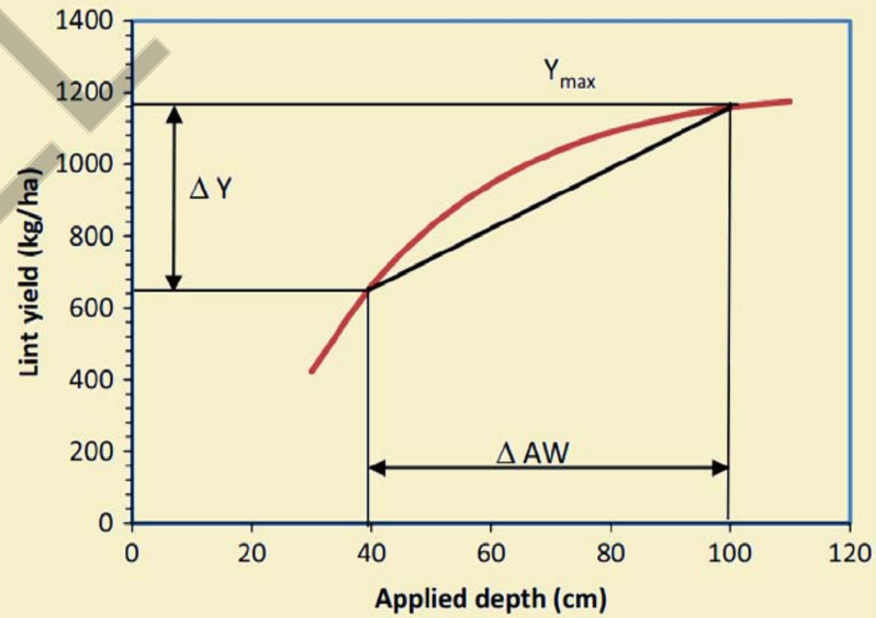
Solution:

AW_e= 80 cm ; y_{max}= 1180 kg/ha; AW_{req}= 100 cm

From the cotton CWPE;

From the graph;

$$\frac{\%\Delta Y}{\%\Delta AW} = \frac{\frac{1161-641}{1161}}{\frac{100-40}{100}} = 0.746$$



Linearized crop water production curve

$$Y_a = y_{max}\left[1 - \frac{\%\Delta Y}{\%\Delta AW}\left(\frac{(AW_{req} - AW_e)}{AW_{req}}\right)\right]$$

$$Y_a = 1180\left[1 - 0.75\left(\frac{100-80}{100}\right)\right] = 1000 \text{ kg/ha}$$

The term $\frac{\%\Delta Y}{\%\Delta AW}$ = the yield response factor used by the FAO.

Then the above equation can be rearranged: $1 - \left(\frac{Y_a}{Y_{max}}\right) = K_y\left[1 - \frac{AW_e}{AW_{req}}\right]$

Or $$K_y = \frac{1 - \frac{Y_a}{Y_{max}}}{1 - \frac{AW_e}{AW_{req}}} = \frac{\Delta Y,\%}{\Delta AW,\%}$$

Combined estimation of crop yield includes all stresses

Actual crop yield = f (stress included salinity, water, nitrogen, pest, and other stresses)

Example 59.5:

There is 10 % yield loss due to pests, 10 % yield loss due to salinity and the depth of applied water to sugar beets is 90 % of that required. Maximum sugar beet yield is 40 t/ha. What is the yield of sugar beets?

Solution:

Use the above procedure **Example 59.4** for finding the yield and % reduction due water stress

$Y_a = 40\left[1 - 0.75\left(\frac{100-90}{100}\right)\right] = 37$ t/ha

% yield reduction due to water stress = $\frac{37}{40} \times 100 = 93\%$

$$Expected\ yield = 40\frac{t}{ha}(0.93 \times 0.9 \times 0.9) = 30\ t/ha$$

Engineering Economic Analysis

- ✓ It combines present (capital investment) and future benefits (crop yield) and costs (water cost, crop yield, energy cost, and labor) into one number: **Cost-Benefit ratio**

- ✓ It shows whether conversion to pressurized system will ultimately result in greater profit
  - ✓ Conversion to a pressurized system may result in lower water costs and greater crop yield but have higher energy and capital costs

- ✓ It does this by converting all future costs and benefits to the present value based on the time value of money.

Engineering Economic Analysis

- ✓ The required rate of return is **the interest rate** that a company expects to earn on investments
- ✓ In engineering economic analysis, **if a proposed project returns a profit at the required rate of return, even if the profit is only one dollar**, then the decision is made to invest in the project.
- ✓ The future value of money is calculated with the following formula:

$$F = P\,(1 + i)^{n}$$

Where, F= future value; P= present value; i= interest rate; n= number of years

Engineering Economic Analysis

Example 59. 6:

If $1.00 is placed into an account for 5 years at an interest rate of 6 %, then the value in 5 years is

$$F = P\,(1+i)^n$$

$$F = \$1.00 \times \,(1+0.06)^5$$

$$= \$1.34$$

On the other hand, money that is received in 5 years is not worth as much as it is today and should be discounted.

The present value of money received in the future is

$$P = \frac{F}{(1+i)^n}$$

Engineering Economic Analysis

Example 59.7:

The expected annual income from a project is \$500/yr for 5 years, and the project requires a \$2,000 investment. Determine whether or not to invest in the project at two required rates of return: 6 % and 8 %.

Solution:

The net present value at a 6 % required rate of return: $F = P\,(1+i)^n$ or $P = \frac{F}{(1+i)^n}$

$$P = \frac{500}{(1+0.06)^1} + \frac{500}{(1+0.06)^2} + \frac{500}{(1+0.06)^3} + \dots\dots\dots + \frac{500}{(1+0.06)^5}$$

$$P = 472 + 445 + 419 + 396 + 373 = \$2106.1$$

Net presence value = present value of five years expected income-investment

Net presence value = 2106.1-2000 $= \$106.1$

Net presence value = $106 (>0; invest in the project)

Similarly the net present value @8% required rate of return

$$P = \frac{500}{(1+0.08)^1} + \frac{500}{(1+0.08)^2} + \frac{500}{(1+0.08)^3} + \dots\dots\dots + \frac{500}{(1+0.08)^5}$$

$$P = 463 + 429 + 397 + 367 + 340$$

Net presence value = present value of five years expected income-investment

Net presence value = $463 + 429 + 397 + 367 + 340 - 2000$

$Net\ present\ value = -\$4$ (<0; do not invest @ 8%)

Discussion:

@6% investment rate: The present value is >0 hence decision to **invest to the project**

8% investment rate: The present value is <0 hence the decision would be **not to invest in the project**

Typical life and annual maintenance cost percentage for irrigation system components

System and components	Life (yr)	Annual maintenance (% of cost)
1. Sprinkler systems	10–15	2–6
Center pivot-standard	15 +	5
Linear move	15 +	6
solid set	20 +	1
2. Micro systems	1–20	2–10
Drip	5–10	3
3. Surface & subsurface systems	15	5
pump only	15 +	3
Wells	25 +	l

Example 59.8

Determine the present value of the income from alfalfa 6 years from now at a required rate of return of 7 %. (1) Assume no inflation. (2) Assume inflation of costs of 5 % per year and no inflation in the selling price of alfalfa. The present value of alfalfa production is \$631/acre-yr. Operating expenses are \$321/acre-yr

Solution:

1. No inflation.

$$Present\ value\ of\ year\ 6\ profit\ = (\$631 - \$321) \times \frac{1}{(1+0.07)^6} = \$207$$

2. Costs inflate at a rate of 5% a year

$$Costs\ in\ year\ 6{:}\ \$321 \times (1+0.05)^6 = \$430/acre$$
$$Profit\ in\ year\ 6{:}\ \$631 - \$430 = \$201/acre$$

Present value of year 6 profit (with inflation)

$$= \$201\left(\frac{1}{1+0.07}\right)^6 = \$134\ /acre$$

Cash Flow Diagrams

- ✓ **Cash flow diagrams** show the expected crop income, energy costs, water costs, replacement costs, etc. each year for the life of the project
- ✓ Inflation and other changes in prices are incorporated into the spreadsheet
- ✓ Total benefits minus costs are calculated each year for the cash flow diagram
- ✓ The total for each year is then discounted to the present value based on the required rate of return

Thank You!!

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NPTEL ONLINE CERTIFICATION COURSES

Irrigation and Drainage

Lecture No: 60 Irrigation Planning and Management using CROPWAT

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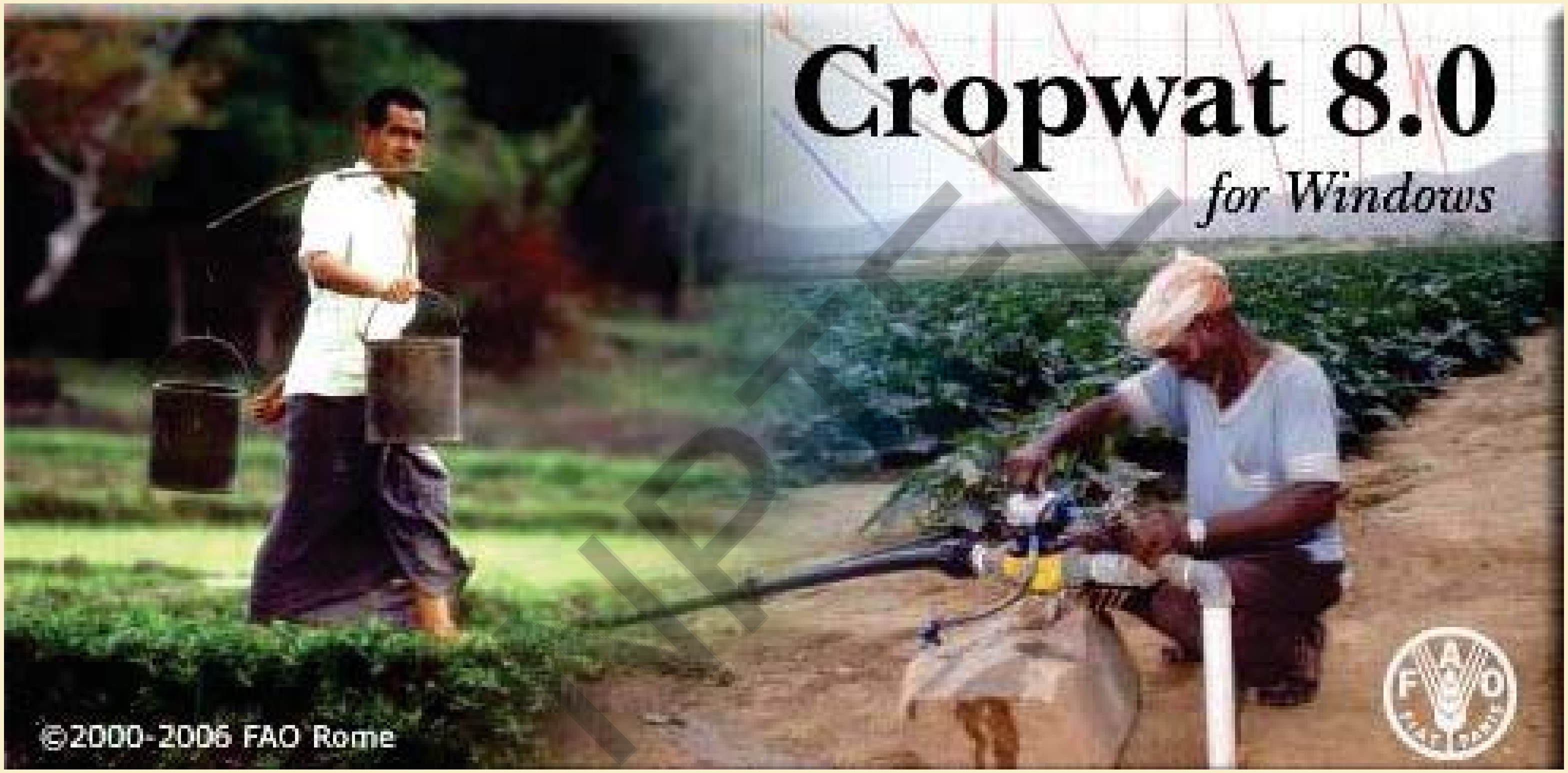
CROPWAT 8.0



http://www.fao.org/land-water/databases-and-software/cropwat/en/

Introduction

CROPWAT: Calculates **crop water requirements** and **irrigation schedules**

- ✓ Evapotranspiration (ET_o: input or estimate) using the Penman-Monteith formulae for crop water requirements (CWR)
- ✓ Effective rainfall, Crop data (dry crop or rice) and soil data as input for calculating CWR and irrigation scheduling (dry crop or rice)
- ✓ Scheme supply for multiple crops by cropping pattern
- ✓ Wide variety of options for data input and the calculations

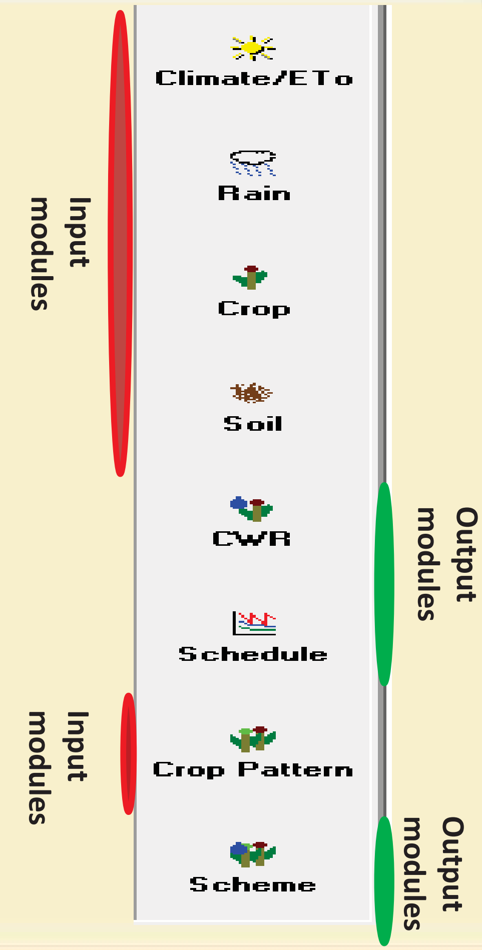
Introduction

CROPWAT structure

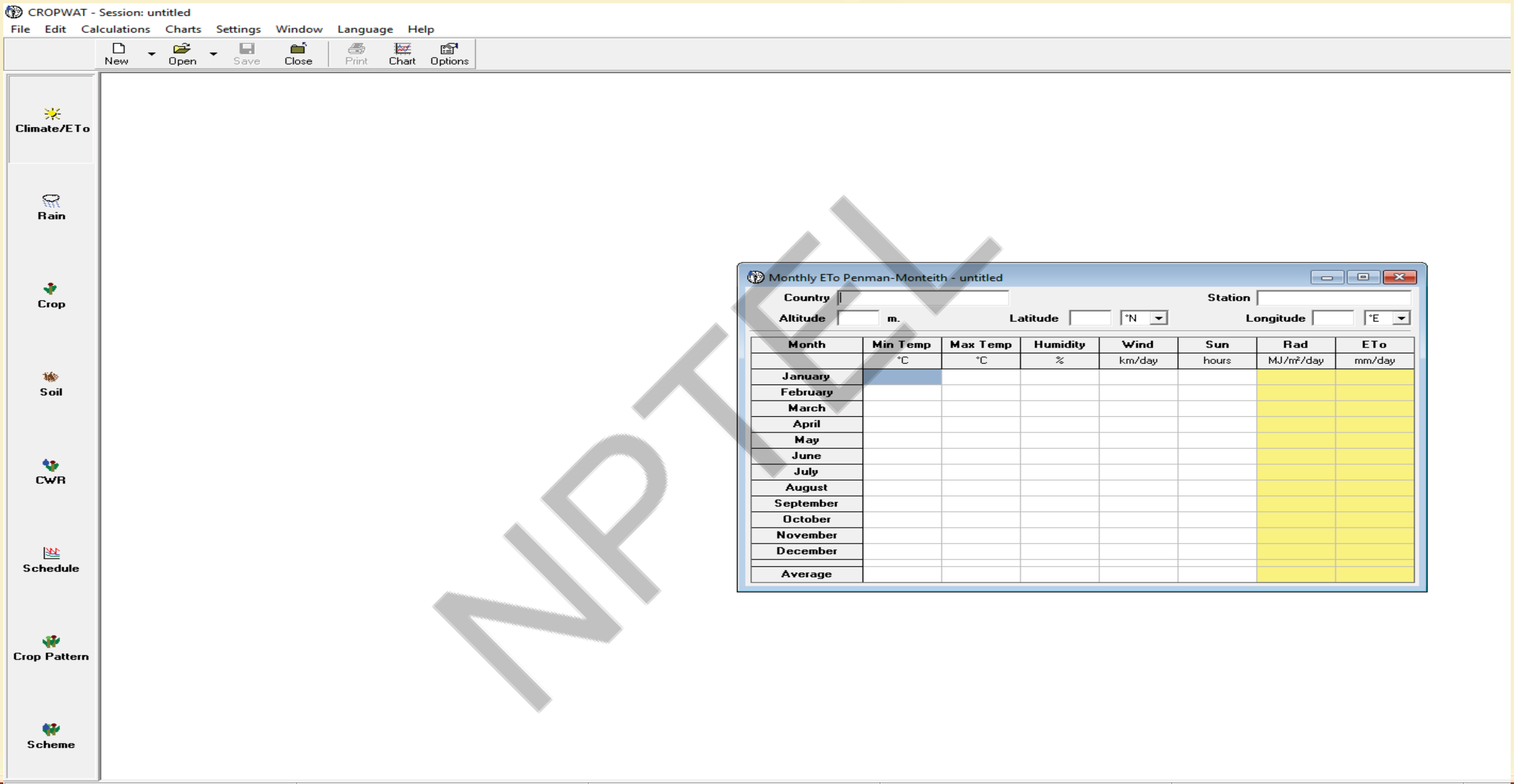
- ✓ Organised in 8 different modules
  - ✓ data input modules: 5
  - ✓ calculation modules: 3

- ✓ The modules are located on **Modules bar** (left hand side of the main window)

- ✓ Easy access to modules (climatic, crop and soil data for calculation of crop water requirements, irrigation schedules and scheme supplies)



CROPWAT 8.0


CROPWAT - Session: untitled
File Edit Calculations Charts Settings Window Language Help
New
Open
Save
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Print
Chart
Options
Climate/ETo
Rain
Crop
Soil
CWR
Schedule
Crop Pattern
Scheme
Monthly ETo Penman-Monteith - untitled
Country
Station
Altitude
m.
Latitude
°N
Longitude
°E
Month
Min Temp
°C
Max Temp
°C
Humidity
%
Wind
km/day
Sun
hours
Rad
MJ/m²/day
ETo
mm/day
January
February
March
April
May
June
July
August
September
October
November
December
Average

Introduction

Data input modules :

1. Climate/ETo: for the input of measured ET_0 *or* of climatic data for estimating ET_0

2. Rain: for the input of rainfall data and calculation of effective rainfall

3. Crop (dry crop or rice): for the input of crop data and planting date

4. Soil: for the input of soil data for (only needed for irrigation scheduling)

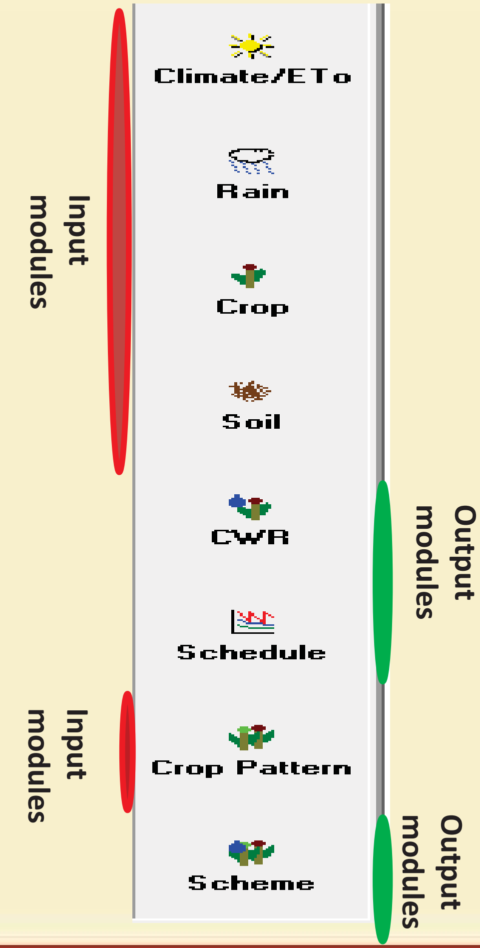
5. Crop pattern: for the input of a cropping pattern for scheme supply calculations

Calculation modules:

6. CWR - for calculation of Crop Water Requirements

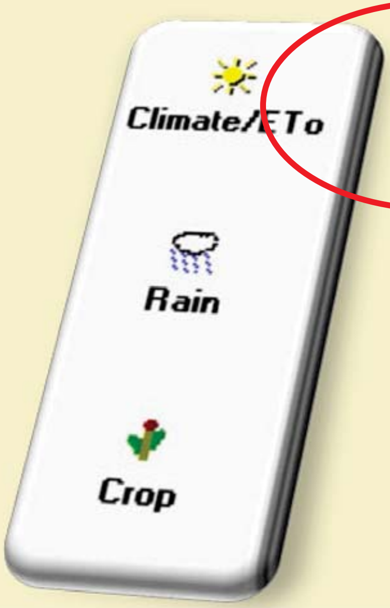
7. Schedules (dry crop or rice) - for the calculation of irrigation schedules

8. Scheme - for the calculation of scheme supply based on a specific cropping pattern



The input data

1. Climate/ET_0



Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\KURNOOL.pen

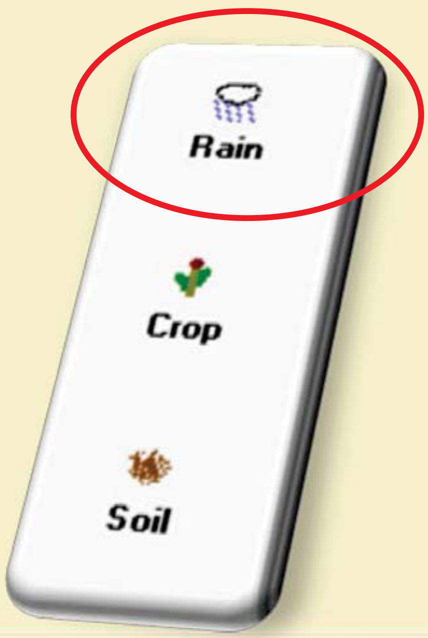
Country: Location 9529   Station: KURNOOL

Altitude: 281 m.   Latitude: 15.80 °N   Longitude: 78.06 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	17.0	31.3	47	104	8.8	18.7	3.99
February	19.3	34.3	37	112	9.3	21.2	4.91
March	22.5	37.5	30	121	9.7	23.5	5.93
April	26.0	39.3	34	138	9.2	23.6	6.66
May	27.2	40.0	37	225	8.3	22.2	7.93
June	25.0	35.6	54	354	5.8	18.3	7.19
July	23.8	32.5	64	363	4.4	16.2	5.74
August	23.5	32.1	63	302	4.9	16.9	5.47
September	23.3	31.9	65	207	5.5	17.3	4.83
October	22.4	32.4	61	95	8.7	20.7	4.58
November	19.2	31.0	56	78	7.7	17.6	3.73
December	16.6	30.3	51	69	8.4	17.7	3.40
Average	22.1	34.0	50	181	7.5	19.5	5.36

The input data

2. Rain



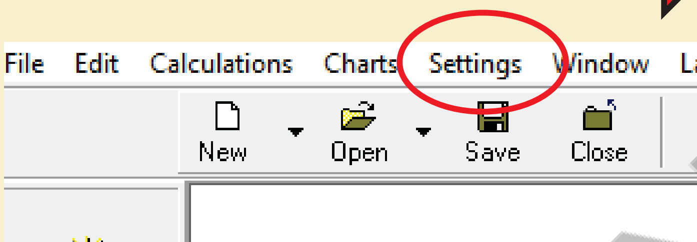
Monthly rain - C:\ProgramData\CROPWAT\data\rain\KURN-86.CRM

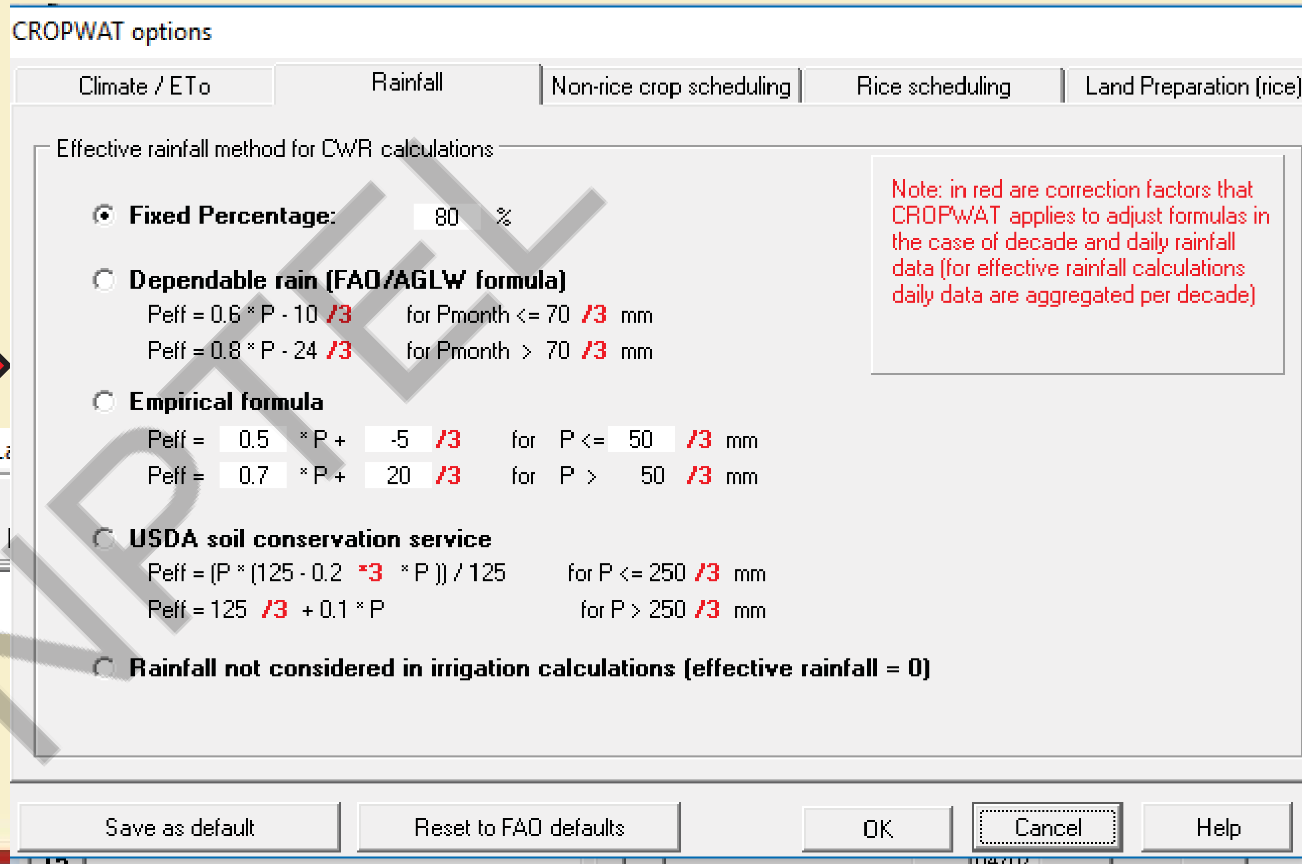
Station: KURNOOL   Eff. rain method: Fixed percentage

	Rain	Eff rain
	mm	mm
January	0.0	0.0
February	0.0	0.0
March	0.0	0.0
April	0.0	0.0
May	25.0	20.0
June	50.0	40.0
July	75.0	60.0
August	100.0	80.0
September	8.0	6.4
October	107.0	85.6
November	67.0	53.6
December	0.0	0.0
Total	432.0	345.6

The input data

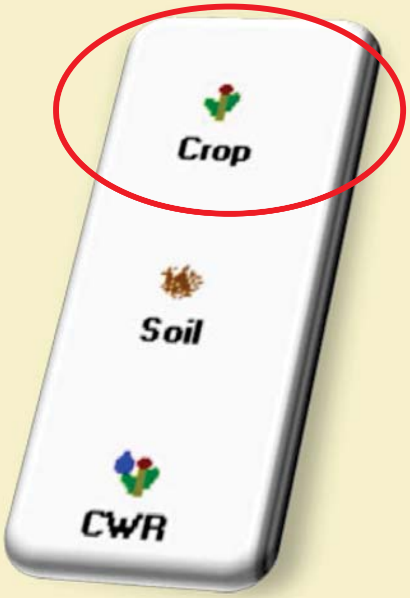
2. Rainfall

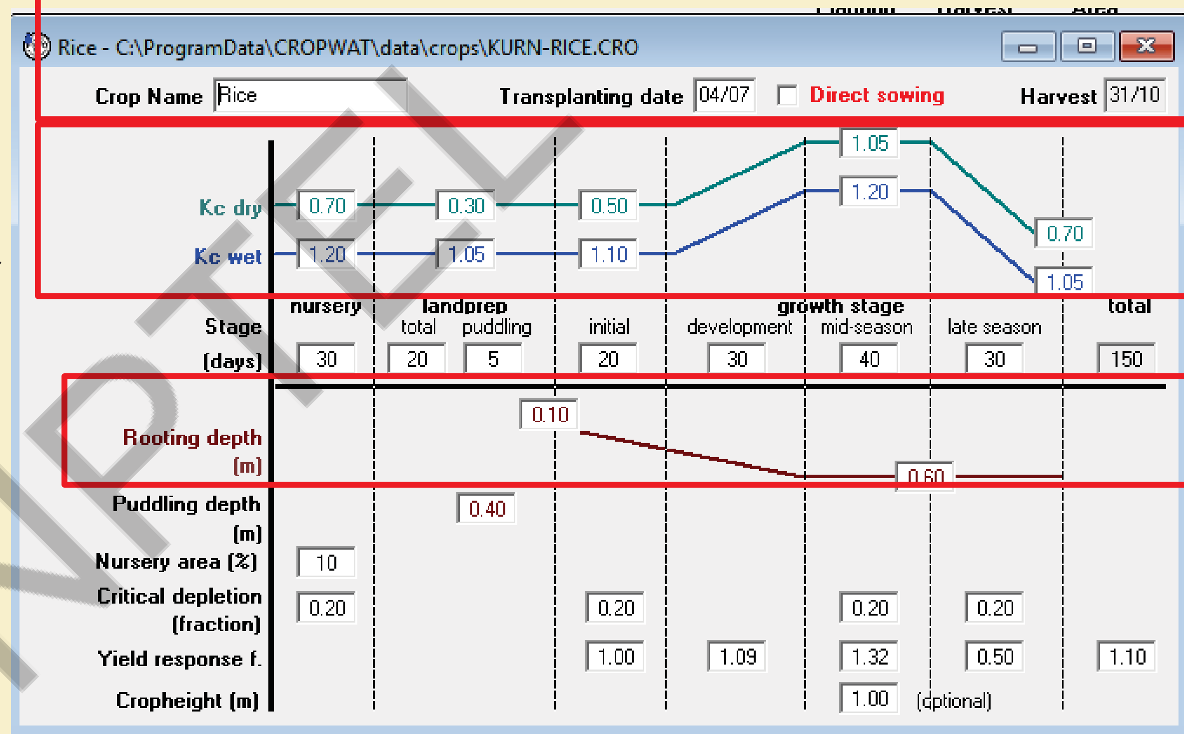




The input data

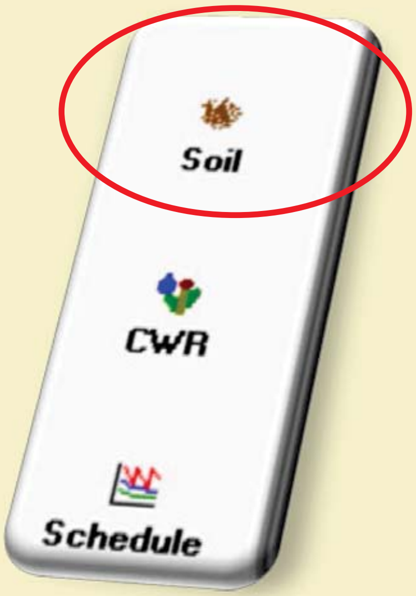
3. Crop

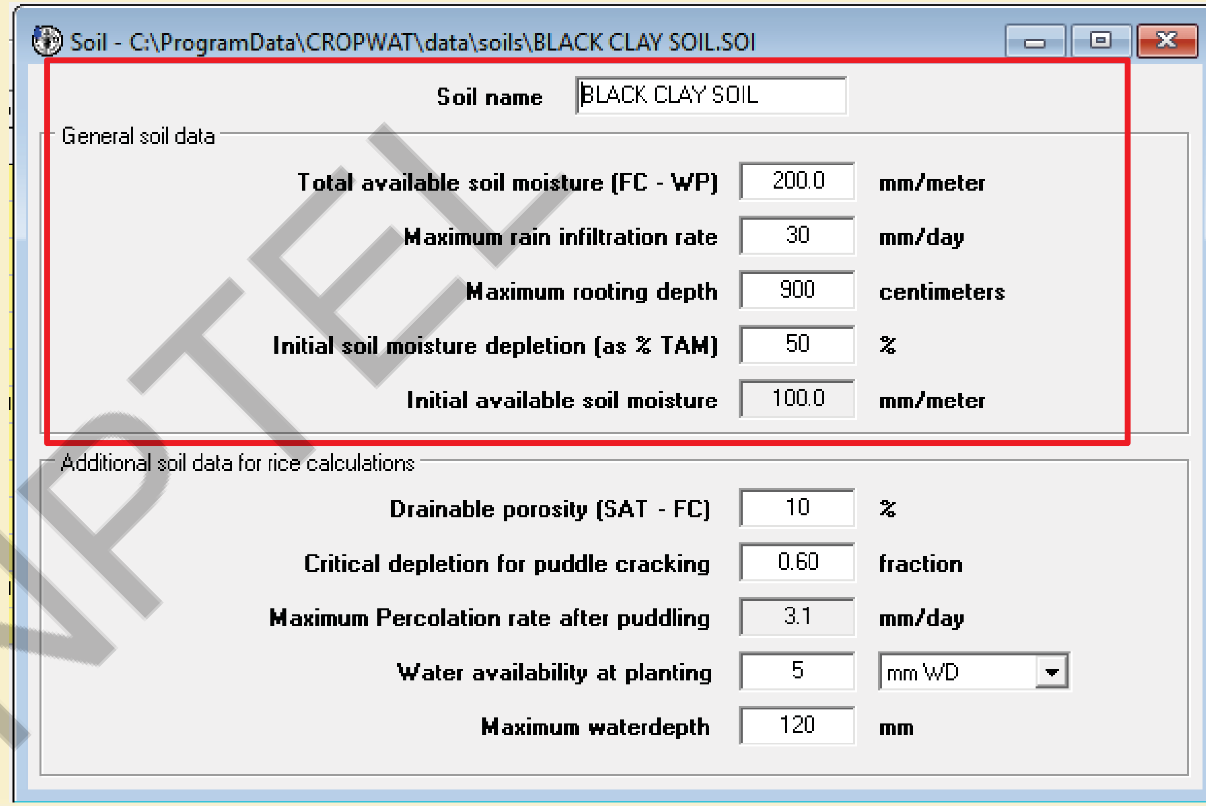




The input data

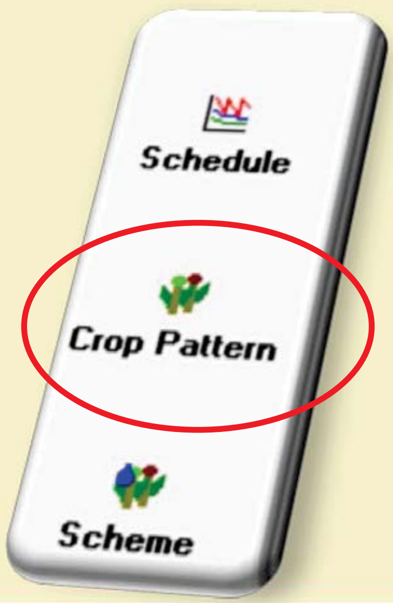
4. **Soil**

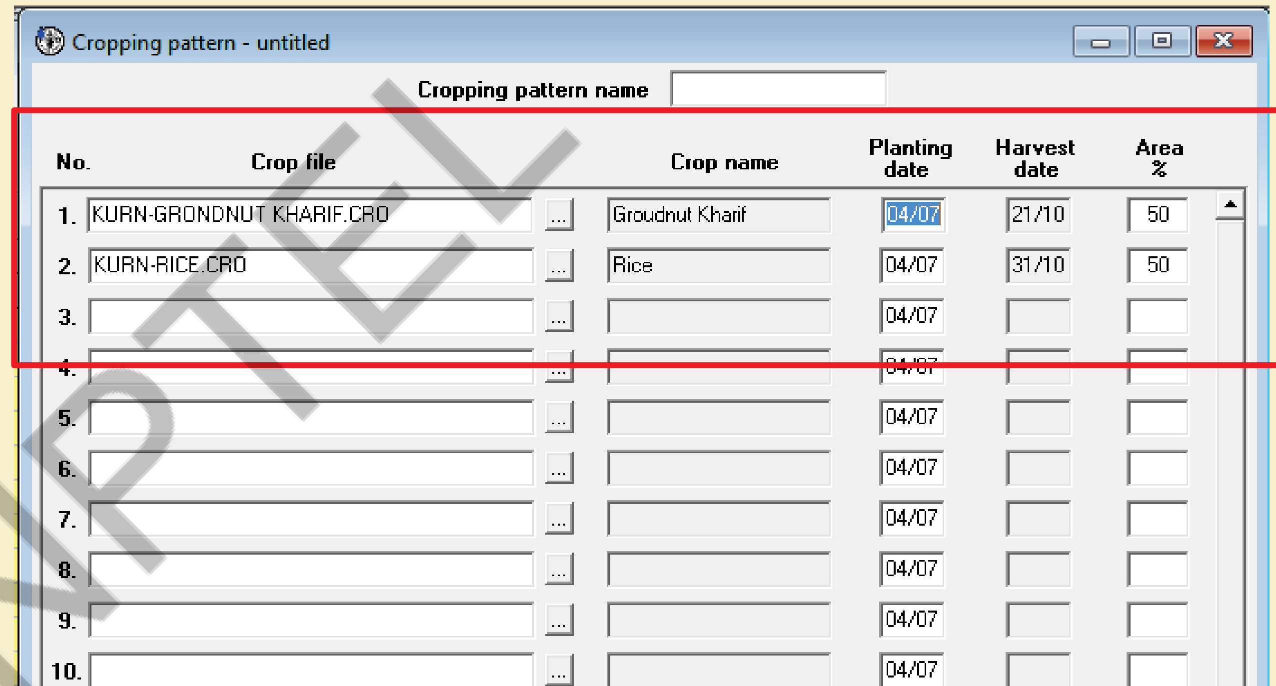




The input data

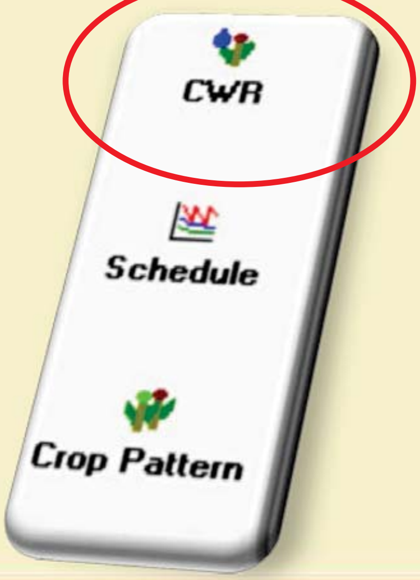
5. **Crop pattern**

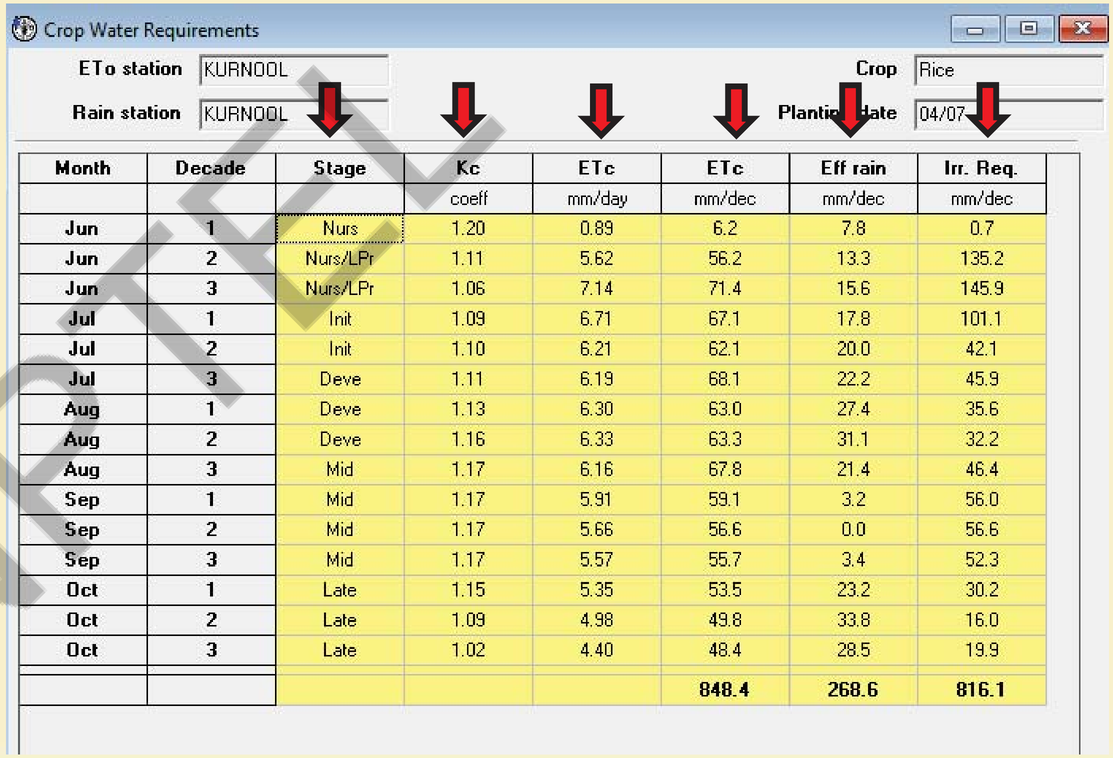




Model Output

1. Crop water requirement




Crop Water Requirements

ETo station KURNOOL

Rain station KURNOOL

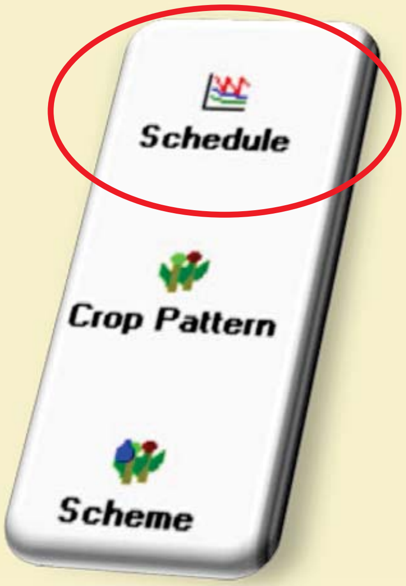
Crop Rice

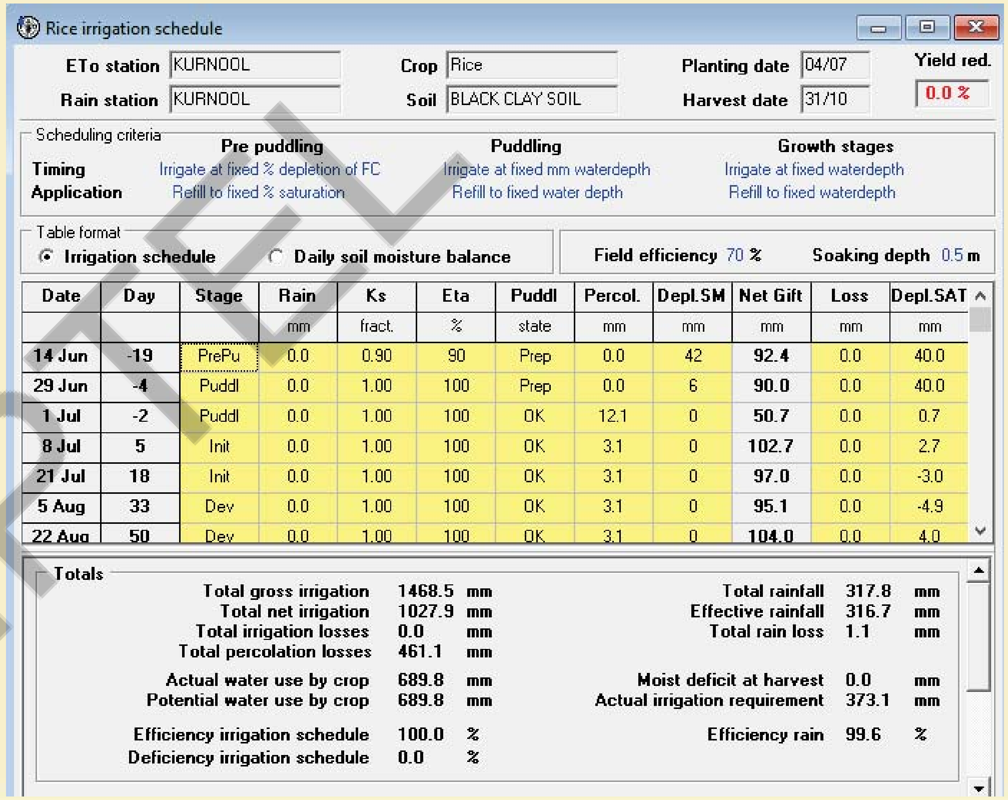
Planting date 04/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Nurs	1.20	0.89	6.2	7.8	0.7
Jun	2	Nurs/LPr	1.11	5.62	56.2	13.3	135.2
Jun	3	Nurs/LPr	1.06	7.14	71.4	15.6	145.9
Jul	1	Init	1.09	6.71	67.1	17.8	101.1
Jul	2	Init	1.10	6.21	62.1	20.0	42.1
Jul	3	Deve	1.11	6.19	68.1	22.2	45.9
Aug	1	Deve	1.13	6.30	63.0	27.4	35.6
Aug	2	Deve	1.16	6.33	63.3	31.1	32.2
Aug	3	Mid	1.17	6.16	67.8	21.4	46.4
Sep	1	Mid	1.17	5.91	59.1	3.2	56.0
Sep	2	Mid	1.17	5.66	56.6	0.0	56.6
Sep	3	Mid	1.17	5.57	55.7	3.4	52.3
Oct	1	Late	1.15	5.35	53.5	23.2	30.2
Oct	2	Late	1.09	4.98	49.8	33.8	16.0
Oct	3	Late	1.02	4.40	48.4	28.5	19.9
					848.4	268.6	816.1

Model Output

2. Irrigation Scheduling





Rice irrigation schedule

ETo station KURNOOL | Crop Rice | Planting date 04/07 | Yield red.
Rain station KURNOOL | Soil BLACK CLAY SOIL | Harvest date 31/10 | 0.0 %

Scheduling criteria

	Pre puddling	Puddling	Growth stages
Timing	Irrigate at fixed % depletion of FC	Irrigate at fixed mm waterdepth	Irrigate at fixed waterdepth
Application	Refill to fixed % saturation	Refill to fixed water depth	Refill to fixed waterdepth

Table format: Irrigation schedule / Daily soil moisture balance

Field efficiency 70 % Soaking depth 0.5 m

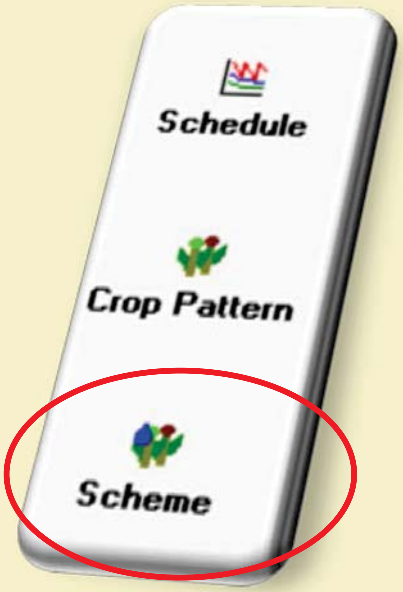
Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
14 Jun	-19	PrePu	0.0	0.90	90	Prep	0.0	42	92.4	0.0	40.0
29 Jun	-4	Puddl	0.0	1.00	100	Prep	0.0	6	90.0	0.0	40.0
1 Jul	-2	Puddl	0.0	1.00	100	OK	12.1	0	50.7	0.0	0.7
8 Jul	5	Init	0.0	1.00	100	OK	3.1	0	102.7	0.0	2.7
21 Jul	18	Init	0.0	1.00	100	OK	3.1	0	97.0	0.0	-3.0
5 Aug	33	Dev	0.0	1.00	100	OK	3.1	0	95.1	0.0	-4.9
22 Aug	50	Dev	0.0	1.00	100	OK	3.1	0	104.0	0.0	4.0

Totals

Total gross irrigation	1468.5	mm	Total rainfall	317.8	mm
Total net irrigation	1027.9	mm	Effective rainfall	316.7	mm
Total irrigation losses	0.0	mm	Total rain loss	1.1	mm
Total percolation losses	461.1	mm			
Actual water use by crop	689.8	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	689.8	mm	Actual irrigation requirement	373.1	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	99.6	%
Deficiency irrigation schedule	0.0	%			

Model Output

3. Scheme Supply



Scheme Supply

ETo station: KURNOOL

Rain station: KURNOOL

Cropping pattern:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Rice	0.0	0.0	0.0	0.0	0.0	281.7	189.0	114.3	164.9	66.2	0.0	0.0
2. Groudnut Kharif	0.0	0.0	0.0	0.0	0.0	0.0	18.2	79.4	151.0	17.3	0.0	0.0
Net scheme irr.req.												
in mm/day	0.0	0.0	0.0	0.0	0.0	4.7	3.3	3.1	5.3	1.3	0.0	0.0
in mm/month	0.0	0.0	0.0	0.0	0.0	140.9	103.6	96.8	157.9	41.7	0.0	0.0
in l/s/h	0.00	0.00	0.00	0.00	0.00	0.54	0.39	0.36	0.61	0.16	0.00	0.00
Irrigated area	0.0	0.0	0.0	0.0	0.0	50.0	100.0	100.0	100.0	100.0	0.0	0.0
(% of total area)												
Irr.req. for actual area	0.00	0.00	0.00	0.00	0.00	1.09	0.39	0.36	0.61	0.16	0.00	0.00
(l/s/h)												

Thank You!!