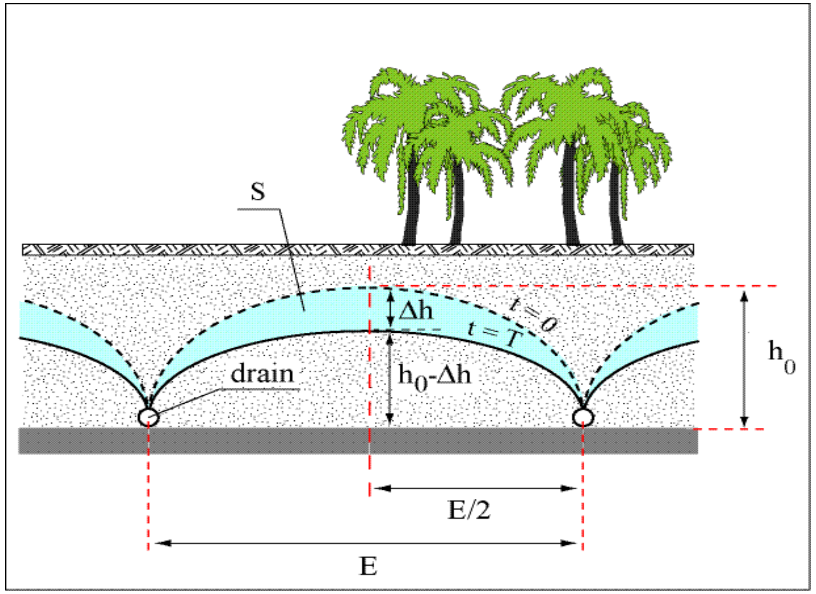
Irrigation and Drainage Engineering

(Soil Water Regime Management)



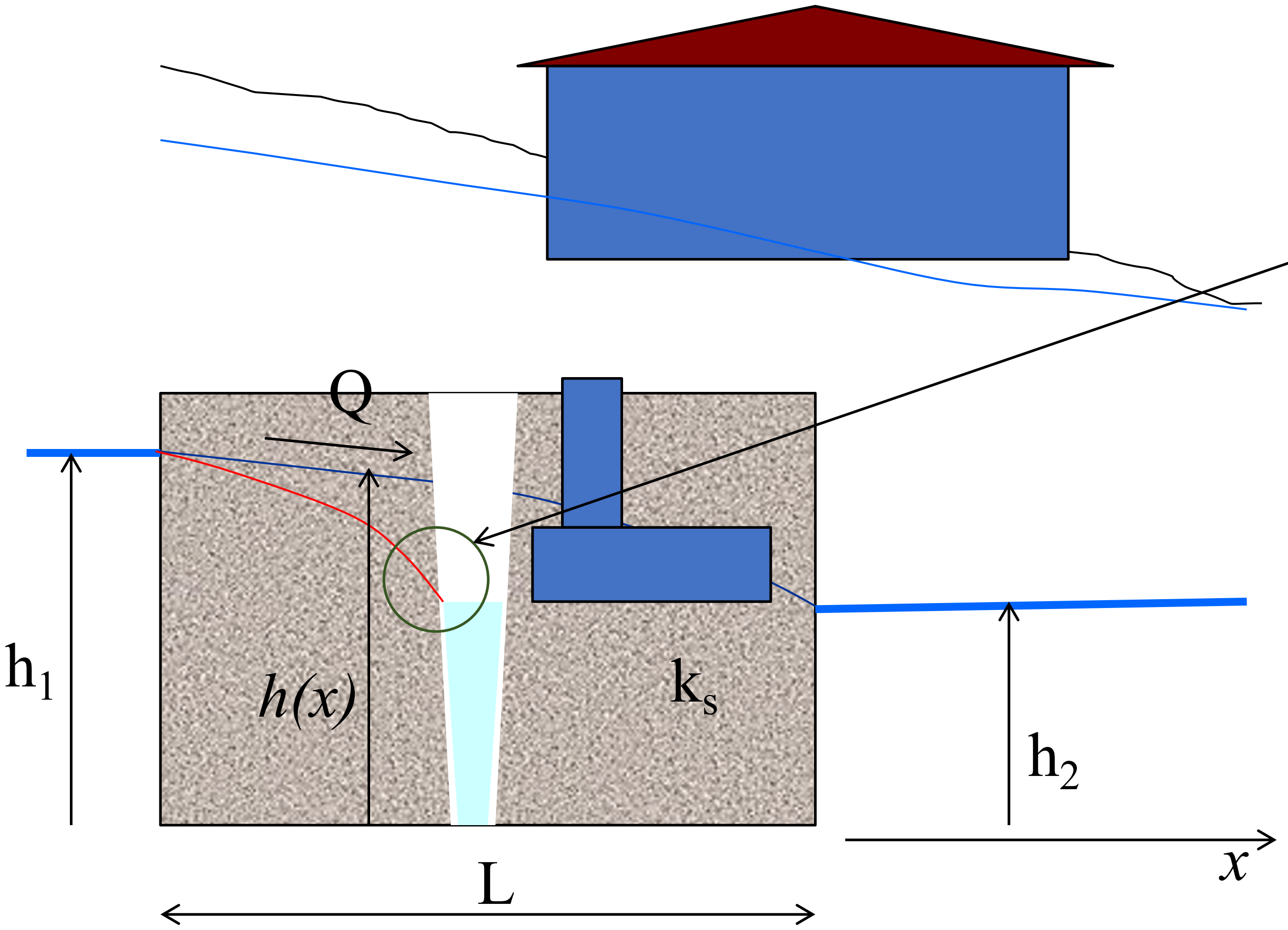
(ENV-549, A.Y. 2025-26)

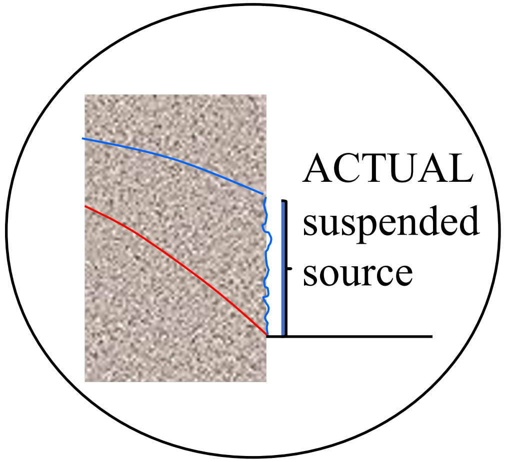
4ETCS, Master option

Prof. Paolo Perona
Platform of Hydraulic Constructions

Lecture 11-1. Drainage: wells, transient regime and design criteria

Draining trenches in unconfined aquifers





e.g., Polibarinova-Khocina studies

Filtration velocity $v = -k_s \dfrac{dh}{dx}$

Flow rate per unit width

$$q = -k_s h \frac{dh}{dx} \qquad q\,dx = -k_s h\,dh$$

$$\int_0^L q\,dx = -\int_{h_1}^{h_2} k_s h\,dh$$

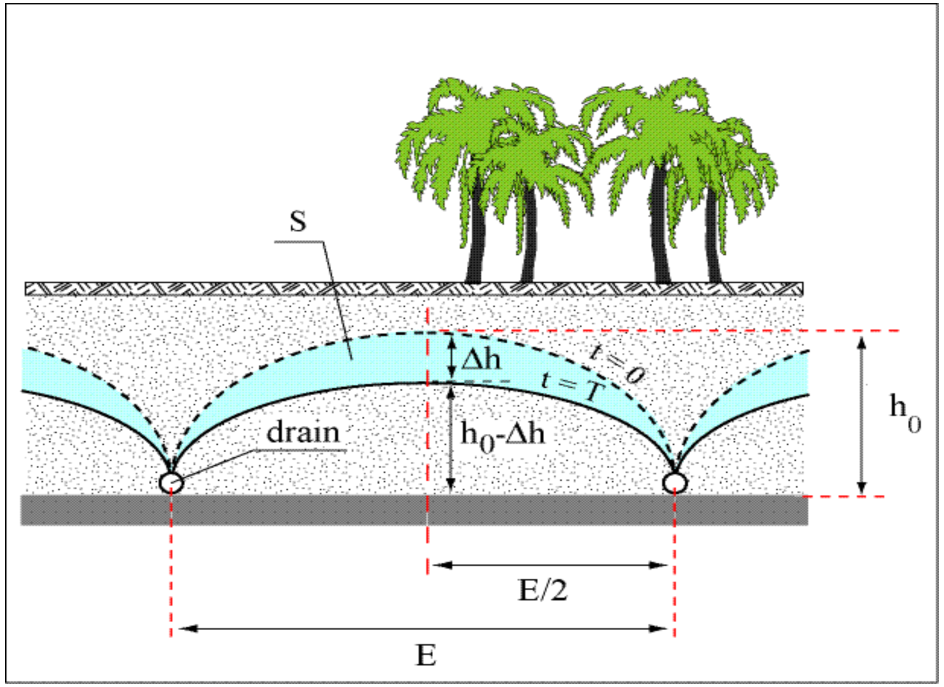
$$q = \frac{k_s}{2L}\left(h_1^2 - h_2^2\right)$$

Flow rate Q over trench width *b*, $Q = qb$

Notice the difference for the distributed recharge!!

Transient regime: Drains laid on an impermeable layer

Variable regime: decreasing water table (drying phase)



$$q_y(t) = \frac{4\,K\,h(t)^2}{E} \qquad q_y(t) = -\frac{dV}{dt}$$

V' : specific volume of aquifer feeding a drain

$$V' = \frac{1}{2}\frac{\pi E h}{2}(1m)$$

V : volume of water assumed to feed a drain

V = $\mu\,\pi\,E\,h/4$. ➔ $q_y(t) = -\frac{dV}{dt} = -\frac{\mu\,\pi\,E}{4}\frac{dh}{dt} = \frac{4Kh^2(t)}{E}$

$$\frac{16K}{\mu\,\pi\,E^2}\int_0^t dt = -\int_{h_0}^{h}\frac{dh}{h^2} = \left|\frac{1}{h}\right|_{h_0}^{h} = \frac{h_0 - h}{h\,h_0}$$

$$E^2 = \frac{16Kt}{\mu\,\pi}\frac{h\,h_0}{(h_0 - h)}$$

General idea:

Permanent regime ➔ **Variable regime**

$$q_y = \frac{4\,K\,h^2}{E} \quad \Rightarrow \quad q_y(t) = \frac{4\,K\,h(t)^2}{E}$$

Variable water table during the drying phase

Objective: to lower the water table by a height Δ within a time T

Drains laid on an impermeable layer

$$E^2 = \frac{16Kt}{\mu\pi}\frac{h\,h_0}{(h_0 - h)}$$

h_0 : initial conditions

Assuming that the temporal variation in the drawdown can be considered linear :

$\Delta = h_o - h(T)$, soit: $h(T) = h_o - \Delta$

$$E^2 = \frac{16KT}{\mu\pi}\frac{(h_0 - \Delta)\,h_0}{\Delta}$$

If the drawdown is non-linear, it is frequently adopted:

$h(t) = h_0\, e^{-at}$, being for $t = T$: $h(T) = h_0\, e^{-aT}$

a : groundwater reaction coefficient

Variable water table during the drying phase

Objective: to lower the water table by a height Δ within a time T

Case of drains located above the impermeable layer - Glover-Dumm formula

$$E^2 = \frac{\pi^2 K t d}{\mu}\left[\ln\left(1.16\frac{h_0}{h(t)}\right)\right]^{-1}$$

d : equivalent depth

Hyp.: Temporal variation in linear drawdown :

$\Delta = h_o - h(T)$, soit: $h(T) = h_o - \Delta$

$$E^2 = \frac{\pi^2 K T d}{\mu}\left[\ln\left(1.16\frac{h_0}{h_0 - \Delta}\right)\right]^{-1}$$

If the drawdown is non-linear, it is frequently adopted:

$h(t) = h_0\, e^{-at}$, being for $t = T$: $h(T) = h_0\, e^{-aT}$

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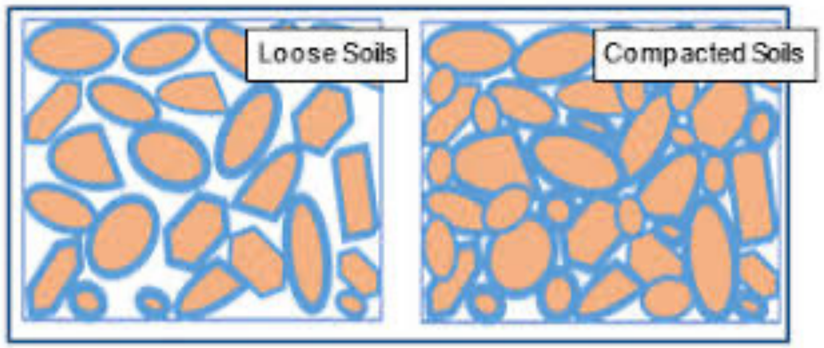
Standard drain spacing: examples

Heavy or compact soils	10*- 15 m
Fine soils	15 - 20 m
Silty-sandy soils	15 - 25 m
Sandy soils	20 - 35 m



* In very clayey soils, only a few metres apart

Characteristic geometry of drains

- **Depth of the drains**
  - ✓ **minimum: 80 cm**
  - ✓ **maximum: 1.5 to 2 m**

  Depth frequently imposed: low permeability horizon, outlet elevation, etc.

- **Depth of collectors**
  - ✓ **avoid depths > 3 m**
  - ✓ **generally surrounded by a gravel encapsulation filter to increase their resistance to external factors***

- **Maximal length of drain lines**
  - ✓ **frequently imposed (topography, location of collectors, surface area to be drained, etc.)**
  - ✓ **free surface flow ➔ L = f (collected flow, slope, diameter, type of drains, etc..).**

  Max. length between 200 et 300 m.

- **Slope of drains**
  - ✓ **often conditioned by topography**
  - ✓ **v > 0.4 - 0.5 m/s, otherwise filters**
  - ✓ **minimum slope: 1 to 2 ‰**

* for diameters greater than 60 cm and if the soil cover is less than 1 m or greater than 2.5 m, concrete encasement is used

Sizing of drains and collectors

$$Q = V\,S$$

$$V = K\,R^{2/3}\,I^{1/2} \qquad \text{(Manning-Strickler)}$$

$$Q = K\,R^{2/3}\,I^{1/2}\,S$$

Drains:

Permanent regime: $Q_{max} = q_c\,E\,L$

Wetted section < drain section (open surface flow, etc.)

Q: flow rate
S: wetted cross-section
V: average water velocity
K: roughness coefficient
R: hydraulic radius; $R = S/P$
P: wetted perimeter
I : slope of the load line
slope of the pipe under uniform flow conditions

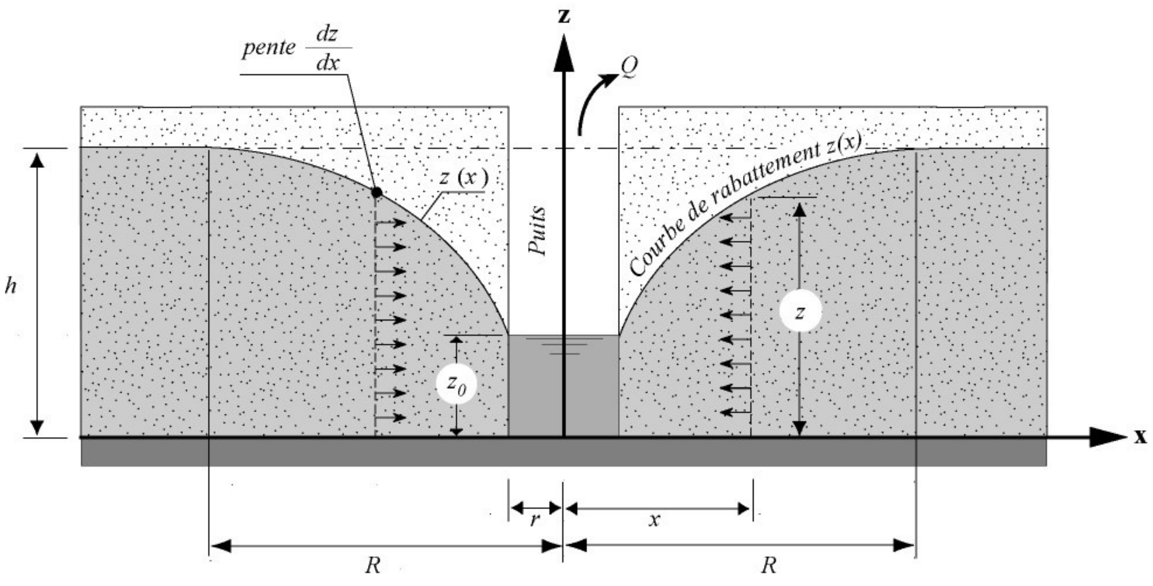
Drainage by pumping wells from a free water table

Objective: to calculate the flow rate Q that can be extracted from a well of radius r reaching the impermeable bedrock, so as to maintain a constant head of water zo in the well, when steady state is reached.

The influence of pumping is felt over a certain distance R (radius of action) from the axis of the well.

Surface of the water table = conical surface of revolution (cone of depression). Isopies: concentric circles; the liquid threads converge towards the well.

→ aquifer with converging streamlines



Flow rate Q through a cylindrical surface of radius x and height z concentric with the well :

$$Q = q\,S \quad \text{et:} \quad S = 2\,\pi\,x\,z \qquad Q = 2\,\pi\,x\,z\,K_s\,\frac{dz}{dx}$$

By integration $$Q\int_r^R \frac{dx}{x} = 2\,\pi\,K_s \int_{z_o}^{h} z\,dz$$

we obtain: $$Q = \pi\,K_s\,\frac{\left(h^2 - z_o^2\right)}{\ln(R/r)}$$

* positive sign because the flux q is opposite to the direction of the x axis

Drainage by pumping wells from a free water table

Advantages

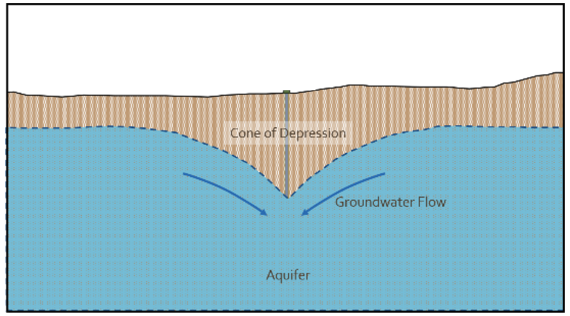
- the water table can be lowered to great depths;
- the water pumped can be used for irrigation, if its quality is good;
- pumping can reduce the pressure of deep aquifers, increasing downward flow;

Disadvantages

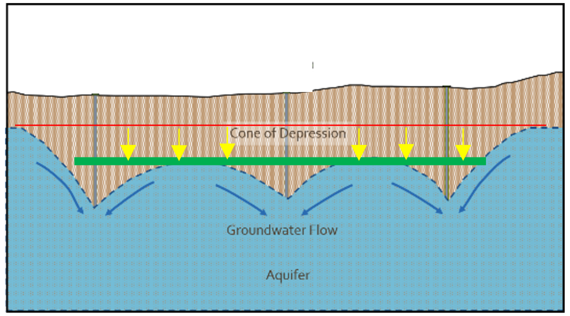
- complex and costly structures
- only suitable for aquifers with favourable hydraulic characteristics
- not viable for small areas

Drawdown by "interfering" wells

The cone of depression tends towards a quasi-permanent regime.
In general, the zones of influence of the various drainage wells overlap (interference)



(a) Single abstraction point



(b) Multiple abstraction points

To calculate the drawdown, we use the effect superposition method, which states (for linear systems) that the drawdown at any point P is the sum of the drawdowns induced by the individual wells.

Drainage as superposition of interfering wells

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

In general, the flow from an individual well* is :

$$Q = \pi K \frac{\left(h^2 - z^2\right)}{\ln\left(R/x\right)}$$

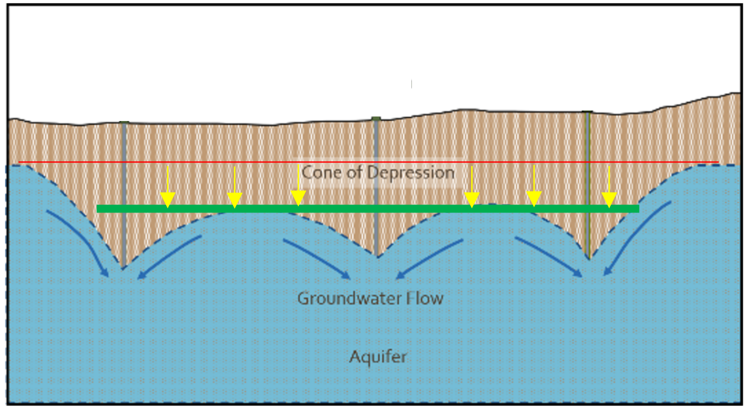
by rewriting :

$$h^2 - z^2 = \frac{Q}{\pi K} \ln\left(R/x\right)$$

For N wells (superposition principle) :

$$h^2 - z^2 = \sum_{i=1}^{N} \frac{Q_i}{\pi K} \ln\left(R_i/x_i\right)$$

Change sign when compute for x>R



(b) Multiple abstraction points

Q_i : pumping rate in well i
x_i : distance from the point in question to the well i
R_i : range of wells i
h : height of the water table outside the pumping zone
z : height of the water table during pumping at the point in question

*** pour un point (x,z) quelconque**

Conception and Layout of a drainage network

Conception

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

1. **Precise topographical survey (1/1000)**
2. **Determination of soil characteristics**
3. **Network design**

✓ study of the hydrological environment

✓ definition of the ASD

✓ determination of the characteristic drainage rate

✓ choice of drain depth and minimum water table depth

➔ **Calculating drain spacing**

- **Developing the network**

✓ study of the shape of the land, identification of thalwegs and ridge lines

✓ preliminary sketch: layout of collectors, layout of longitudinal profiles, layout of inspection chambers (changes in gradient and direction, connections to other collectors) (every 100 to 150 m)

✓ detailed drainage layout

✓ determination of lengths, gradients and depths

- **Calculation of flow rates to be evacuated**
- **Sizing drains and collectors**

Different drain layout diagrams

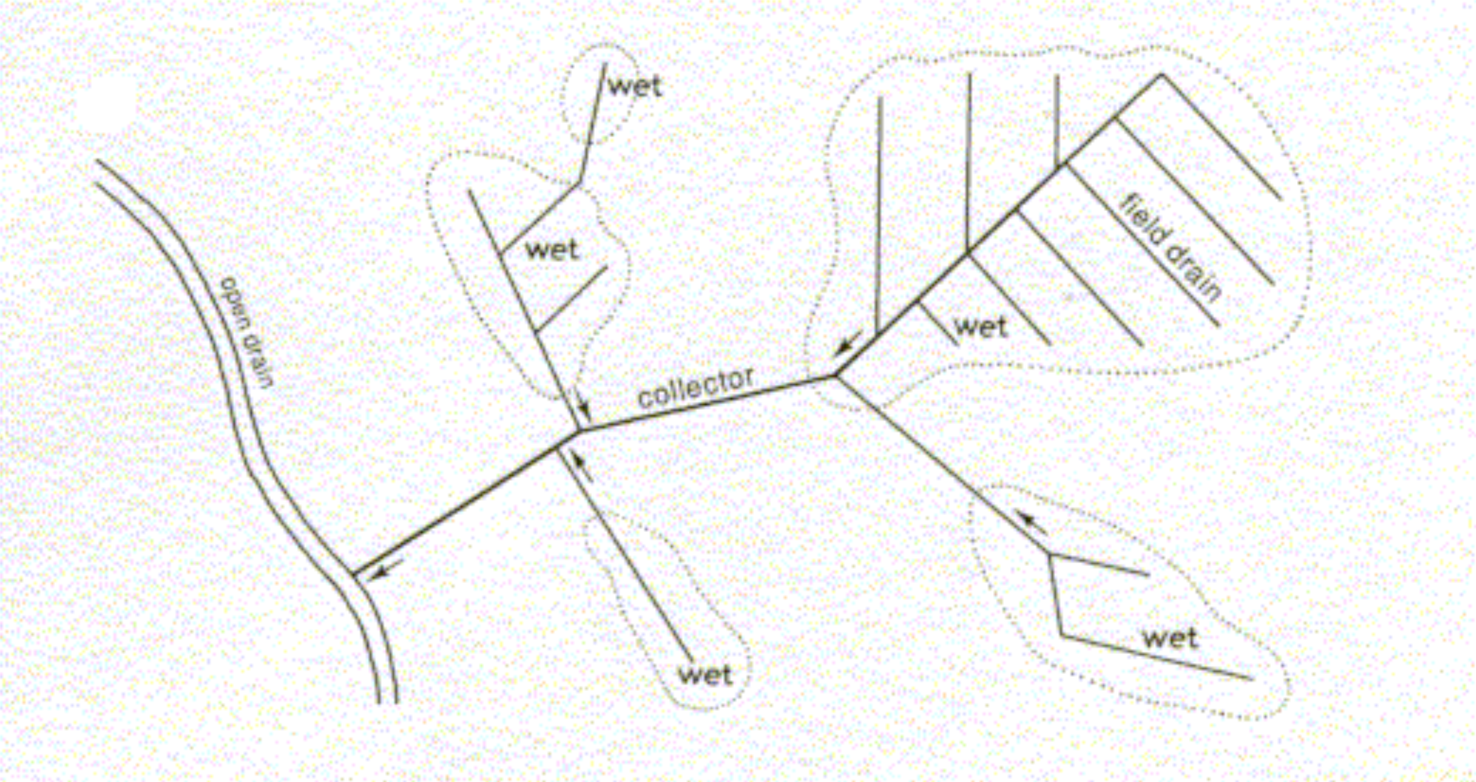
The spatial layout of the drains and collectors depends on:

– the size of the area affected

– the topography

– the position of the outfall

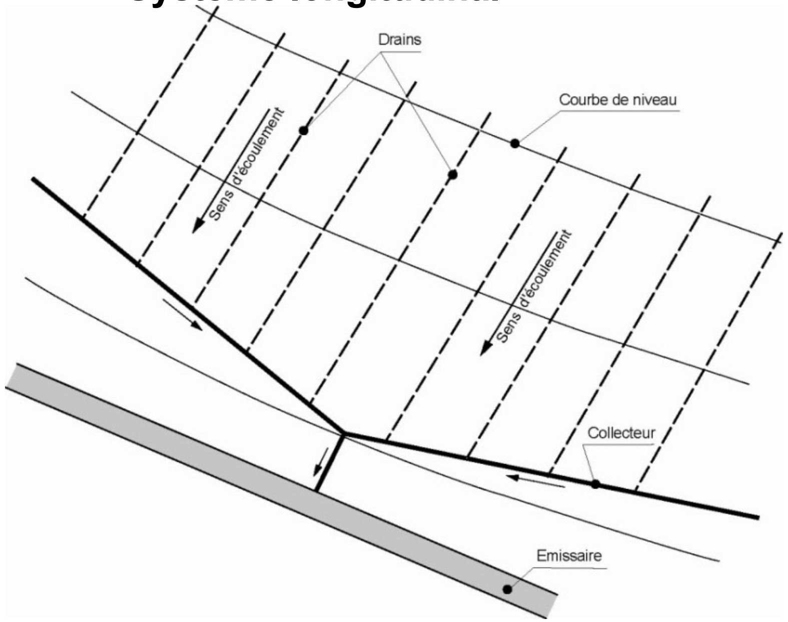
- **Spatially separated areas to be drained**:
  - natural system



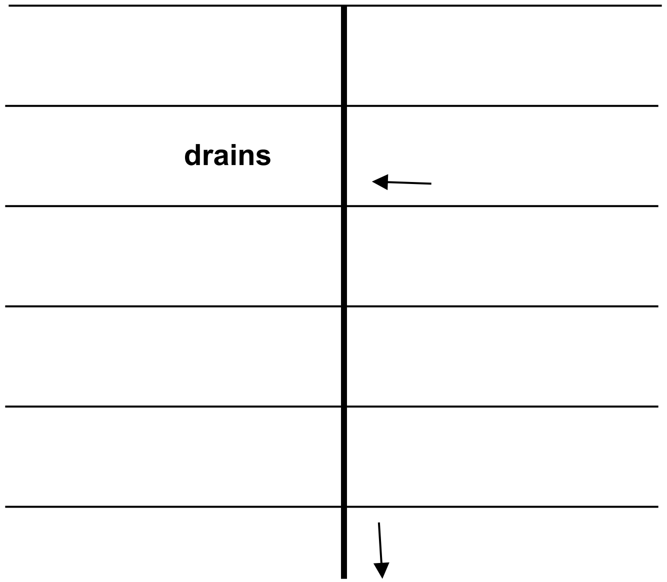
Natural system

- **Continuous drainage area:**
  - regular systems with parallel drains
    - longitudinal system
    - transverse system
    - oblique system

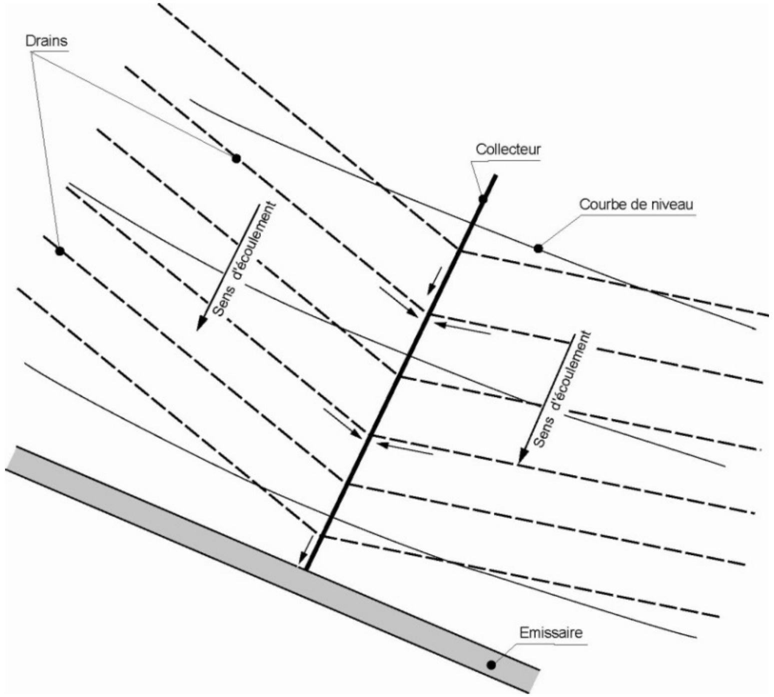
Système longitudinal



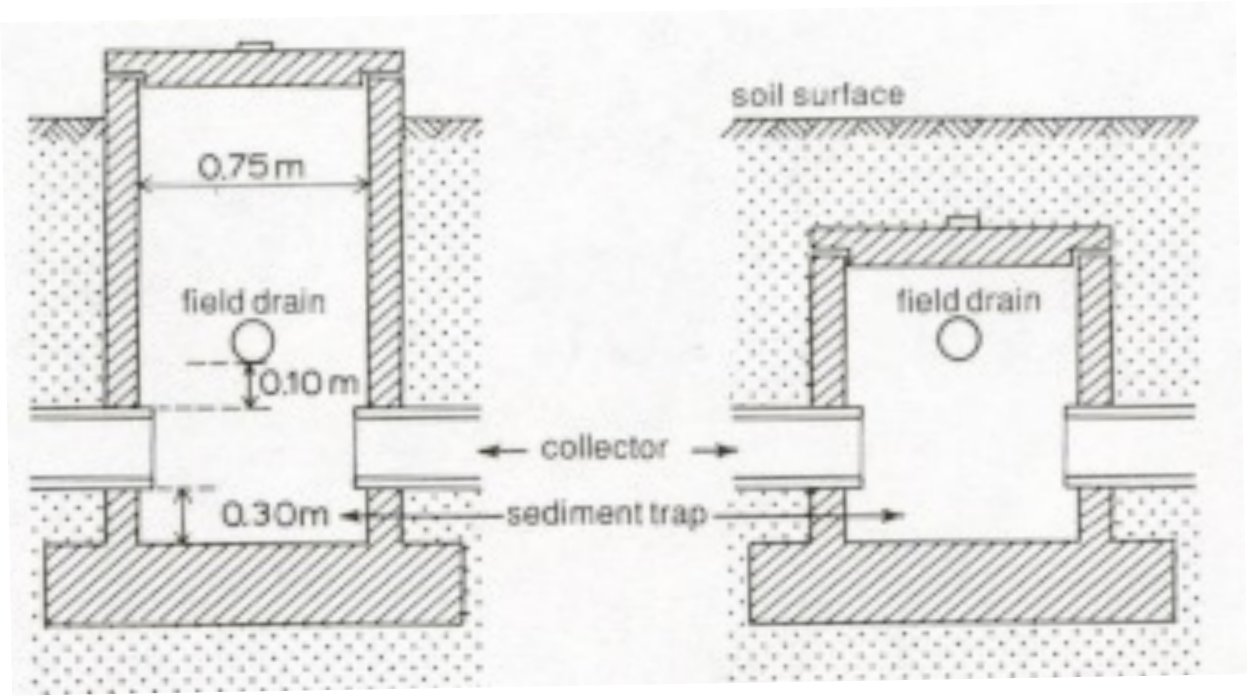
Système transversal



Système oblique (en arêtes de hareng)



Inspection chambers



Presentation of a drainage project

Recommendation SIA 406

Directives concerning Land Improvements

In particular:

Recommendation SIA 406.17

Site plan for a drainage scheme

SERVICE FEDERAL DES AMELIORATIONS FONCIERES

Berne, le 13 février 1992
3023.1 ams/bor

Aux Services cantonaux chargés des améliorations foncières et des constructions rurales

Circulaire 1992/2

Recommandation SIA 406, contenu et présentation de projets d'améliorations foncières

(en allemand, français et italien)

Mesdames et Messieurs,

La norme SIA 171 "Directives pour la présentation de projets d'améliorations foncières", appliquée depuis une vingtaine d'années, fut soumise à une révision totale par la Commission SIA 406 dès 1986. Les travaux ont été achevés en 1991, et la nouvelle recommandation SIA 406 "Contenu et présentation de projets d'améliorations foncières" put ainsi être mise en vigueur par le Comité-Central de la SIA le 1er décembre 1991.

Il parut en effet indiqué de remplacer la norme 171, car les exigences que doivent remplir les projets ne cessent de croître et les questions de coordination ne sont pas réservées aux spécialistes des domaines techniques. Contrairement à l'ancienne, la nouvelle norme ne traite pas seulement la présentation des projets, elle fait aussi fonction de recommandation pour leur contenu.

1. Rapports avec d'autres directives et recommandations

La recommandation SIA 406 s'inscrit dans le contexte des nouvelles dispositions légales et du désir de bien étayer les projets et d'assurer qu'ils soient étudiés à fond. Avec le guide "Protection de la nature et du paysage lors d'améliorations foncières" de 1983, la brochure "Documentation pour les améliorations foncières subventionnées" de 1984 et la publication "Etude de l'impact sur l'environnement (EIE) lors d'améliorations foncières" parue en 1989, elle forme une base commune visant à assurer une élaboration, évaluation et réalisation rationnelles des projets d'améliorations foncières.