Irrigation and Drainage Engineering

(Soil Water Regime Management)

(ENV-549, A.Y. 2025-26)

4ETCS, Master option

Prof. Paolo Perona
Platform of Hydraulic Constructions

Lecture 2-2: Irrigation concepts and basis for network design. Gravity irrigation

Irrigation practice

$$B_n = ETM - Pe - R = K_c\, ET_o - \alpha P - R$$

B_n: net irrigation water requirements

ETM: maximum evapotranspiration

P_e: effective precipitation

R: reserve available at the start of the calculation period

K_c: crop coefficient

ET_0: reference evapotranspiration

α : rainfall reduction coefficient

P: total rainfall

- *Irrigation not continuous, but intermittent*
- *Root zone = reservoir characterised by critical thresholds:* θ_{fc} *and* θ_{twp} (θ_{pwp} if plant under stress)

➔ ***need to define some irrigation practice parameters***

- flow rate to be supplied to the operator
- dose to be applied
- frequency of irrigation
- duration of irrigation, etc.

Scoping studies

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

- a study of soil characteristics (to determine the hydrodynamic properties of the soil)

- a hydrological study (to determine the quantities of water available);

- a geological study (particularly necessary for gravity networks, in which water is transported by canals that rest on the ground);

- a topographical survey on an appropriate scale (1/500, 1/1000 or 1/2000, important for sprinkler and localised irrigation);

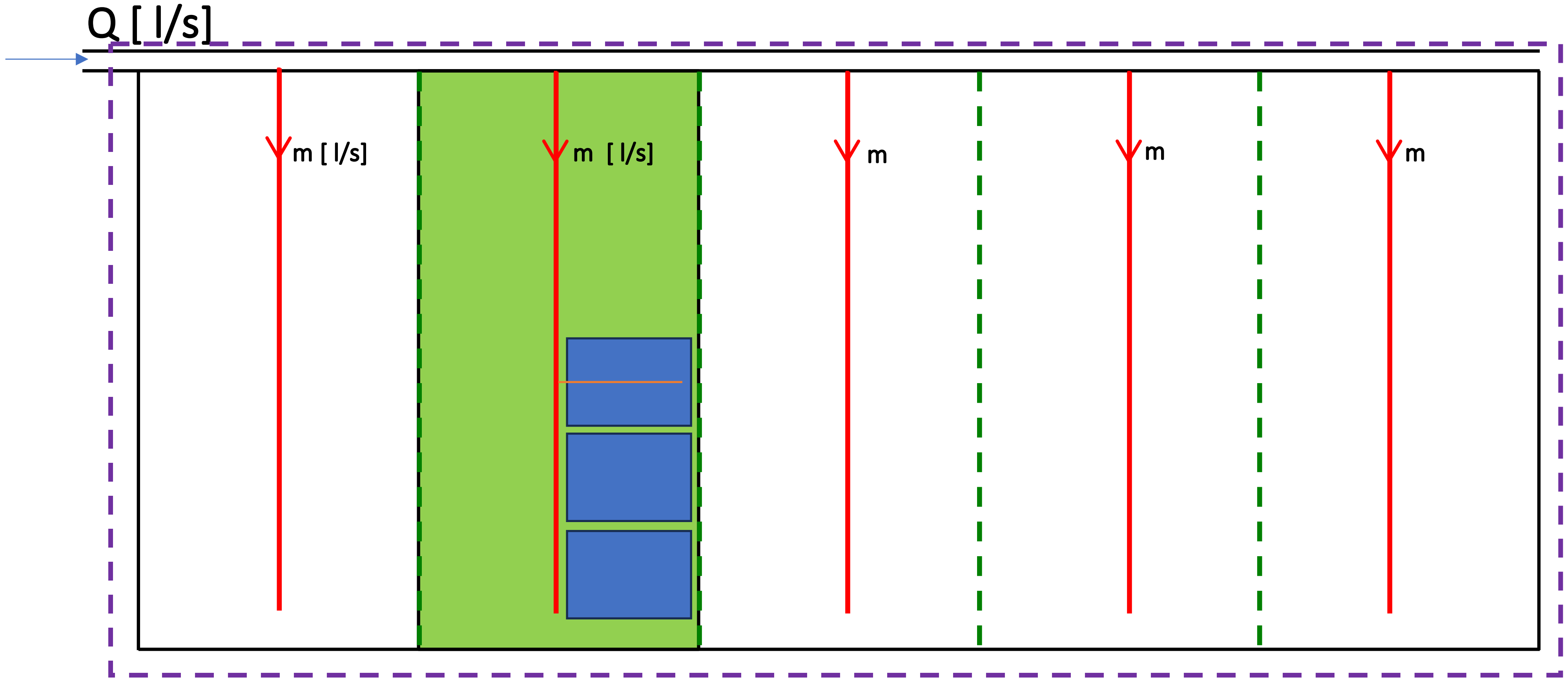
- a study of the quality of the water (physical, chemical and biological);

- a collection of climatic data and analyses (to assess crop water requirements);

- gathering information on the crops envisaged (i.e., type of crop, rotation, cropping calendar, root depth, resistance to salts, etc.)

- a socio-economic study (nature of the crops grown in the region, degree of adaptability of the farmers, etc)

Geometry of irrigated perimeters



Irrigated perimeter

District (or quartier)

Plot (or parcel)

Effective water need

$$B = \frac{B_n}{E}$$

B : effective (or actual) irrigation water need over the considered period (1 month, 1 decade, 1 day, etc.), in mm or m^3/ha

B_n : net water need (result of the water balance), in mm or m^3/ha

E : global irrigation efficiency

The concept of efficiency

Considerable losses occur when water is transported and distributed to the plot (or parcel)

Causes :

- poor management of irrigation practice
- inadequate infrastructures
- inadequate maintenance
- poor institutional organisation
- inadequate training of farmers
- Inadequate timing (e.g., evaporation)
- etc.

World global efficiency: around 40%!

Global efficiency

E = *f* (type of irrigation, nature of soil, topography, etc.)

$$E = \frac{volume\ of\ water\ used\ by\ plants}{Total\ volume\ of\ water\ delivered\ to\ the\ irrigation\ network}$$

$$\mathbf{E = e_t\ e}$$

e_t : water transport efficiency

e : parcel/plot delivery efficiency

<u>Proof</u>

$e_t = (V_{ir}-V_t)/V_{ir}$ V_t : transport losses, V_{ir} : total delivered water volume

$e = (V_{ir}-V_t-V_p)/(V_{ir}-V_t) = V_{vég}/(V_{ir}-V_t)$ V_p : losses at the parcel, $V_{vég}$: water volume used by plants

$E = V_{vég}/V_{ir}=(V_{ir}-V_t)e/(V_{ir}-V_t)/e_t=e\ e_t$

Furrow irrigation

Sprinkler irrigation

Micro-irrigation

Indicative values of E :

- Gravity Irrigation :
  - Sandy soil 30 – 40 %
  - Silt soil 50 – 60 %
  - Clay Soil 60 – 65 %
- Sprinkler : 65 < E < 85 %
- Micro-irrigation : 85 < E < 95 %

Characteristic flowrates

- *Mean flowrate Q (m³/s) over the whole period being considered*

$$Q = \frac{V}{t} = \frac{B\,S}{t} = \frac{B\,S}{N\,J\,3600}$$

Q: flow rate, in m3/s

V: volume of irrigation water to be supplied, in m3

t: network operating time during the period under consideration, in s

B: effective requirements, in m3/ha

S: area to be irrigated, in ha

N: number of hours of daily irrigation

J: number of days of irrigation during the period in question

- *Mean flowrate Q_p in the peak period (m³/s)*

$$Q_p = \frac{V_p}{t} = \frac{B_p\,S}{N\,J\,3600}$$

V_p: volume of irrigation water to be supplied during the peak period, in m3

B_p: effective requirements for the peak period, in m3/ha

Characteristic flow

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

- *Specific peak flowrate q_p (m^3/s ha)*

$$q_p = \frac{B_p}{N\,J\,3600} = \frac{B_p}{t}$$

t : functioning duration of the irrigaiton networkw at peak flowrate, in s

- *Fictitious continuos flowrate q (m^3/s ha)*

$$q = \frac{B}{T'} = \frac{B}{J'\;86400}$$

B : effective needs during the considered period, in m^3/ha

T' : total duration of the considered period, in s

J' : total number of days of the considered period

Peak period, our climate (increasing) : 0.3 < q < 1.0 l/s ha

Irrigation dose

KEY question: How much water (volume/area)?

Maximal irrigation Dose

$$D_n = RAW = (\theta_{fc} - \theta_{twp}) * z_r$$

D_n : maximal net dose, in mm

θ_{fc} : soil retention capactiy (field capacity), in m^3/m^3

θ_{twp}: temporary wilting point, in m^3/m^3

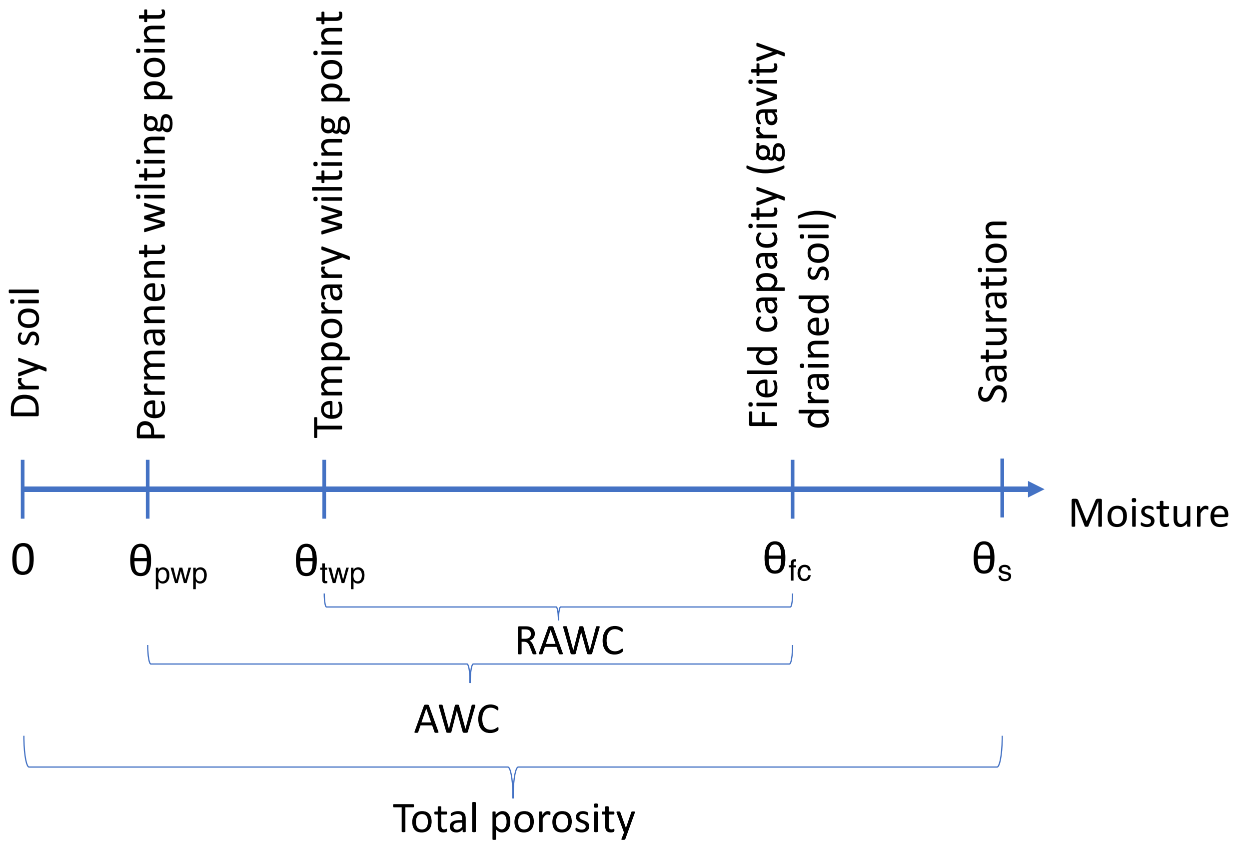
z_r : root depth zone, in mm

$$D_b = \frac{D_n}{e}$$

D_b : Maximal actual (gross) irrigation dose, in mm

e : plot (or parcel) delivery efficiency

Remember the scheme in Lecture 2-1



Irrigation frequency

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

$$n = \frac{B_n}{D_n}$$

KEY question: How often should we provide the irrigation dose?

n : number of gross irrigation doses during the considered period*

B_n : net water needs during the considered period, in mm

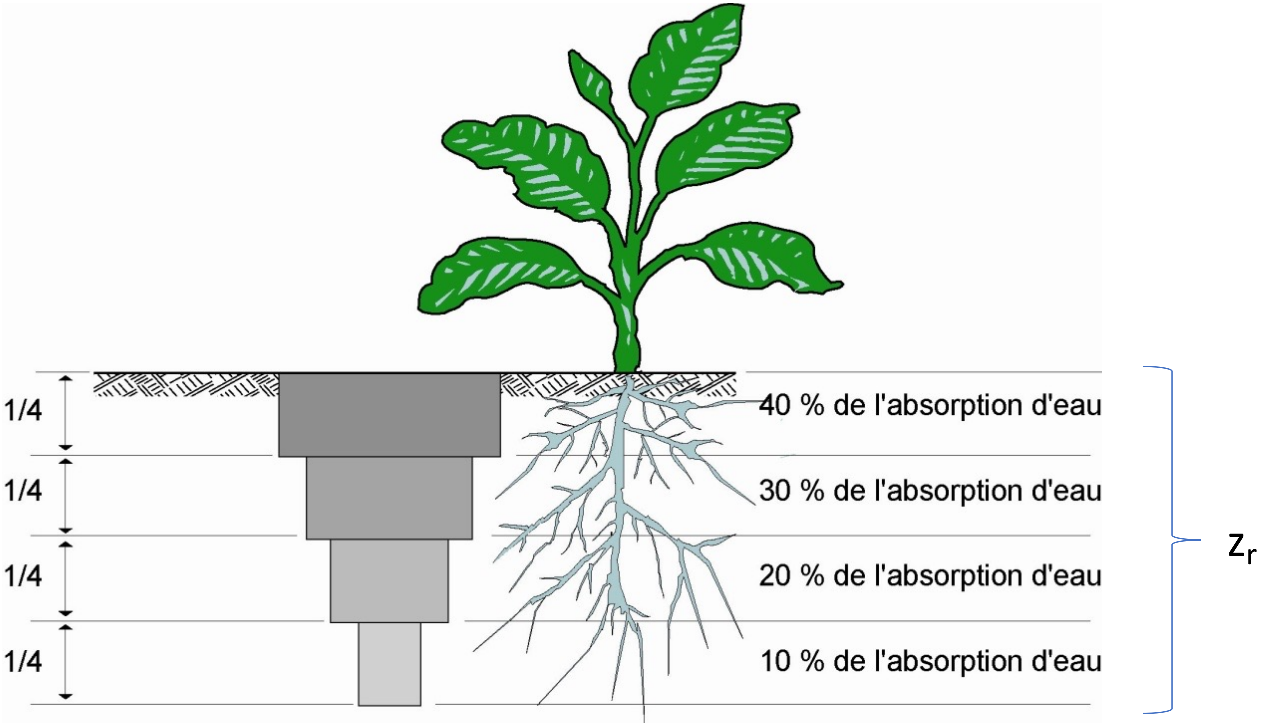
D_n : net irrigation dose, in mm

➔ *n is rounded up to the nearest unit and the actual dose is reduced accordingly*

*** It is indifferent the use of the net or the actual dose, given that both the dose and the needs will be divided by the efficiency at the plot**

Example: Net requirements: 100 mm and net dose: 30 mm, i.e.: n = 3.33 n rounded to 4 or more and dose = 25 mm or less (e.g., 20 mm if n is 5)

Rooting depth to consider (general assumption)



*Schematic representation of root vertical distribution in soil**

In general, irrigation that moistens the soil to a depth of 60 to 120 cm is considered sufficient for most crops.

Indicative values for z_r :

- **Shallow roots (30 - 60 cm)** — **vegetable crops, lawns, meadows**
- **Medium depth (60 - 120 cm)** — **cereals, tomatoes, carrots**
- **Deep (1 - 2 m)** — **fruit trees, vines, cotton**

* **Notice**: We have shown that the vertical density root profile is not necessarily exponential and may show a mode. Actual research tries to take this aspect better into account

Handling flowrate (main d'eau)

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

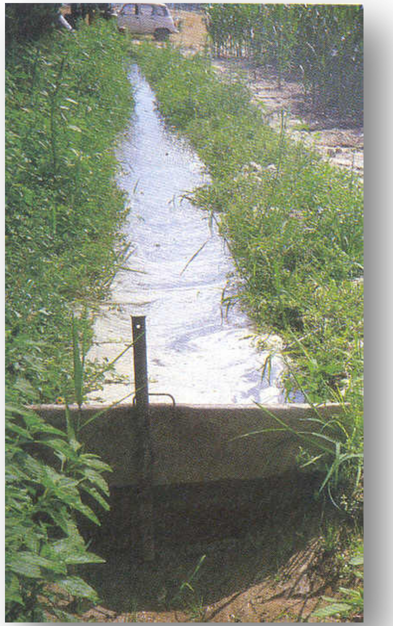
Concept: it defines the flowrate allocated to the irrigation manager (usually delivered at the district zone and then distributed to the plots)

Its value depends on many (not only physical) factors:

- the irrigator's skill
- type of irrigation (furrow, submersion, etc.)
- soil type (max infiltration rate) and topography (e.g., slope)
- plots size
- etc.

Typical values range between

10 < m < 100 l/s



Distribution ditch

Duration of irrigaton

It defines the minimal duration needed to water a parcel (or plot), i.e. more precisely:

This is the time required to apply the gross irrigation dose D_b to the surface area S of a plot with a flow rate equal to the handling flowrate m

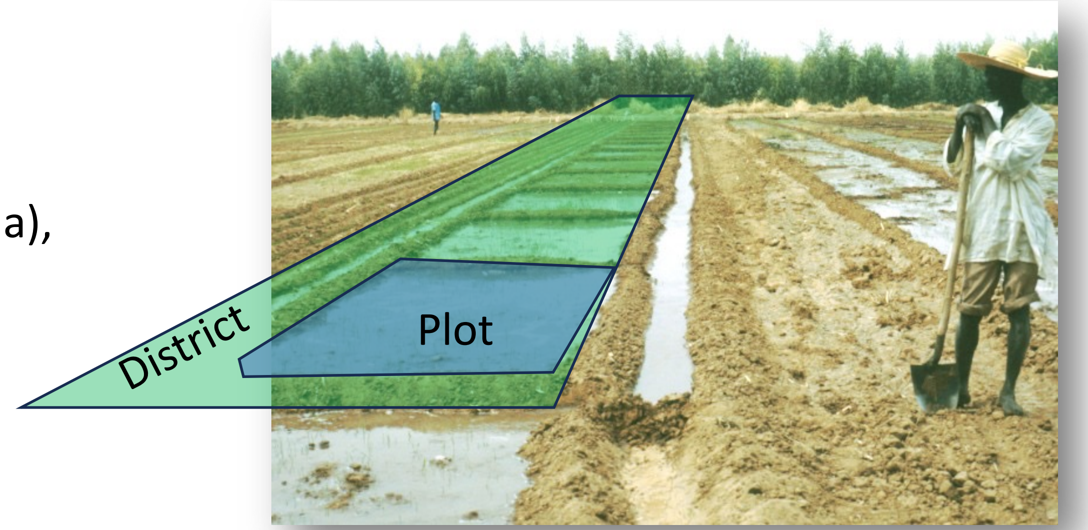
$$t = \frac{D_b\, S}{m}$$

t : time required to apply the dose to the surface S (ha), in s

D_b : Gross irrigation dose, in m^3/ha

S : plot surface, in ha

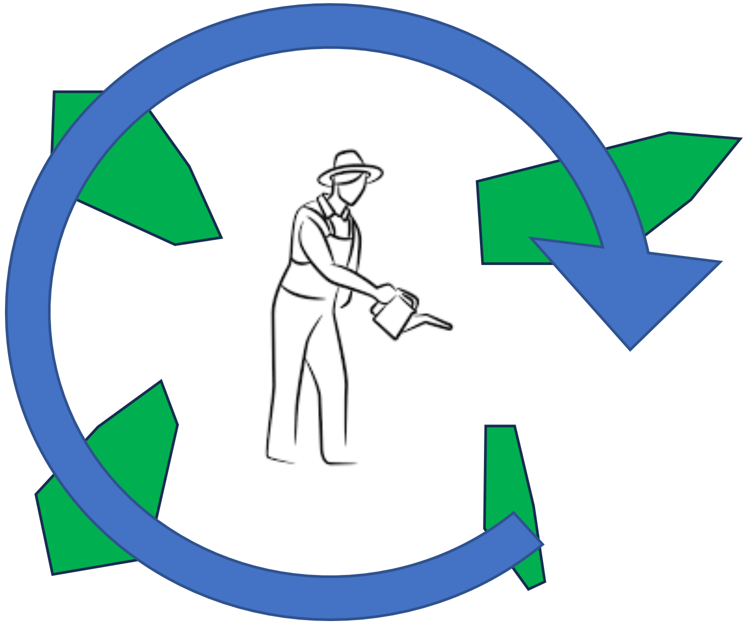
m : handling flowrate, in m^3/s



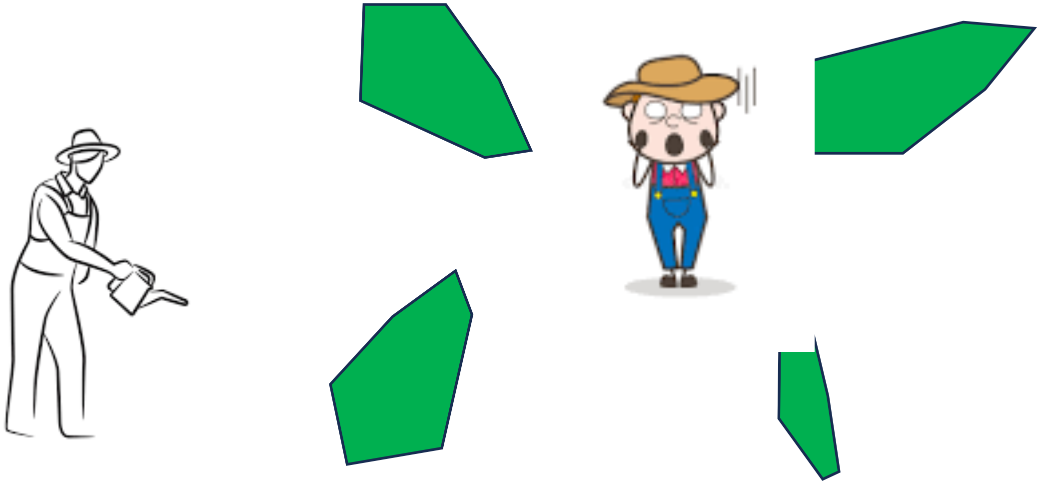
Types of water allocation

Essentially, there are two types:

1) Distribution by rotation



2) Distribution on demand



Distribution by rotation

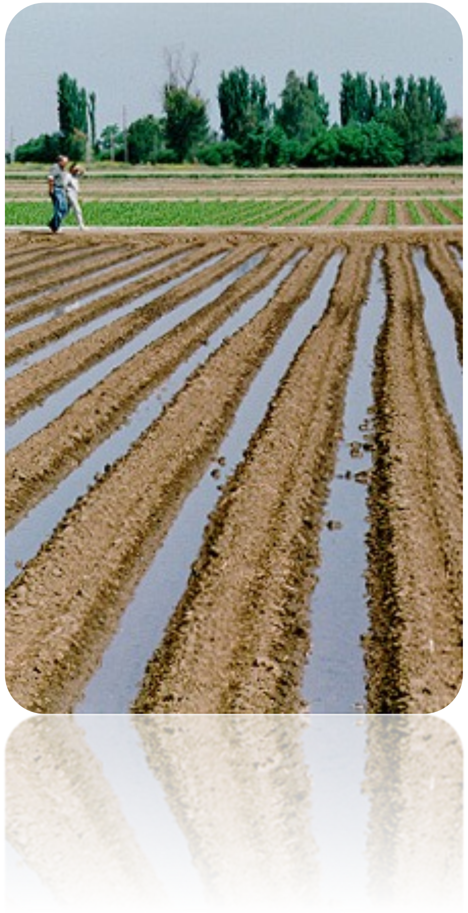
The plots within the irrigated surface (district or quartier) receive water:

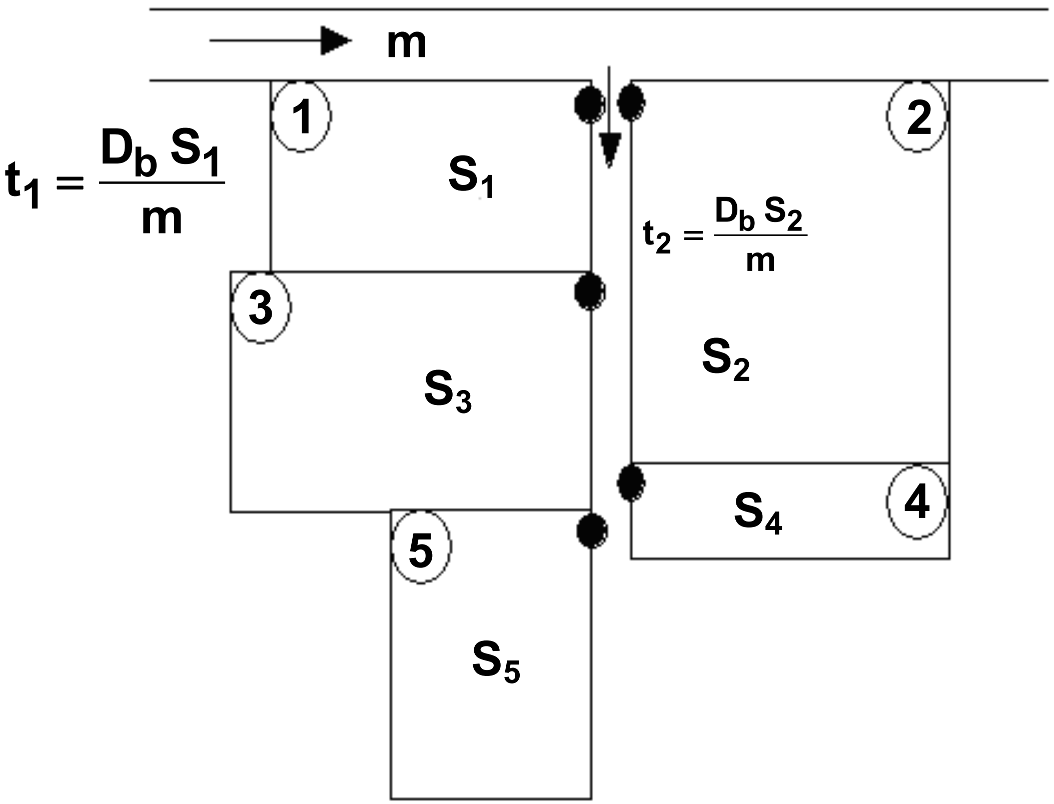
- periodically (frequency or number of times, n, to deliver the total need B in doses, D)
- for a given period of time t (depending on their surface area, S)
- according to a given flow rate (handling water, m)

The time interval between two successive waterings of the same plot is called the rotation.

Several plots are supplied by the same canal, which carries a flow rate equal to the amount of water used, e.g., m. From this canal, a maximum surface area can be irrigated, known as a district (or quartier).

The effective duration of irrigation for a district during a rotation is the water turnover.





Distribution by rotation

Distribution by rotation

Surface of a district (or quartier) S' (ha)

Maximum surface area that can be watered

from a canal carrying the handling flow m

$$S' = \frac{m}{q_p}$$

m : handling flow, en l/s

q_p : specific peak flowrate, en l/s ha

Volume d'eau V_p nécessaire pour arroser une surface S' en période de pointe : $V_p = B_p \, S'$

Volume of water V available in the canal during the peak period : $V = m\,t$

t : duration of canal functioning during the peak period, in s

Maximum surface area S' that can be watered at peak times from a canal fed by a handling flow (Vp = V) :

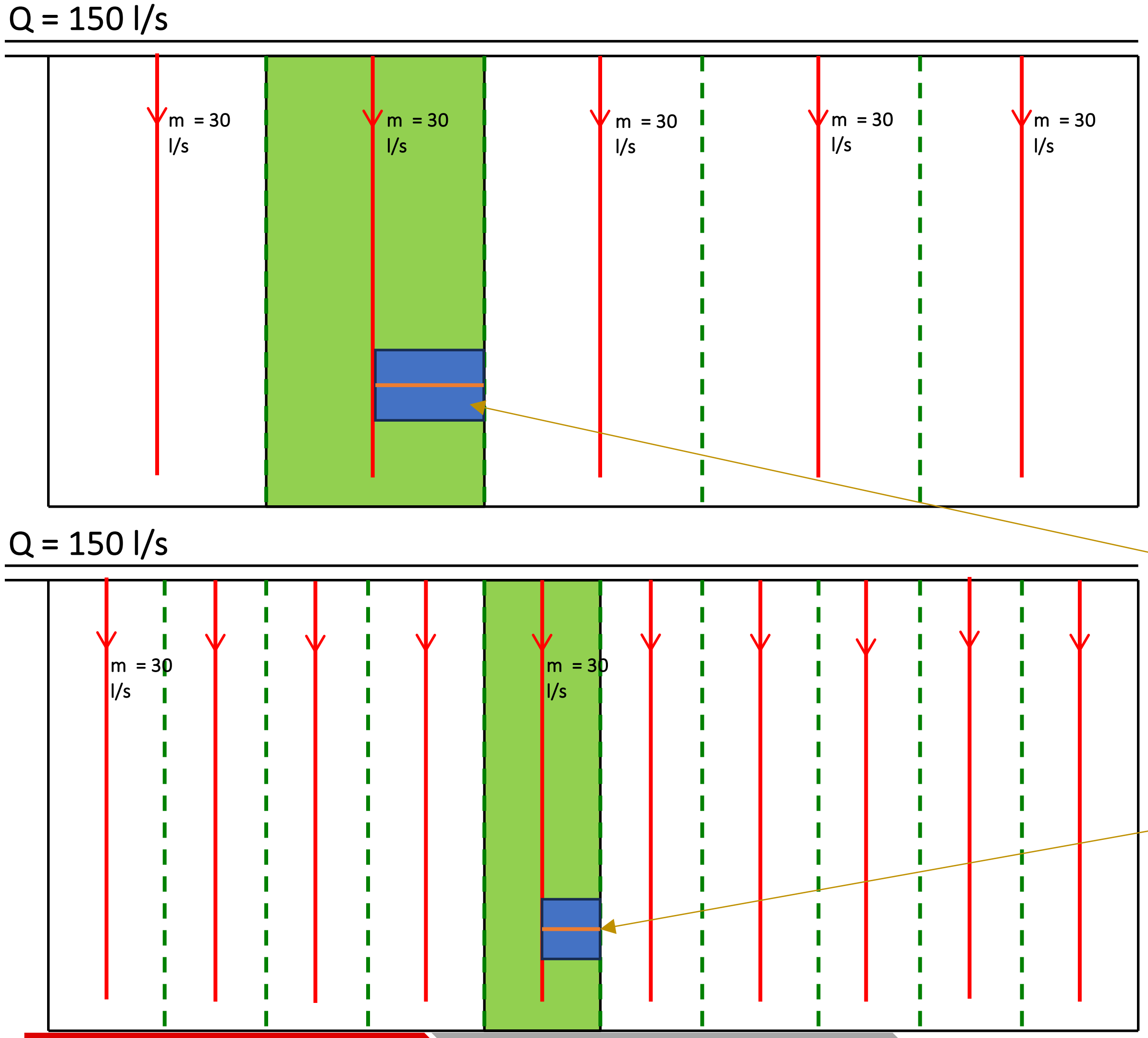
$$S' = \frac{m\,t}{B_p} = \frac{m}{q_p} \qquad q_p = \frac{B_p}{t}$$

Layout of the canals according to the surface area of the districts

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Area of perimeter S: 100 ha ; Area of district S': 20 ha → minimum 5 canals

Flow rate m of secondary canals: 30 l/s → flow rate of main canal 150 l/s



Secondary canals

Limits of areas served by secondary canals

Surface area served by a secondary canal

5 Canals solution

10 canals solution

Note: Districts can be further subdivided in N_p plots of surface S_p such that $S' = N_p\, S_p$ and served by tertiary canals

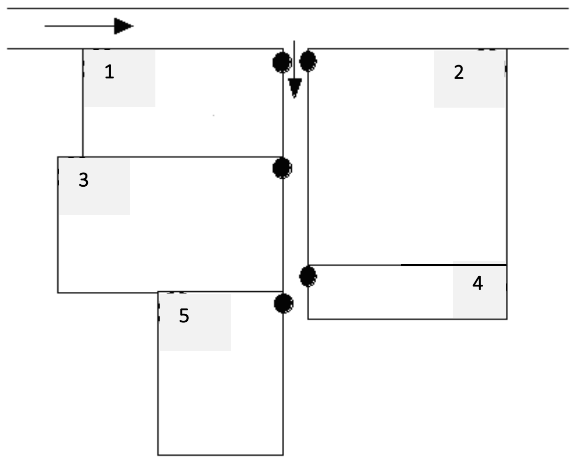
Distribution by rotation

Rotation R [days]: time interval between 2 successive waterings of the same plot

$$R = \frac{J'}{n}$$

J': total number of days in the period under consideration

n: number of irrigations



Water turnover T [hours]: effective irrigation time during one rotation

$$T = \frac{J\,N}{n}$$

J: number of days of irrigation

N: number of daily hours of irrigation

Distribution on demand

We learn about the so-called Clément's formula

Used to calculate the design flow rate of a pipe or canal serving an area S equipped with n flow inlet with handling flowrate m

- Water needs are characterized by the fictitious continous flowrate during peak period, q :

$$q = \frac{B_p}{T'} \quad (m^3/s\ ha)$$

- It considers the irregular and non-permanent use of the network:

r : network temporal use efficiency,

$$r = \frac{T''}{T'} = \frac{\text{durée prévisible d'utilisation du réseau}}{\text{durée totale de la période de pointe}}$$

- It considers the mean flowrate of the canal Q' during the peak period :

$$Q' = \frac{q\,S}{r} = \frac{\text{débit de la période de pointe}}{\text{temps probable d'utilisation}}$$

- Then, the mean number, s of inlets that function simultaneously is:

$$s = \frac{Q'}{m} = \frac{q\,S}{r\,m}$$

Distribution on demand

If the outlets are independent, sufficiently numerous and operate randomly, the design flow rate Q is given by Clément's formula :

Clément's formula

$$Q = Q'\left(1 + u\sqrt{\frac{1}{s} - \frac{1}{n}}\right)$$

Q' : débit moyen de la conduite $\quad Q' = \frac{q\,S}{r}$

s : nombre moyen de prises en fonctionnement simultané $\quad s = \frac{Q'}{m}$

n : nombre total de prises

u : paramètre caractérisant la qualité de fonctionnement du réseau

Prob. of satisfactory pipe operation	u
70%	0.525
80%	0.842
90%	1.282
95%	1.645
99%	2.324

Irrigation methods and techniques

Gravity (furrow) Irrigation

Notion of irrigation perimeters

- Dominant perimeter P_{dom}

- Irrigated perimeter P_{ir}

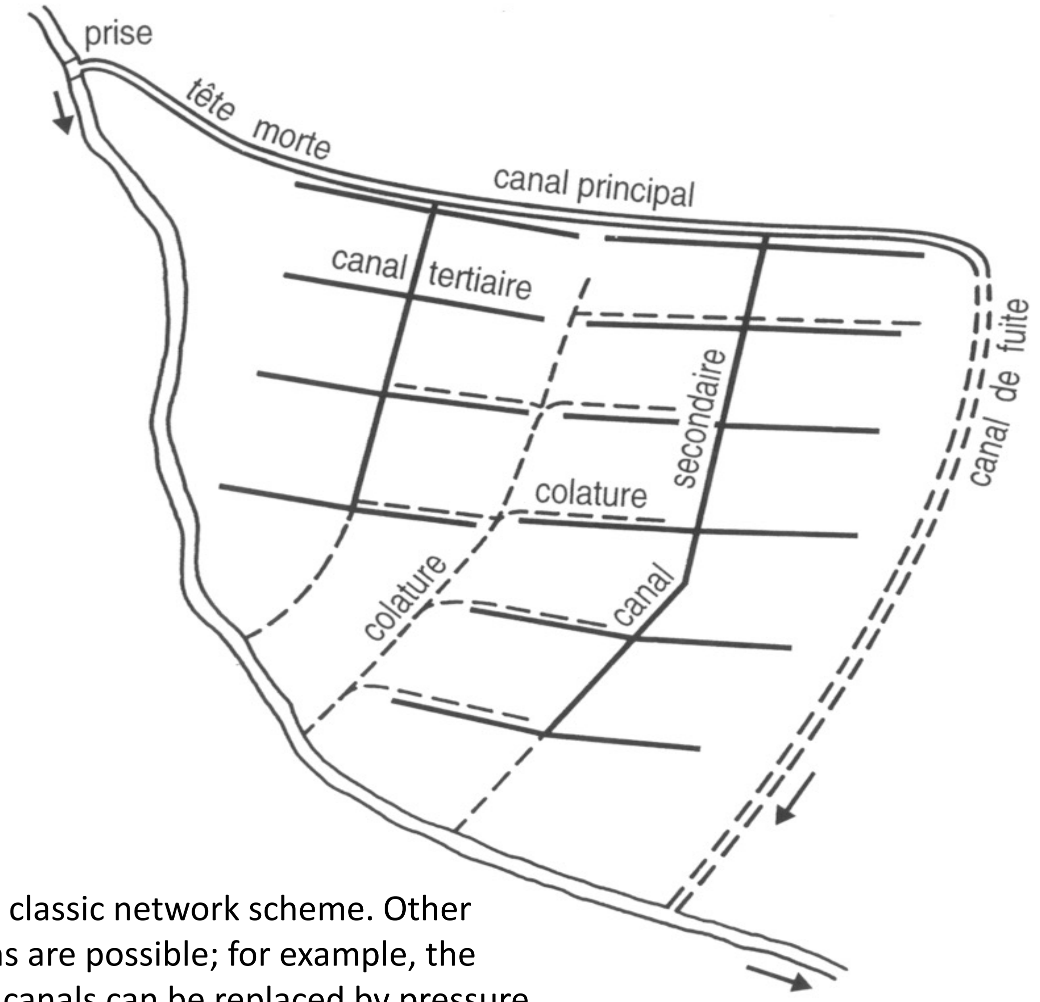
  $P_{ir} = \underbrace{P_{dom} - \text{not agric. Zones}}_{P_{gross}} - \text{ways and paths}$

  Ways and path zones = 5 à 15 % of P_{gross}

  $P_{ir} = P_{gross} - 0.05 \text{ à } 0.15\ P_{gross}$

- Equipped perimeter

General scheme of gravity irrigation network



This is a classic network scheme. Other solutions are possible; for example, the tertiary canals can be replaced by pressure pipes fed by pumps that draw water from the lower-tier canals.

Irrigation water supply

- Intake structures
- Deadhead
- Main, secondary, tertiary channels, etc.

Excess water removal

- Tertiary, secondary, principal colatures, etc.

Access to structures and plots

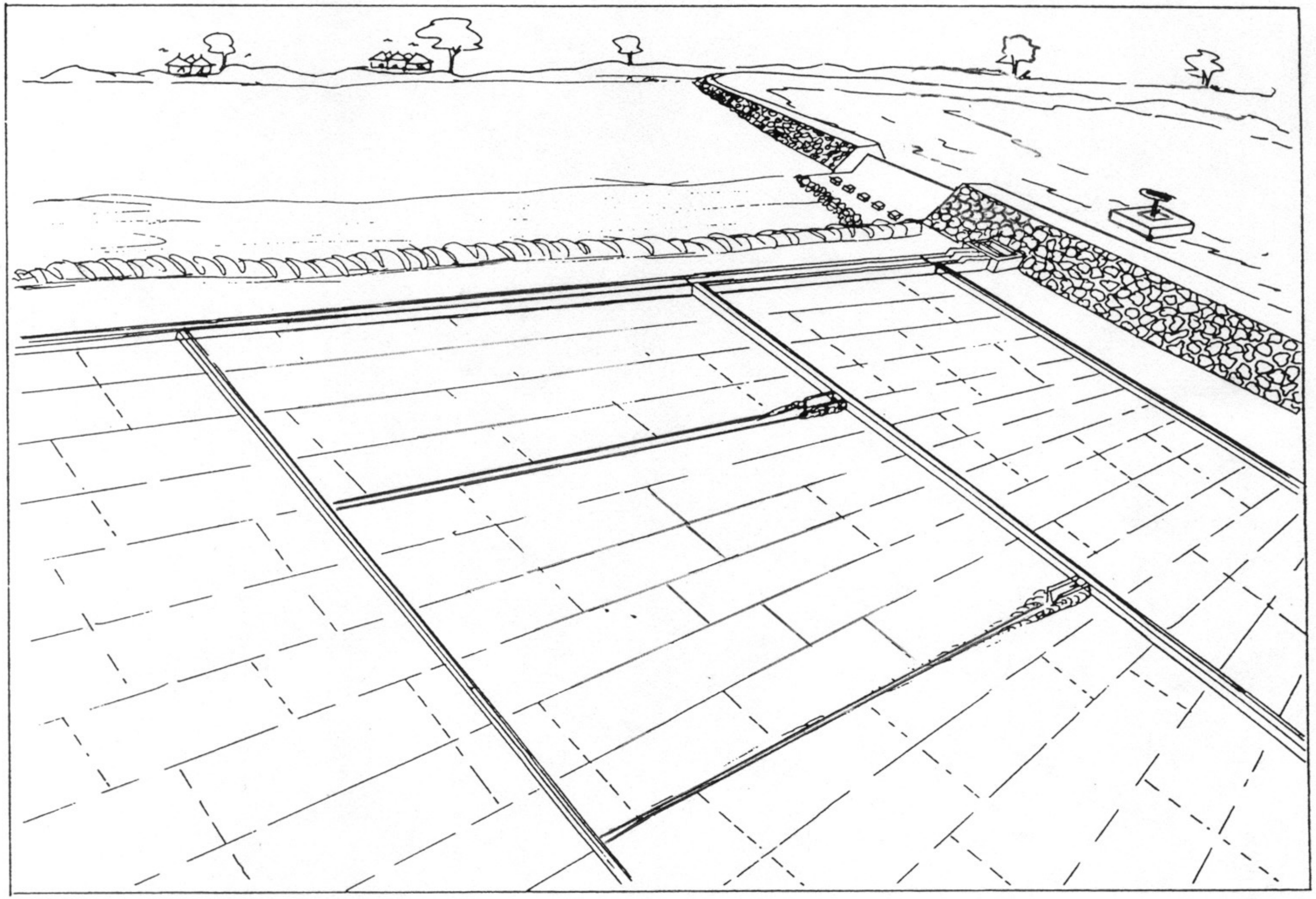
- Roads and traffic lanes

Perimeter security

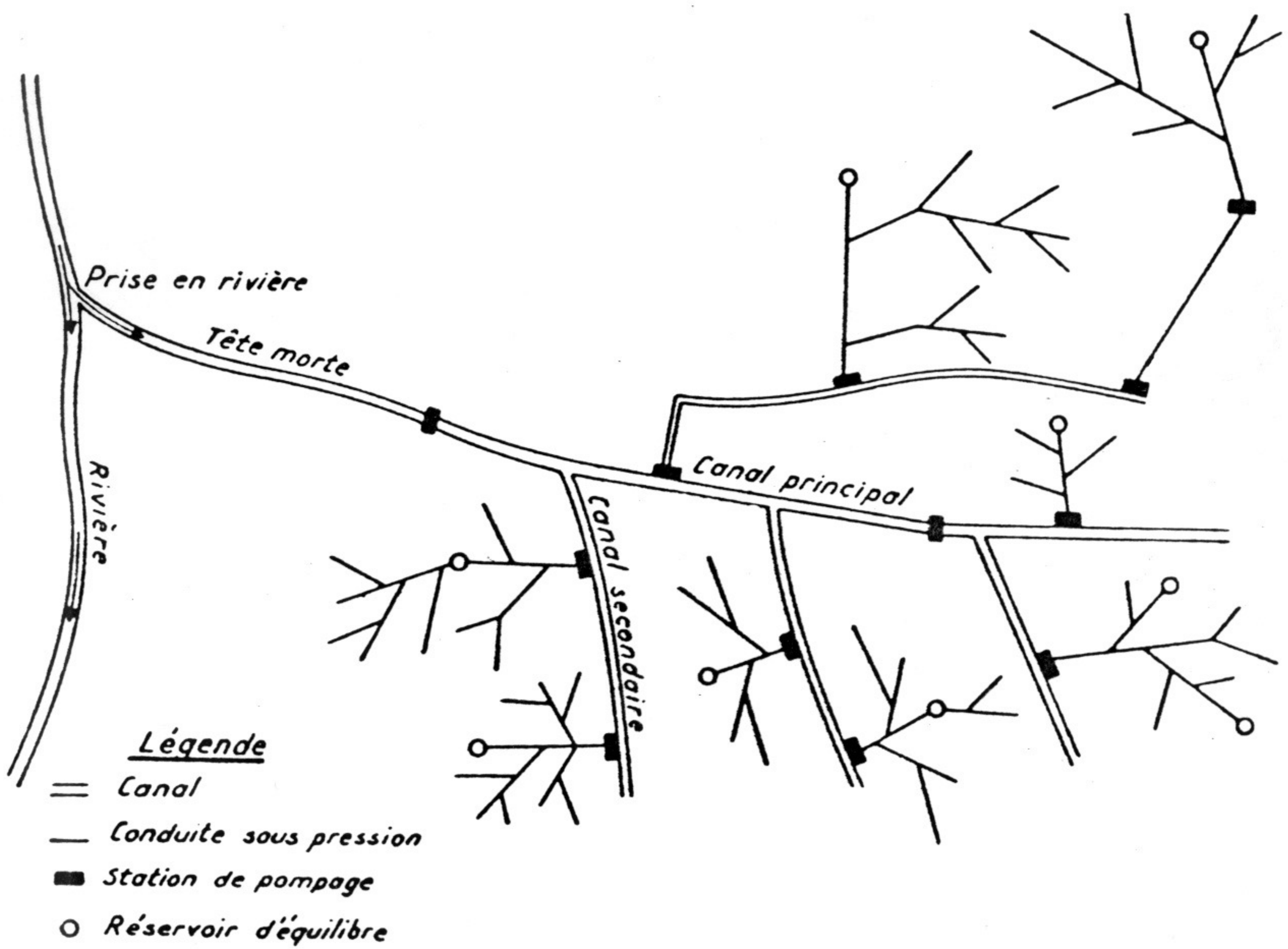
- Dykes, drainage ditches, etc.

Gravity irrigation perimeter fed by artificial reservoir

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

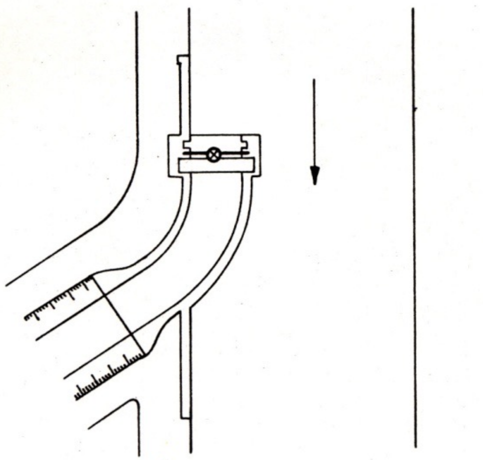


Mixed gravity and pressurized irrigation network

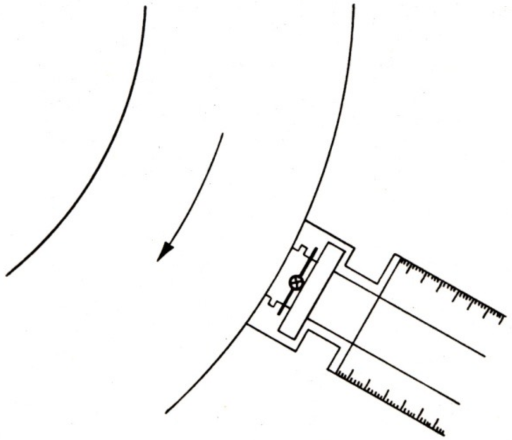


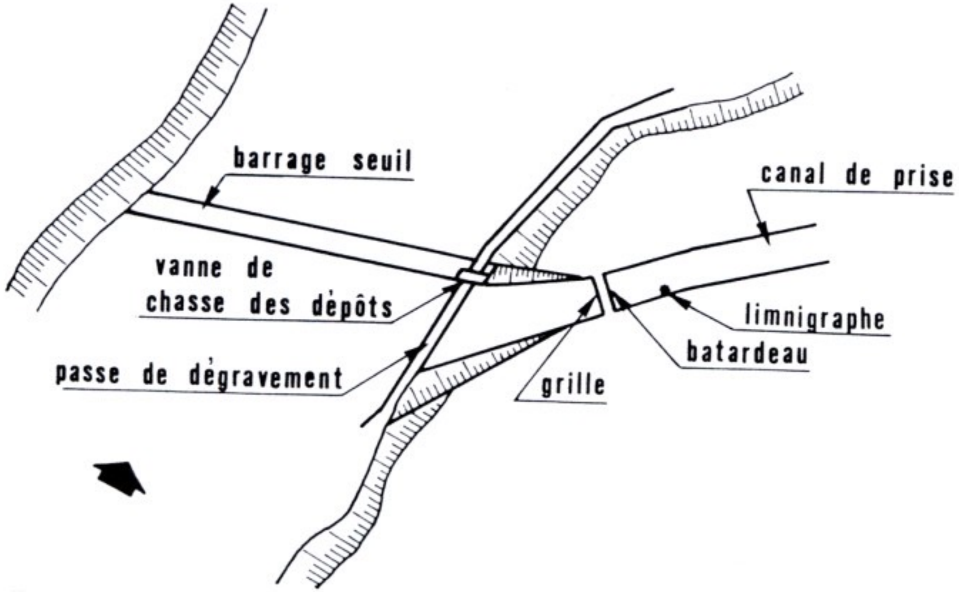
Example of water intakes from water course

PRISE FRONTALE

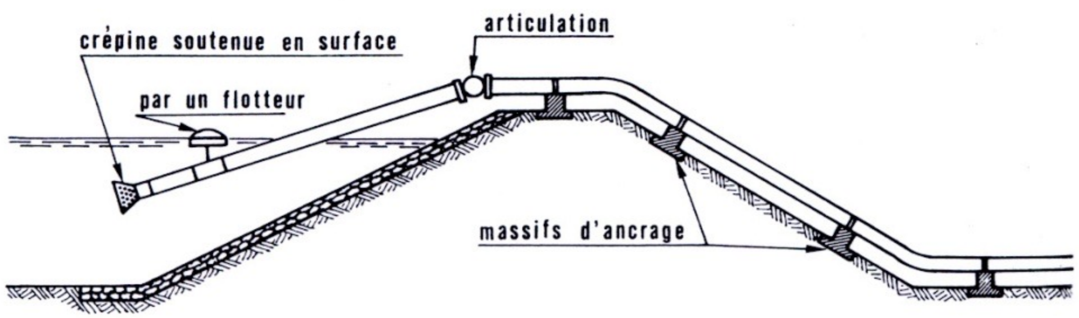


PRISE LATERALE

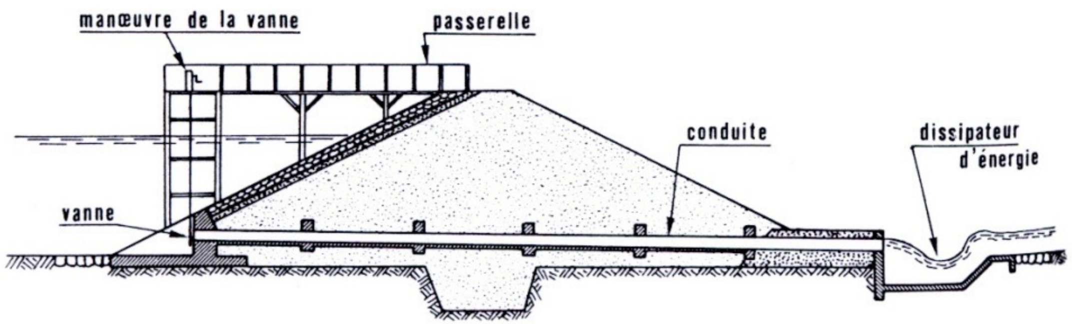




Stillwater intakes



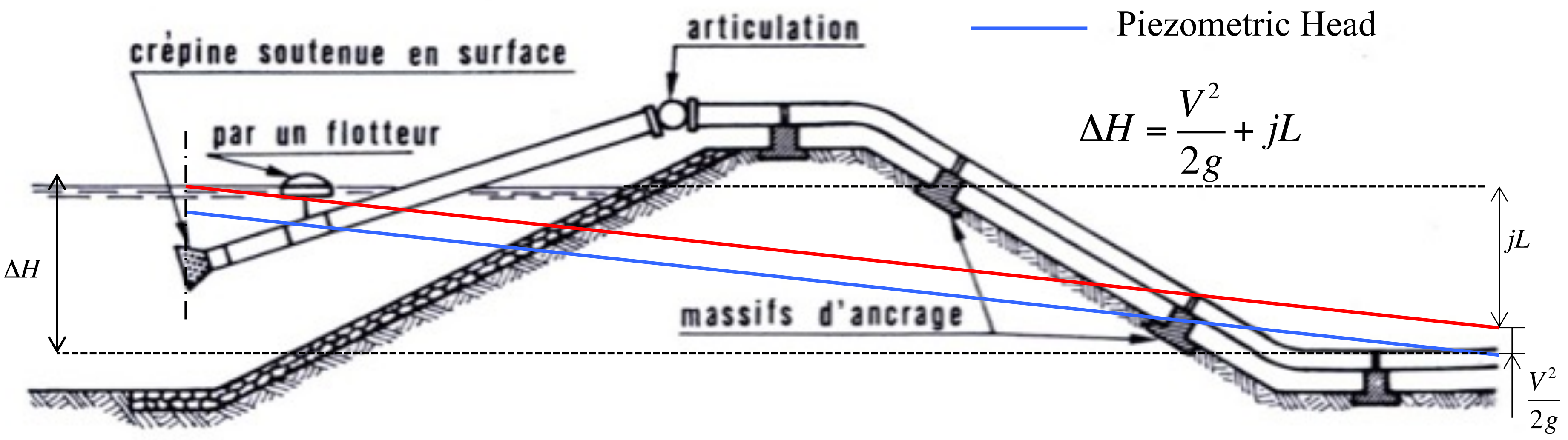
Siphon



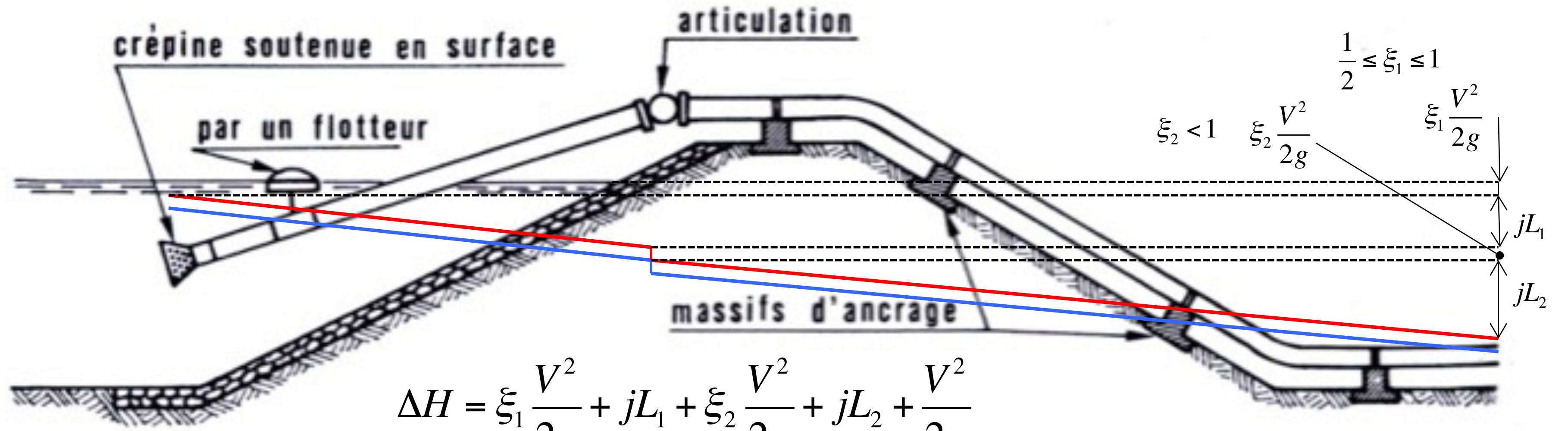
Intake via underground pipe

Intake tower, immersed in a reservoir. The tower has several intake openings and is connected to an adduction gallery.

Energy lines with and without localized losses

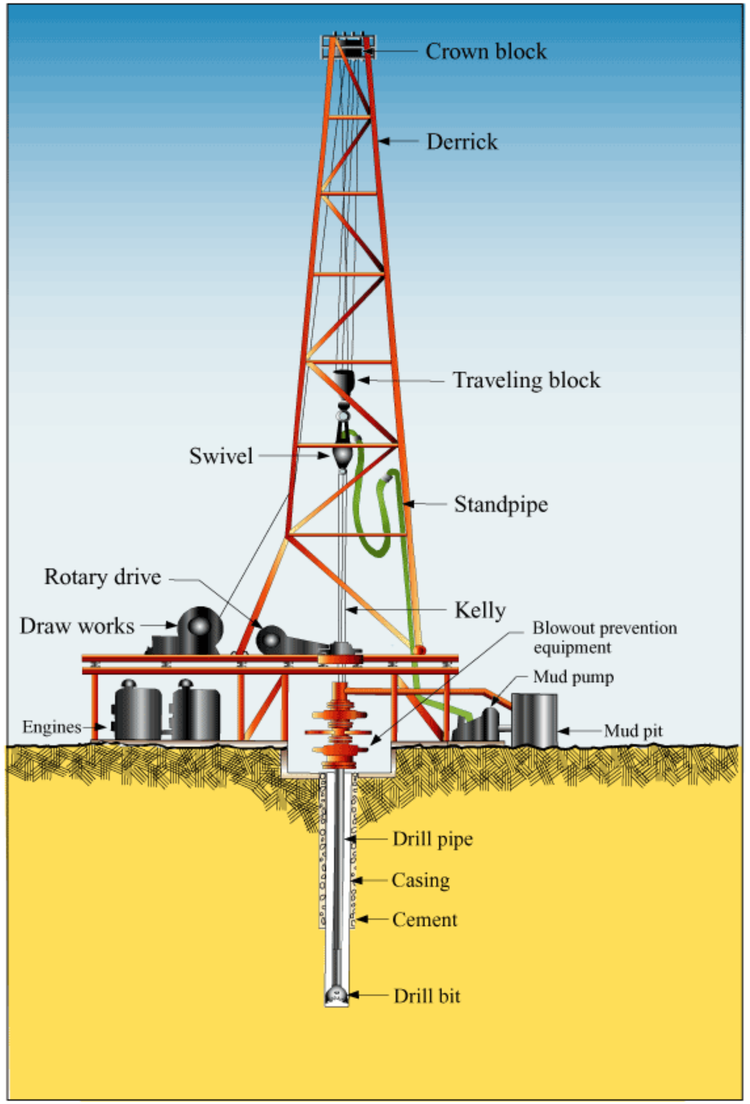


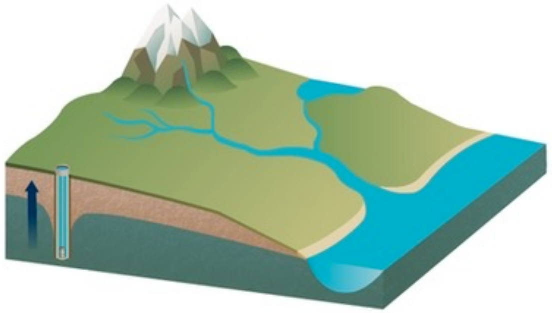
$$\Delta H = \frac{V^2}{2g} + jL$$



$$\Delta H = \xi_1 \frac{V^2}{2g} + jL_1 + \xi_2 \frac{V^2}{2g} + jL_2 + \frac{V^2}{2g}$$

Drilling boreholes to capture groundwater





Gravity network structures

- **linear**
  - ✓ supply of irrigation water
  - ✓ removal of excess water
  - ✓ access to works and plots
  - ✓ perimeter security

(Topic of Lecture 3)

- **punctual**
  - ✓ water regulation structures
  - ✓ flow distribution structures
  - ✓ safety structures
  - ✓ crossing structures
  - ✓ distribution paths and ways

(Topic of Lecture weeks 4)