Chapter 9
Irrigation and Drainage

- Irrigation is the application of water to soil to supply the necessary moisture for plant growth which cannot be provided by natural precipitation.

Wise use of land and water resources potentials

Development of effective irrigation systems

↓

Increase in agricultural outputs

Design and construction of irrigation systems → CE

Operation of irrigation systems → Agricultural Eng.

prior to GAP project

fertile top soil
is wasted due to erosion
because of lack of
land management
↓
wise use of
whatever is left
is important

how GAP looks like now

a basic understanding of soil/water/plant interactions
is needed for proper management

- Presence of enough moisture in the topsoil facilitates the build up of plant tissues through photosynthesis.

- Plant roots extract:
  - soluble nutrients in the soil
  - irrigation water

- The necessary energy for this extraction → oxidation of organic matter in the roots with the oxygen which is present in the pores

- Fully saturated soil → No air entrainment!

  ∴ roots cannot extract the required soluble nutrients

- Excess water in the pores → proper drainage

- In Turkey, 26 million ha of land is irrigable

- Economically irrigable amount of this value:
  - ~15 % by surface waters
  - ~2 % by groundwater

- Benefits of irrigation:
  - physical conditions in the soil are improved
  - excessive salt in the soil is leached
  - local hydrometeorological conditions are improved
    Ex: Atatürk Dam changed the humidity of the region, so that different crops can be grown.
  - a variety of crops may grow
  - multiple cropping may be achieved

Suitability of Land for Irrigation:

- Certain land features should exist for appreciable benefits from irrigation
  - Arable land → good quality soil that is suitable for cultivation
  - Irrigable land → arable land where sufficient water is available
  - Non-irrigable land, Ex: sandy soil (very permeable)

- Deep soil of good quality → desired output

- Irrigation soil contains certain proportions of:
  - clay
  - silt
  - sand

- Ideal irrigation soil: sandy loam:
  ~ 60% sand + ~ 20% silt + ~ 20% clay

Land Classification by USBR (6 classes)

- Prior to planning & design of irrigation system, land should be classified.

- Parameters to be considered in assessment:

	Class 1
Type of soil	sandy loam
Slope of the land	< 4%
Requirement for levelling	little or no-levelling
Electrical conductivity of water	EC < 4 millimhos/cm

Class 1 : Best, Ex: sandy loam

Class 6 : Worst

Determination of Irrigation Water Demand:

- Consumptive use (EP from planted areas) = ?

- Consumptive use = transpiration + evaporation

- Some of the methods for EP:
  - Modified Penman method
  - Jensen-Haise method
  - Hargraves method
  - Blaney - Criddle method → widely used in Turkey
  - Direct measurements using tanks and lysimeters → expensive

Blaney-Criddle method (1950)

$$u_c = 25.4kf$$

u_c = consumptive use in mm/month
k = $k_1 * k_2$ (crop coefficient)
k_1 = seasonal coefficient
k_2 = monthly coefficient
f = climatic factor

Multiple crops
↓
total consumptive use
must be calculated wrt
areal percentage of each crop

$$f = \left(\frac{1.8t + 32}{100} \right) P$$

t = mean monthly temperature in °C
P = ratio of monthly to annual day time hours

Crop Irrigation Requirement, CIR

portion of the consumptive use that must be supplied by irrigation

$$CIR = u_c - P_{eff}$$

CIR = crop irrigation requirement (mm/month)
u_c = consumptive use (mm/month)
P_{eff} = monthly effective precipitation (mm/month)

For multiple crops

$$\sum CIR = \sum A_i \left(u_{c_i} - P_{eff}\right)$$

Irrigation Efficiencies:

- Losses in irrigation systems are due to:
  - conveyance (taşıma, nakletme)
  - application
  - storage
  - use

Types of losses:

- operational wastes
- seepage in canals
- evaporation
- deep percolation losses
- surface runoff losses

Ex: water ddischarged thru waste ways because of refusal by users to take the total flow, leakage thru gates, losses from overflow or breakage of canal banks

1. Water conveyance efficiency, e_c:

crop irrigation requirement should be modified by some efficiency terms to take into account the possible losses in the water amount

$$e_c = 100\frac{W_f}{W_r}$$

W_f = water delivered to the farm (m^3/s)
W_r = water diverted from the river or reservoir (m^3/s)

2. Water application (farm) efficiency, e_f :

$$e_f = 100\frac{W_s}{W_f}$$

W_s= water stored in the soil root zone during irrigation (m^3/s)
W_f = water delivered to the farm (m^3/s)

Overall irrigation efficiency, e:

$$e = e_c e_f$$

Farm delivery requirement, FDR:

$$\underset{\text{(mm/month)}}{FDR} = \frac{CIR}{e_f}$$

CIR = crop irrigation requirement
e_f = farm efficiency

- Ex: In an irrigation project, 30% of the diverted water is lost in conveyance & 25% is lost in application. Compute the overall irrigation efficiency.

  $e = e_f \times e_c = 0.7(0.75) = 52.5\ \%$

- Ex: An irrigation discharge of 4 m^3/s is diverted from a river into a main canal. Of this amount, however only 3.25 m^3/s is delivered to the farm. The surface runoff over the irrigated area is approx. 500 lt/s. The contribution to gw by means of deep percolation is 300 lt/s. Determine water conveyance efficiency & application efficiency.

  $w_r = 4\ m^3/s$

  $w_f = 3.25\ m^3/s$

  $e_c = w_f/w_r = 3.25/4 = 81.25\%$

  overall efficiency, $e = 0.81(0.75) = 60.8\%$

  $w_s = 3.25\text{-}0.5\text{-}0.3 = 2.45\ m^3/s$

  $e_f = w_s/w_f = 2.45/3.25 = 75.38\%$

Total delivery requirement, TDR (mm/month):

$$TDR = \frac{CIR}{e}$$

CIR = crop irrigation requirement
e = overall irrigation efficiency

Irrigation modulus (water duty):

water requirement of an avg. unit area at the max. demand month on a continuous flow basis

$$q_{max} = TDR_{max}\left(\frac{mm}{month}\right)\times\frac{1\,month}{(30-31)\times 86400\,s}\times\frac{10000\,m^2}{1\,ha}\times\frac{1\,m}{1000\,mm}\times\frac{1000\,lt}{1\,m^3}$$

$$q_{max} = \frac{TDR_{max}\times 10000}{(30-31)\times 86400}$$

$$\left[q_{max}\right] \cong 1.0 \quad lt/s/ha$$

Design of irrigation systems:

- operational requirements
- types of network
- water application methods

to be considered jointly

NO universally accepted design since

- local conditions
- farming habits
- availability of water
- availability of technology
- availability of labor

CHANGE!

Irrigation network types

Irrigation water is distributed to the project area by means of one of the networks such as:

- open channel
- canalet
- pipeline
- sprinklers

- Selection of network type is based on economic analysis.

- Consider simultaneously:
    - available technology
    - labor
    - materials
    - water quality problems
    - operational requirements
    - local conditions
    - availability of water
    - farming habits

- Select the alternative with maximum net benefit

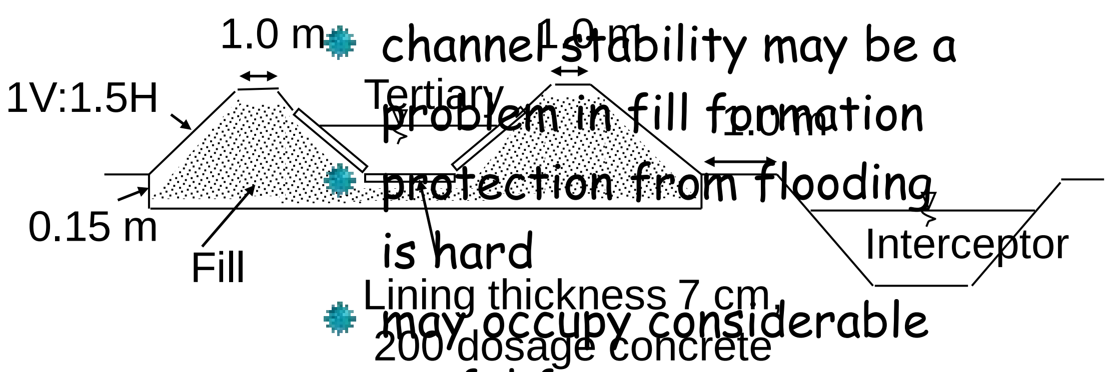
- Classical irrigation-drainage networks → composed of open channels
- irrigation canals → lined
- drainage canals → unlined

ADVANTAGES

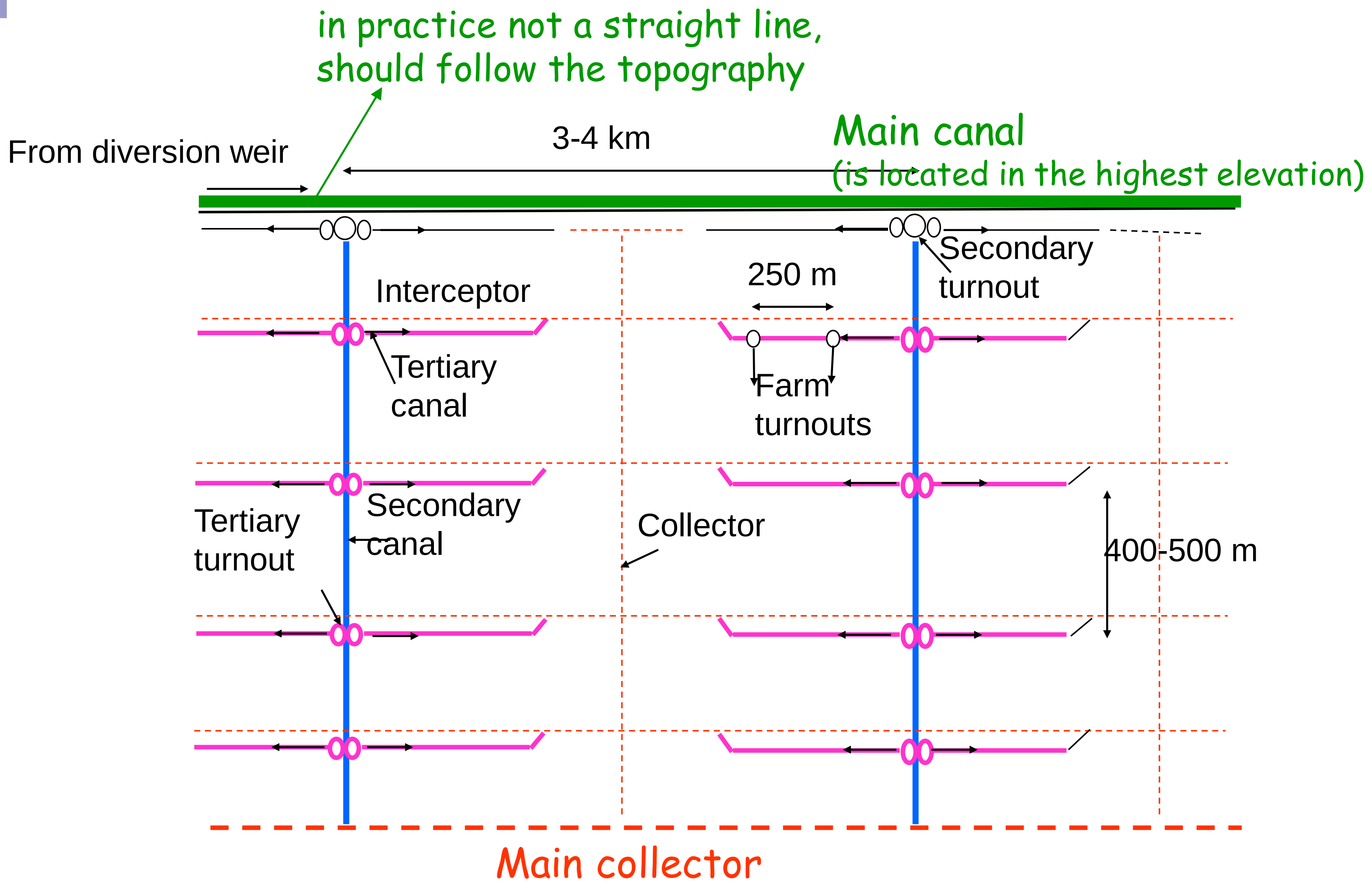
- simple
- easy maintenance

DISADVANTAGES

- channel stability may be a problem in fill formation
- protection from flooding is hard
- may occupy considerable useful farm area



Typical tertiary and interceptor



only pink tertiary canals
supply water to the field

this wall causes the water level to rise
then water is diverted into A

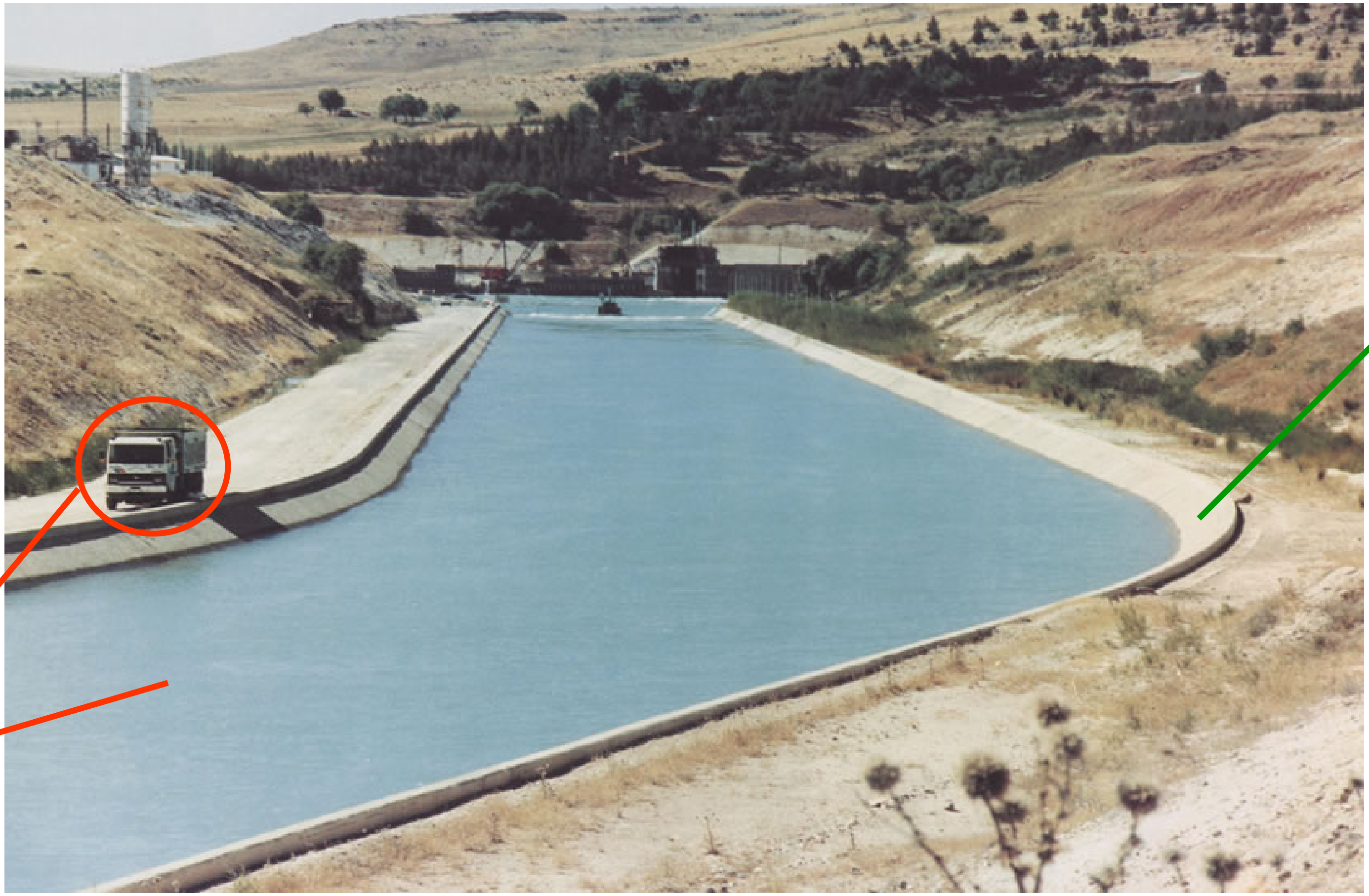
since the water in the river is little downstream is dry

A

goes to the land to be irrigated or to a storage first

Lefke diversion weir in North Cyprus

Aksu (Antalya) diversion weir



occupies a lot of land

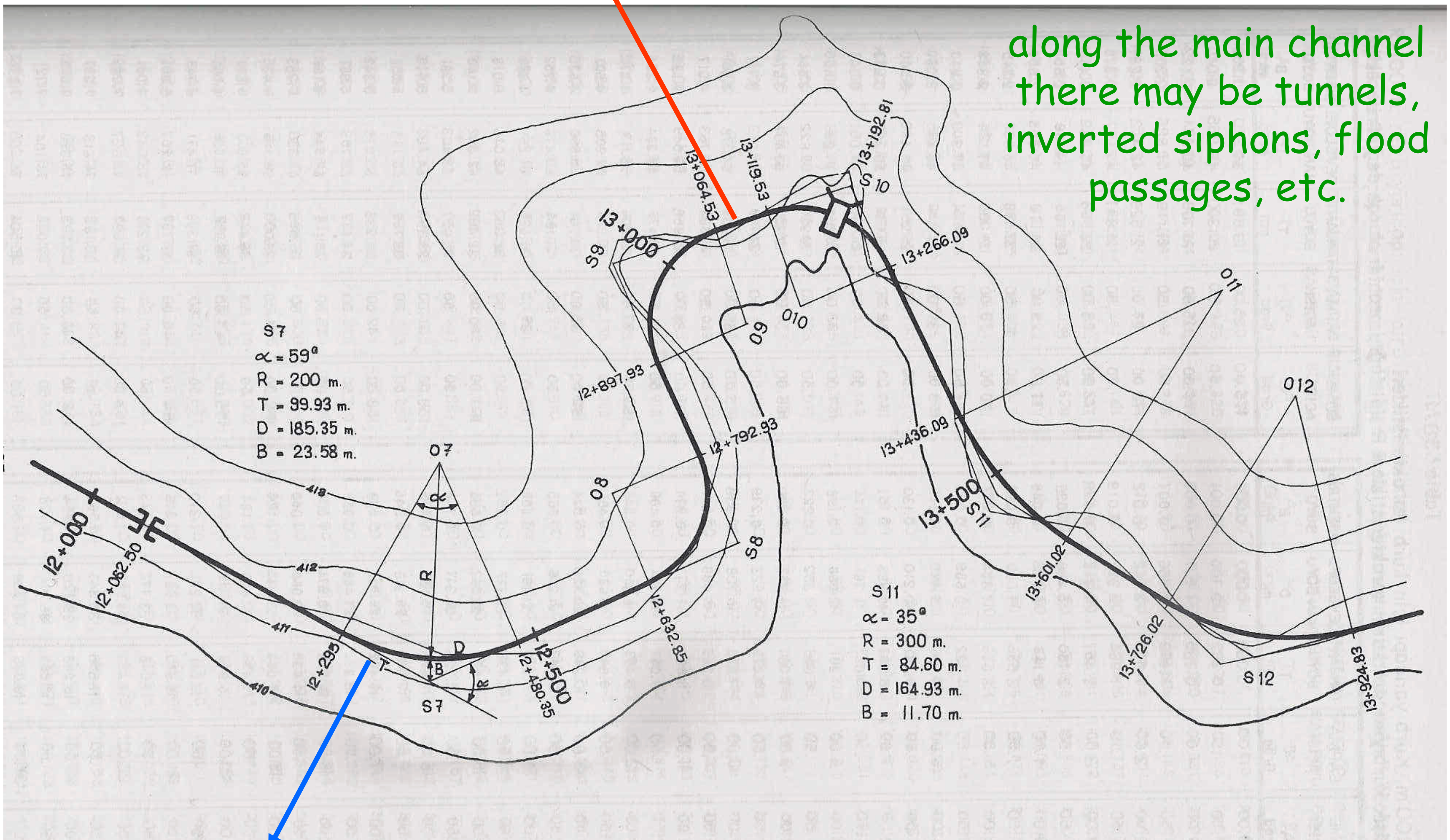
lined

Harran main channel
from Firat to Harran Ovasi

Main channel from Ataturk Dam

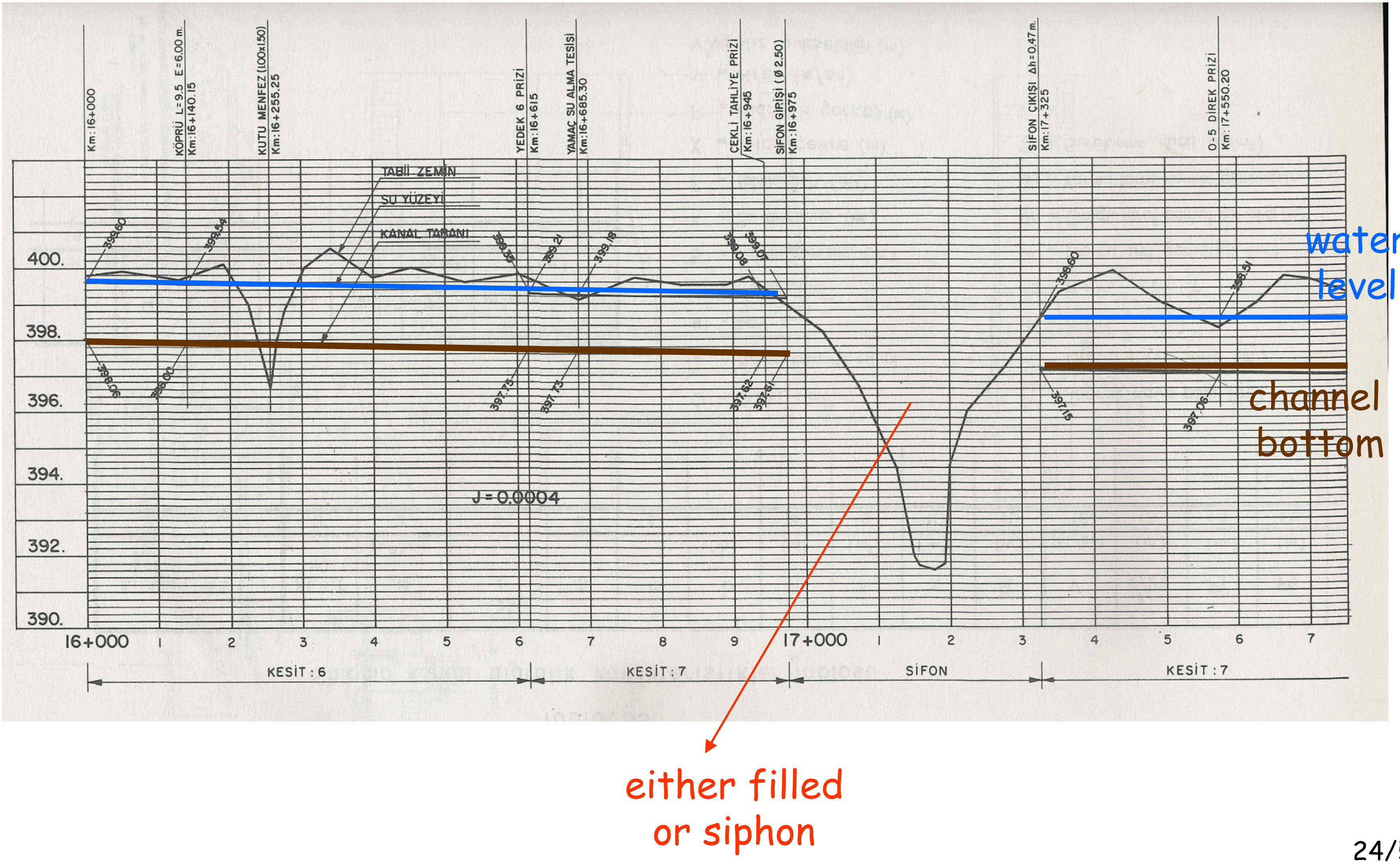
main channel → not straight line, follows the topography

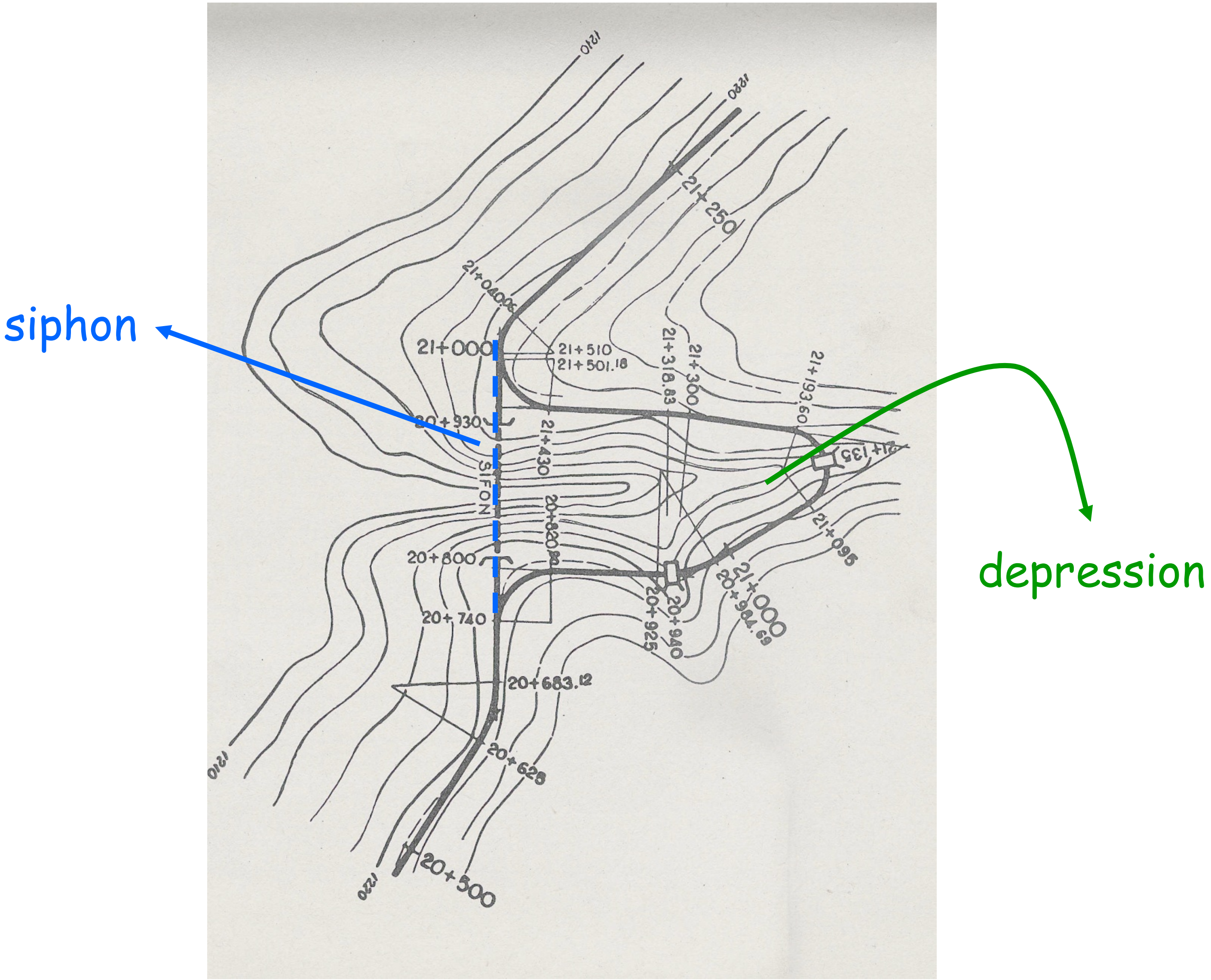
along the main channel there may be tunnels, inverted siphons, flood passages, etc.



the main channel should be located at the highest elevation of the irrigation area parallel to the contour lines

Main channel profile




siphon
depression
1210
1220
21+250
21+040.06
21+000
21+510
21+501.18
21+318.83
21+300
21+193.60
21+135
20+930
21+430
SIFON
20+820.90
20+800
21+095
21+000
20+984.69
20+940
20+925
20+740
20+683.12
20+628
20+500

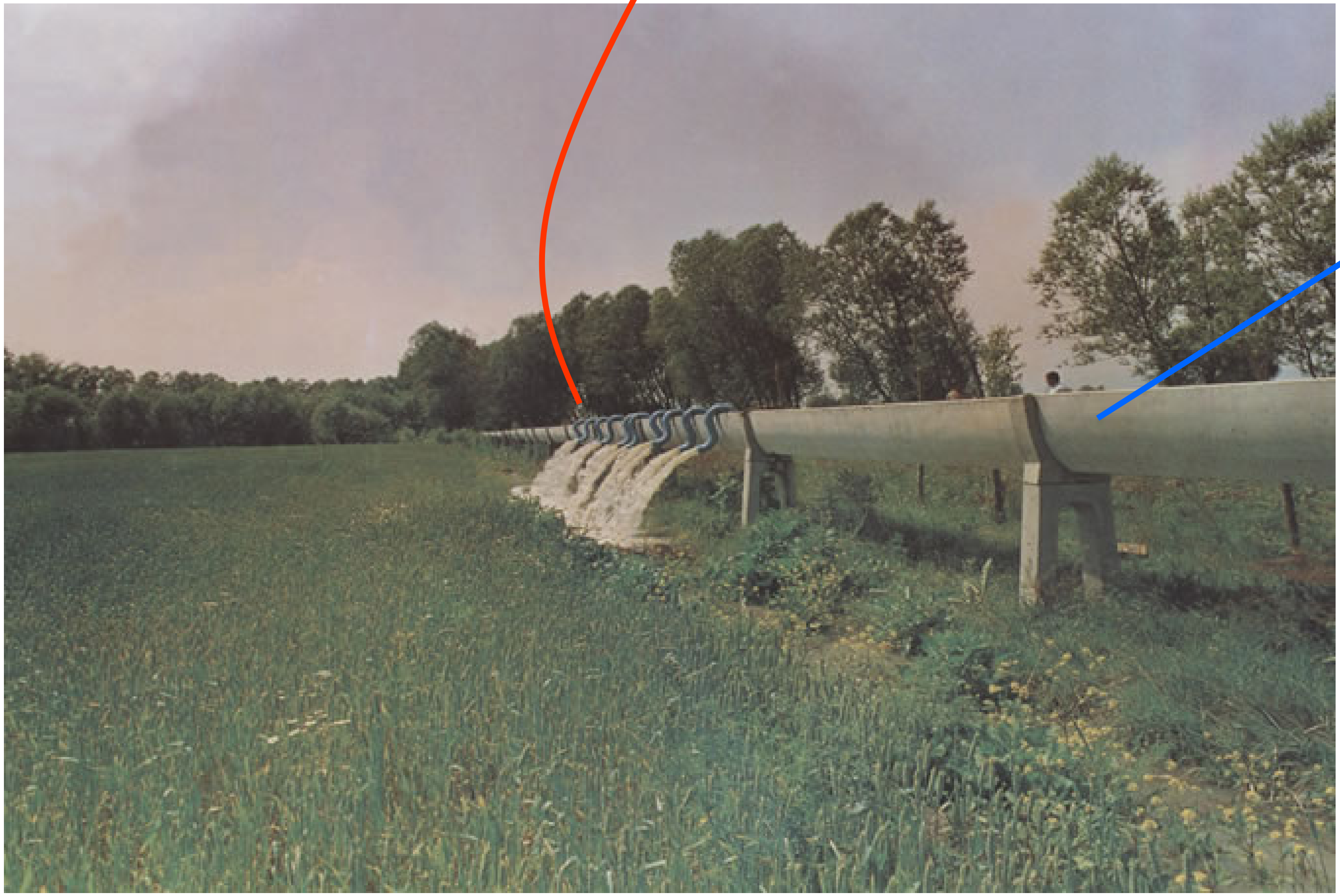
Alternative 1: that goes around the mountain

Alternative 2: tunnel (Cost of tunnel is high)

mountain or hill

portable plastic siphons

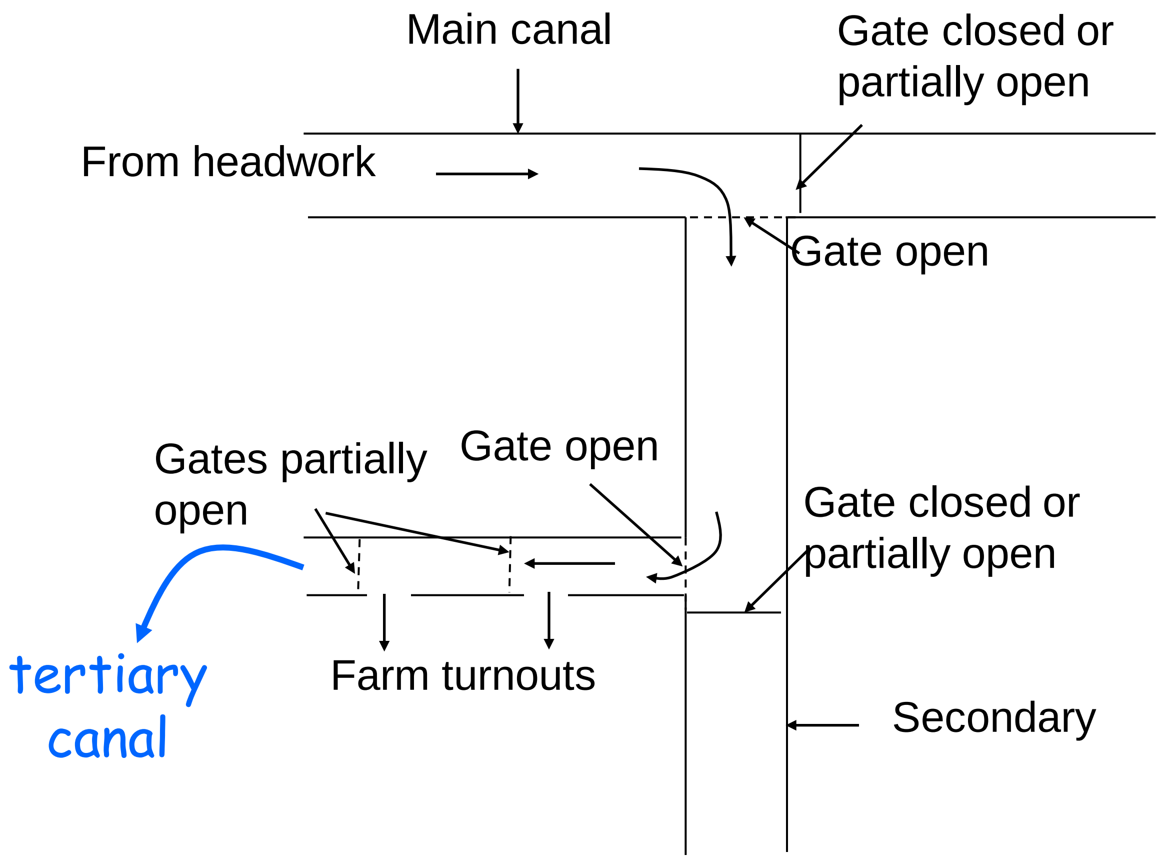
canalet



parcels will be irrigated in turns

Turnout operation

composed of
vertical lift gates



Automation in irrigation canals → increases efficiency

Demand method:

- Determination of design discharge, Q_{des} in irrigation canals
- Based on continuous watering → conservative approach

Assumption:

Max. water demand is continuously available in canals

Derivation:

n = no. of turnouts operating at the same time on a tertiary
q = discharge withdrawn from each turnout (lt/s)
Q_t = nq (at the beginning of a turnout)
Q_c = Aq_{max} (discharge for continuous application)
q_{max} = irrigation modulus (lt/s/ha)

Apply periodic watering with $Q_t > Q_c$

$$nq > Aq_{max}$$

$$nq = FAq_{max}$$

$$Q = AFq_{max}$$

Q_t = required discharge at the beginning of the tertiary

Q_c = discharge to be delivered to an area of A by tertiary

(consider continuous application of max. demand)

Q = canal capacity in lt/s

F = flexibility coefficient (>1.0)

q_{max} = irrigation modulus in lt/s/ha

Read F from Table 10.8 by using q_{max} and A.

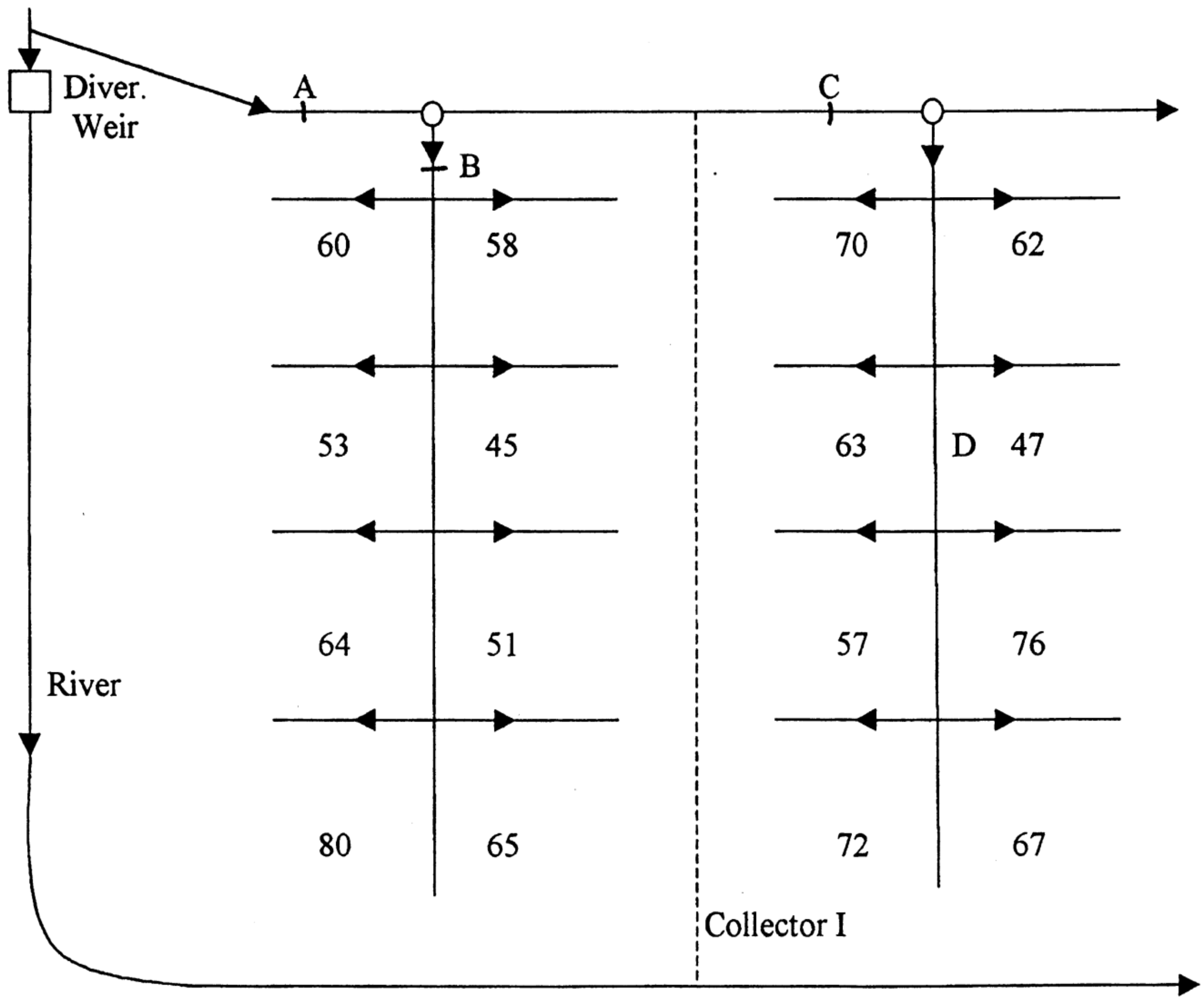
Example 28

Preliminary layout of a classical irrigation - drainage network is shown in figure. Areal crop distribution in the project area is as follows: 25% rice, 35% corn and 30% sugar beet. Rest of the area is kept fallow (empty). The area lies at a latitude of 34° in the northern hemisphere. The irrigation soil is of sandy loam type. The overall irrigation efficiency is 60%. Distribution of effective precipitations and temperatures during the growing season (June 1 and September 30) is as follows:

P_{eff} = 16 mm, 13 mm, 8 mm, 14 mm and t = 20°C, 25°C, 30°C, 27°C, in June, July, August and September, respectively.

a) Determine the capacities of irrigation canals at the points indicated on the figure using demand method.

b) Determine the section dimensions of the trapezoidal irrigation channels at points *A* & *C* having side slopes of 1V:1.5H and bottom widths of b = 1.5 m & 1.0 m (at *A* & *C* respectively). Compute the average flow velocities in the channels. Take S_0 = 0.0006 and n = 0.015.



*All units are in hectares

Solution

Blaney-Criddle Method

$$u_c = 25.4kf$$

$$k = k_1 k_2$$

$$f = \left(\frac{1.8t + 32}{100}\right)P$$

Crop irrigation requirement → $CIR = u_c - P_{eff}$

$$CIR_{total} = 0.25(u_{c_{rice}} - Peff) + 0.35(u_{c_{corn}} - Peff) + 0.30(u_{c_{sugarbeet}} - Peff)$$

Total delivery requirement → $TDR = CIR / e$ (e=60%)

Irrigation modulus → $q_{\max} = \dfrac{TDR_{\max} \times 10000}{(30-31) \times 86400}$

Demand Method → $Q = A \times F \times q_{\max}$ (lt/s)

$$u_c = 25.4kf$$

$$k = k_1 k_2$$

$$f = \left(\frac{1.8t + 32}{100}\right) P$$

Table 10.3

		Table 10.4	k_1			k_2			k			
Month	**t(°C)**	**P**	**Rice**	**Corn**	**Sugar Beet**	**Rice**	**Corn**	**Sugar Beet**	**Rice**	**Corn**	**Sugar Beet**	**f**
June	20	9.70	1.10	0.80	0.70	1.33	0.46	2.42	1.46	0.37	1.70	6.60
July	25	9.88				1.31	1.46	1.92	1.44	1.17	1.34	7.61
August	30	9.33				1.35	1.62	1.00	1.49	1.30	0.70	8.02
September	27	8.36				0.48	1.00	0.42	0.53	0.80	0.30	6.74

**All tables are provided in Yanmaz, A.M.

	U_c=25.4*k*f				Percentage*CIR					
Month	**Rice**	**Corn**	**Sugar Beet**	**P_{eff} (mm)**	**Rice (0.25*CIR)**	**Corn (0.35*CIR)**	**Sugar Beet (0.3*CIR)**	**Total CIR**	**TDR (CIR/e)**	**q_{max} (l/s/ha)**
June	244.75	62.03	284.99	16	57.19 +	16.11 +	80.70 =	154.00 /0.6=	256.66	
July	278.34	226.15	259.01	13	66.34	74.60	73.80	214.74	**357.90**	**1.34**
August	303.52	264.82	142.60	8	73.88	89.89	40.38	204.15	340.25	
September	90.73	136.96	51.36	14	19.18	43.04	11.21	73.43	122.38	

$$CIR = u_c - P_{eff} = 244.75 - 16 = 228.75 \Rightarrow (0.25 \times 228.75) = 57.19$$

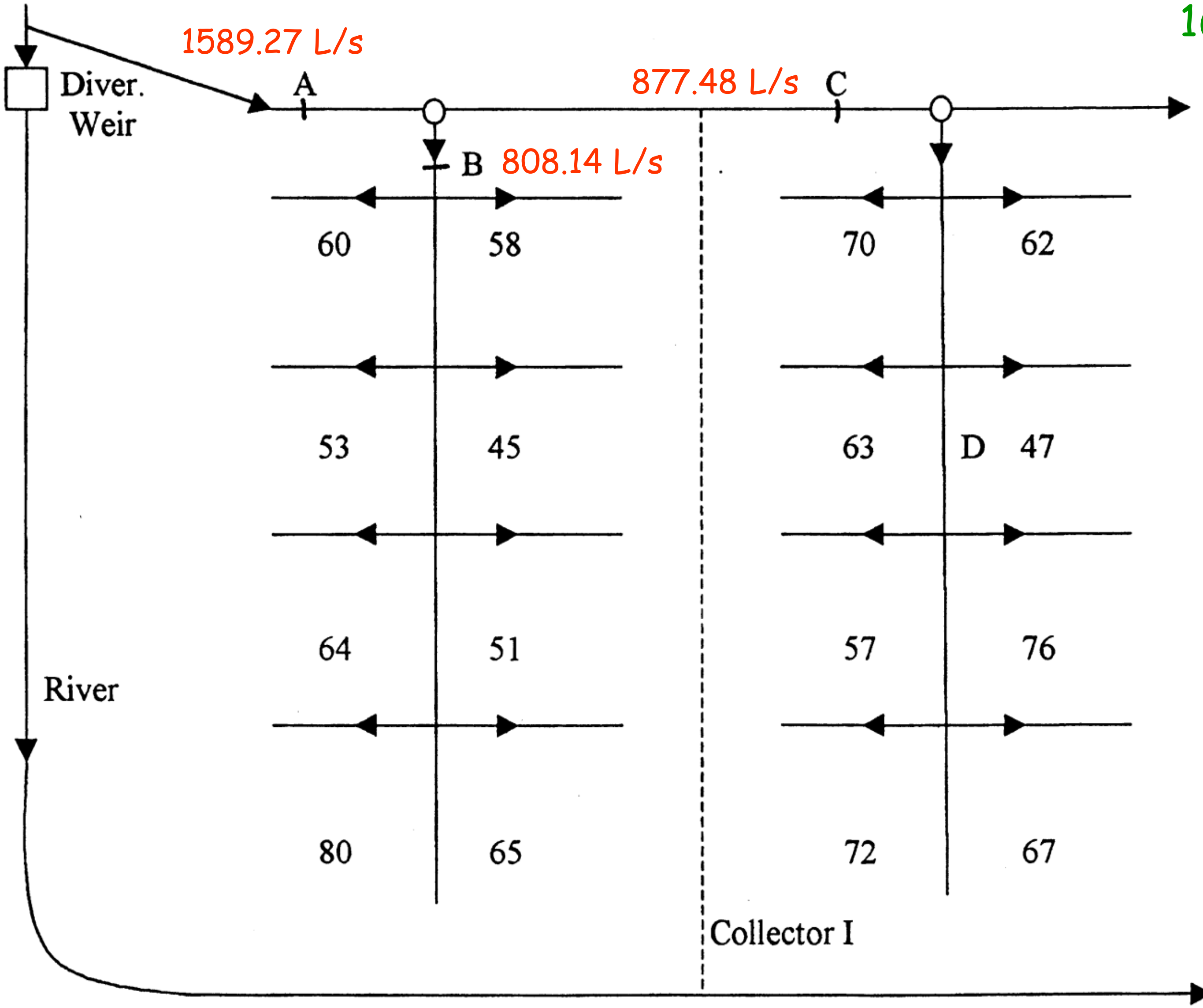
$$q_{max} = \frac{TDR_{max} \times 10000}{(30-31) \times 86400}$$

Table 10.8

Point	Area (ha)	q_{max}	F	Q (lt/s)
A	990	1.34	1.198	1589.27
B	476		1.267	808.14
C	514		1.274	877.48

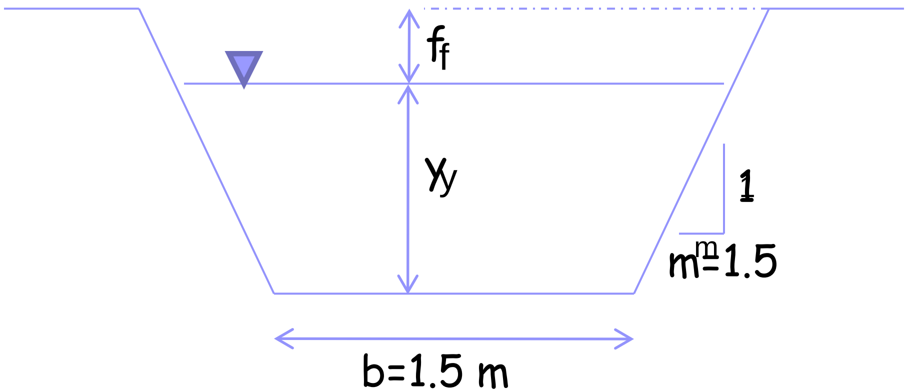
$$Q = A \times F \times q_{max}$$

877.48 + 808.14 =? ~~1589.27 L/s~~ 1685.62 L/s



*All units are in hectares

b)



b

$$A = y(b + my)$$

$$P = b + 2y\sqrt{m^2 + 1}$$

$$f = 0.2(1 + y)$$

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2}$$

m^3/s

For point A

$$b = 1.5\ m, \qquad Q_A = 1.59\ m^3/s$$

$$A = y(1.5 + 1.5y)$$

$$P = 1.5 + 2y\sqrt{1.5^2 + 1} = 1.5 + 3.61y$$

$$1.59 = \frac{1.5y(1+y)}{0.015}\left(\frac{1.5y(1+y)}{1.5+3.61y}\right)^{2/3}\sqrt{0.0006}$$

$$y = 0.68\ m$$

$$f = 0.2(1 + 0.68) = 0.34\ m$$

$$A = 0.68(1.5 + 1.5 \times 0.68) = 1.71\ m^2$$

$$u_A = Q_A / A_A = 0.78\ m/s$$

$$0.5\ m/s < u_A < 2.5\ m/s$$

For point C;

$$b = 1.0\ m$$

$$Q_C = 0.88\ m^3/s$$

$$A = y(1.0 + 1.5y)$$

$$P = 1.0 + 2y\sqrt{1.5^2 + 1} = 1.0 + 3.61y$$

$$0.88 = \frac{y(1.0+1.5y)}{0.015}\left(\frac{y(1.0+1.5y)}{1.0+3.61y}\right)^{2/3}\sqrt{0.0006}$$

$$y = 0.61\ m$$

$$f = 0.2(1 + 0.61) = 0.32\ m$$

$$A = 0.61(1.0 + 1.5 \times 0.61) = 1.17\ m^2$$

$$u_C = Q_C / A_C = 0.75\ m/s$$

$$0.5\ m/s < u_C < 2.5\ m/s$$

Planning & Design of Classical Irrigation-Drainage Systems

- land classification → ignore lands w/ excessive problems
- estimation of water demand for selected crop pattern
  - considering soil type, climate
- comparison of supply and demand
- consideration of water quality requirements
  - with less salt & sand content
- design of water storage or diversion facilities
  - location & size
- selection and design of irrigation distribution network
- organizational establishment for operation/maintenance

DRAINAGE of Irrigated Lands

- Nature of drainage problems:
  - highways
  - airports
  - urban areas
  - irrigated lands

  drainage facilities are designed for these areas to cope with excess surface runoff

Implementation of proper drainage facilities

⇩

better physical & environmental conditions

- Removal of excess water: aeration of root zone and leaching of salts
- Drainage of irrigated land → removal of excess water, which exists either on the surface of the soil or in the root zone

Sources of Excess Water:

excess water can exist → on the surface of the soil
→ in the root

- Seepage losses from reservoirs or canals
- Operational wastes in irrigation systems
- Surface runoff losses due to excessive slope
- Highly impervious surface soil
- Deep percolation losses from irrigated lands
- Excess water from irrigation ~ 0.05 x FDR
- Operational wastes ~ 0.10 x TDR

loss of irrigation water often is gain to drainage water

Although advanced irrigation techniques ↓ need of drainage
excess storm water should still be removed

Surface Drainage

effective in collecting storm runoff & ww from irrigation

- Capacity determination: Select proper return period, T_r
- Classical surface drainage networks:
  - interceptors, $T_r \approx 2$ years
  - collectors, $T_r \approx 10$ years
  - main collectors, $T_r \approx 25$ years

a surface runoff of a flood having a return period of 2 yrs is considered as the design discharge of the interceptor

- Components of capacity:
  - excess water from irrigation
  - operational wastes
  - emergency release, ~TDR (total delivery requirement)
  - storm water

- During storms no irrigation water is applied to the field !
- Storm water >> other capacity components
- $\therefore Q_{des}$ = Storm runoff → reasonable assumption

Modeling of storm runoff:

- advanced hydrologic simulations
- use of simple rainfall/runoff relations
- Rational method
- MacMath's method
- use of synthetic UH's

McMath's Method → widely used in Turkey

Applicable to flat terrains of any size

The peak drainage discharge, Q_p:

$$Q_p = 0.0023 C i S^{1/5} A^{4/5}$$

C = runoff coefficient= $C_1+C_2+C_3$

C_1 = effect of vegetal cover

C_2 = effect of soil type

C_3 = effect of topographic characteristics

S = $1000S_0$

S_0 = bed slope of drainage channel

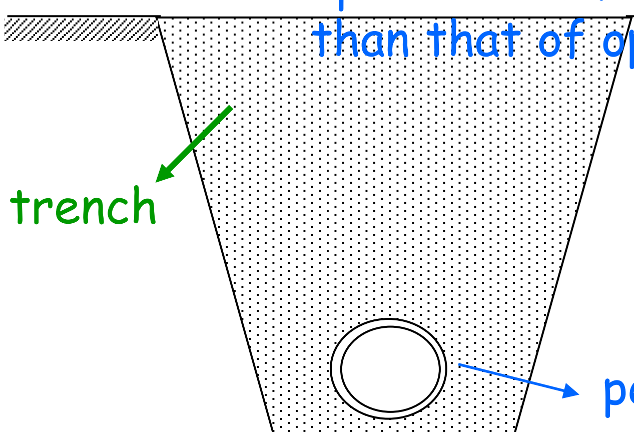
A = area to be drained in ha

i = rainfall intensity in mm/hr ← from intensity-duration-frequency curves

Subsurface Drainage

- Elevation of groundwater table relative to soil surface?
- Monitoring the elevation of GWT → Level of drainage
- Remedial measures:
  - use of deep surface drains (open ditches) → net effective area for cultivation is ↓ed & farming instruments cannot be operated effectively
  - use of wells → drilling & operation is expensive
  - use of subsurface drains

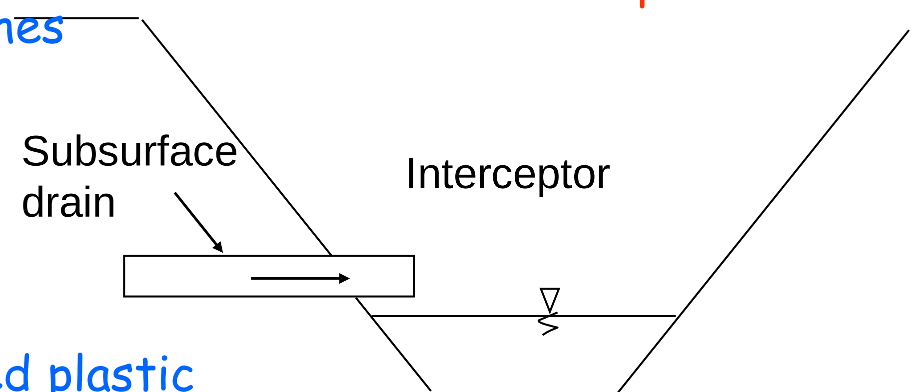
    preferred! initial cost is high but operation & maint. costs are lower than that of open ditches



trench

perforated plastic or concrete drain

connection of a drain with an interceptor

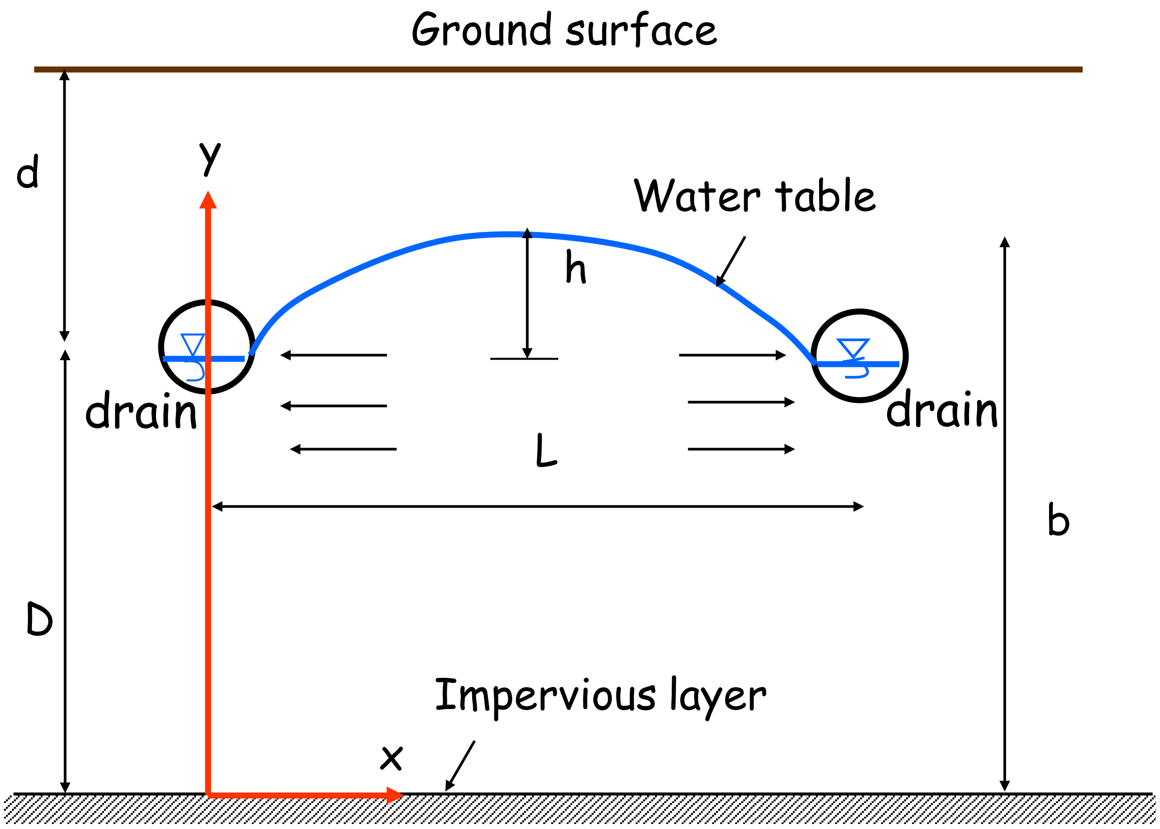


- Selection of proper depth & spacing for subsurface drains:
  - soil permeability
  - type of crop
  - application method of irrigation water

- The common practice:
  - Select a value for the depth of drain, d, from Table (next page)
  - Estimate the hydraulic conductivity of soil, K
  - Estimate a drainage rate
  - Determine spacing between two successive drains, L

Average depth & spacing for subsurface drains

Soil	Class	K (mm/hr) conductivity	L (m) spacing	d (cm) depth
Clay	Very slow	1	9-15	90-110
Clay loam	Slow	1-5	12-21	90-110
Loam	Moderately slow	5-20	18-30	110-120
Fine sandy loam	Moderate	20-65	30-37	120-140
Sandy loam	Moderately rapid	65-130	30-60	120-150
Peat	Rapid	130-250	30-90	120-150
Irrigated soil	Variable	250-25000	45-180	150-240


Ground surface
d
y
Water table
h
drain
drain
L
b
D
Impervious layer
x

Steady-State Subsurface Drainage

- Valid under hypothetical conditions of
  - constant rate of rainfall or irrigation water
  - uniform drainage at all distances from the drain

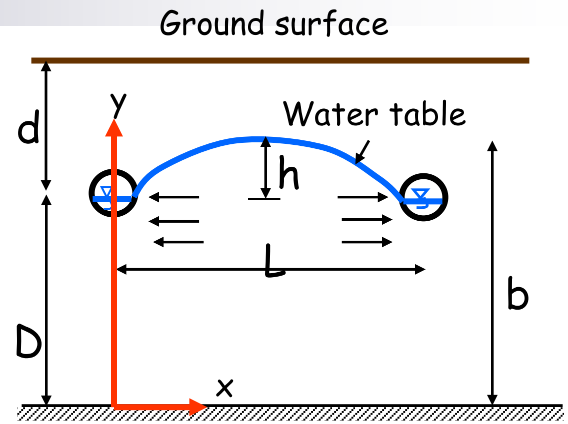
water table shape b/w two drains is invariant

i.e. $\frac{\partial h}{\partial t} = 0$

Assumptions to obtain the formula for L

- Homogenous soil, K=constant
- The drains are evenly spaced a distance L apart
- i = dy/dx (hyd. gradient at any pt = slope of water table above that pt)
- Darcy's law is valid for flow of water through soils
- An impermeable layer underlies the drain at a depth
- Irrigation (rainfall) water is applied at q = constant

Donnan's equation:



Darcy's law:

$$q_x = KAi$$

q_x = flow contributing to the drains in x-direction
K = hydraulic conductivity
A = flow area
i = hydraulic gradient = dy/dx

At x = L/2, i = dy/dx = 0, and hence $q_x = 0$

Linear variation for q_x:

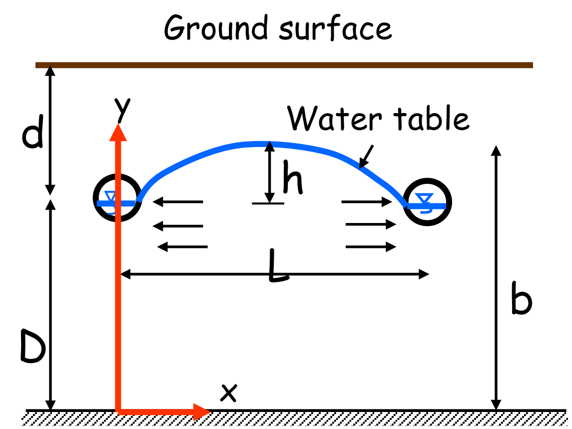
$$q_x = \left(\frac{L}{2} - x\right) q$$

q = rate of rainfall or irrigatio water application

$$\left(\frac{L}{2}-x\right)q = Ky\frac{dy}{dx}$$

$$\int\left(\frac{L}{2}-x\right)qdx = \int Kydy$$

$$\frac{L}{2}qx - q\frac{x^2}{2} = K\frac{y^2}{2} + C$$



Apply boundary conditions to obtain C:

x = 0, y = D & x = L/2, y = b $\Rightarrow$ C= - $KD^2/2$

$$L^2 = \frac{4K\left(b^2 - D^2\right)}{q}$$

Donnan's Equation

Limitation:

- convergence of flow lines near the drains is ignored
- suitable for large L/D

What is the total amount of water that drains to each subsurface drainage pipe?

$$\int_0^{L/2}\left(\frac{L}{2}-x\right)q\;dx=\left(\frac{L}{2}qx-\frac{1}{2}qx^2\right)\Bigg|_0^{L/2}$$

$$=\frac{L}{2}q\frac{L}{2}-\frac{1}{2}q\left(\frac{L}{2}\right)^2$$

$$=q\left(\frac{L^2}{4}-\frac{1}{2}\frac{L^2}{4}\right)$$

$$=q\frac{L^2}{8}$$

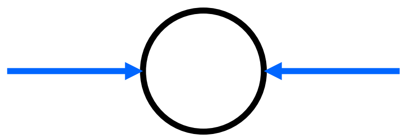
$$\int_D^b Ky\;dy=\left(K\frac{1}{2}y^2\right)\Bigg|_D^b$$

$$=\frac{K}{2}b^2-\frac{K}{2}D^2$$

$$q\frac{L^2}{8}=\frac{K}{2}\left(b^2-D^2\right)$$

$$L^2=\frac{4K}{q}\left(b^2-D^2\right)$$

$$q_x=q\frac{L}{2}$$



$$q_x=q\frac{L}{2}$$

Total flow rate into the pipe per unit length = qL