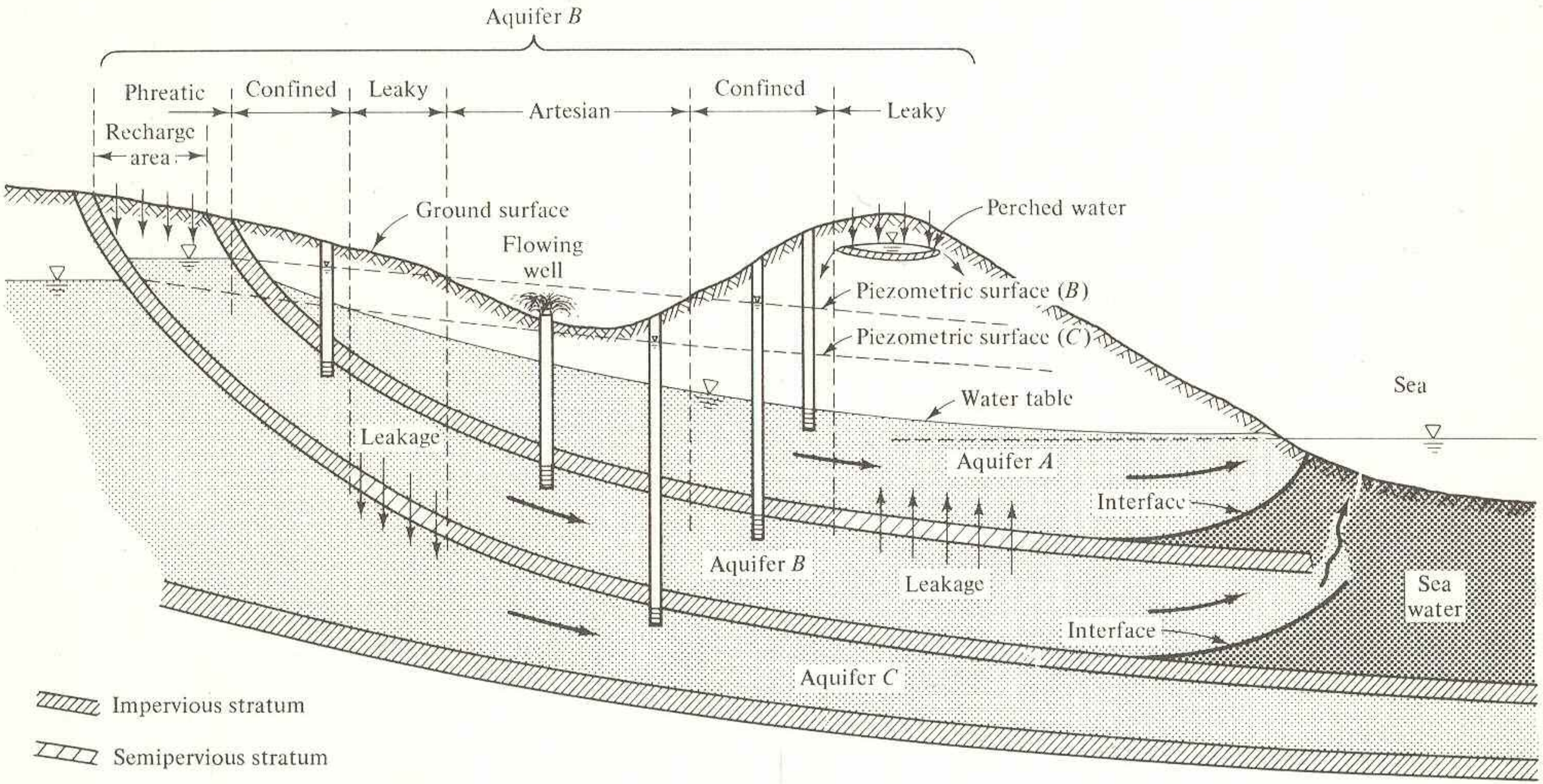


Figure 2-4 Types of aquifers.

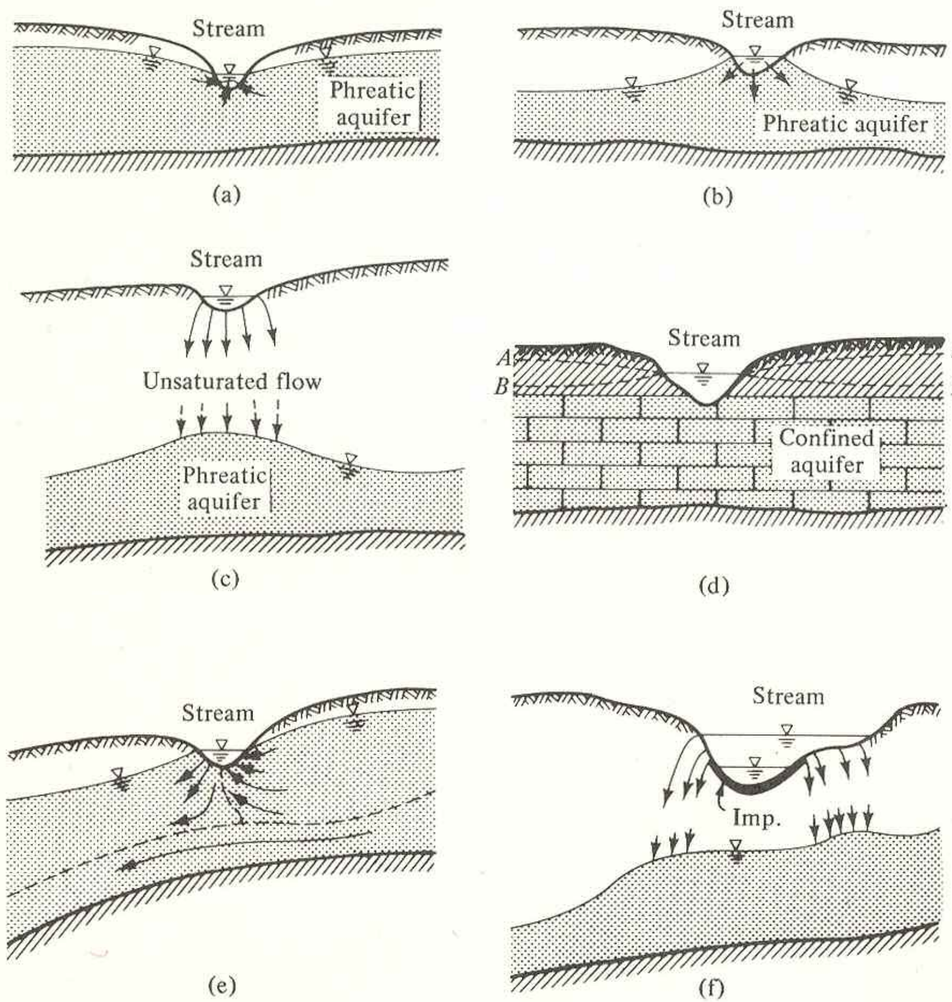


Figure 3-9 River–aquifer interrelationships. (a) Effluent stream. Groundwater drains into stream. (b) Influent stream (shallow water table). River contributes to groundwater flow. (c) Influent stream (deep water table). River contributes to groundwater flow. (d) Influent stream (piezometric surface B), or effluent one (piezometric surface A) intersecting a confined aquifer. (e) A stream which is both influent and effluent. (f) A partly clogged influent stream.

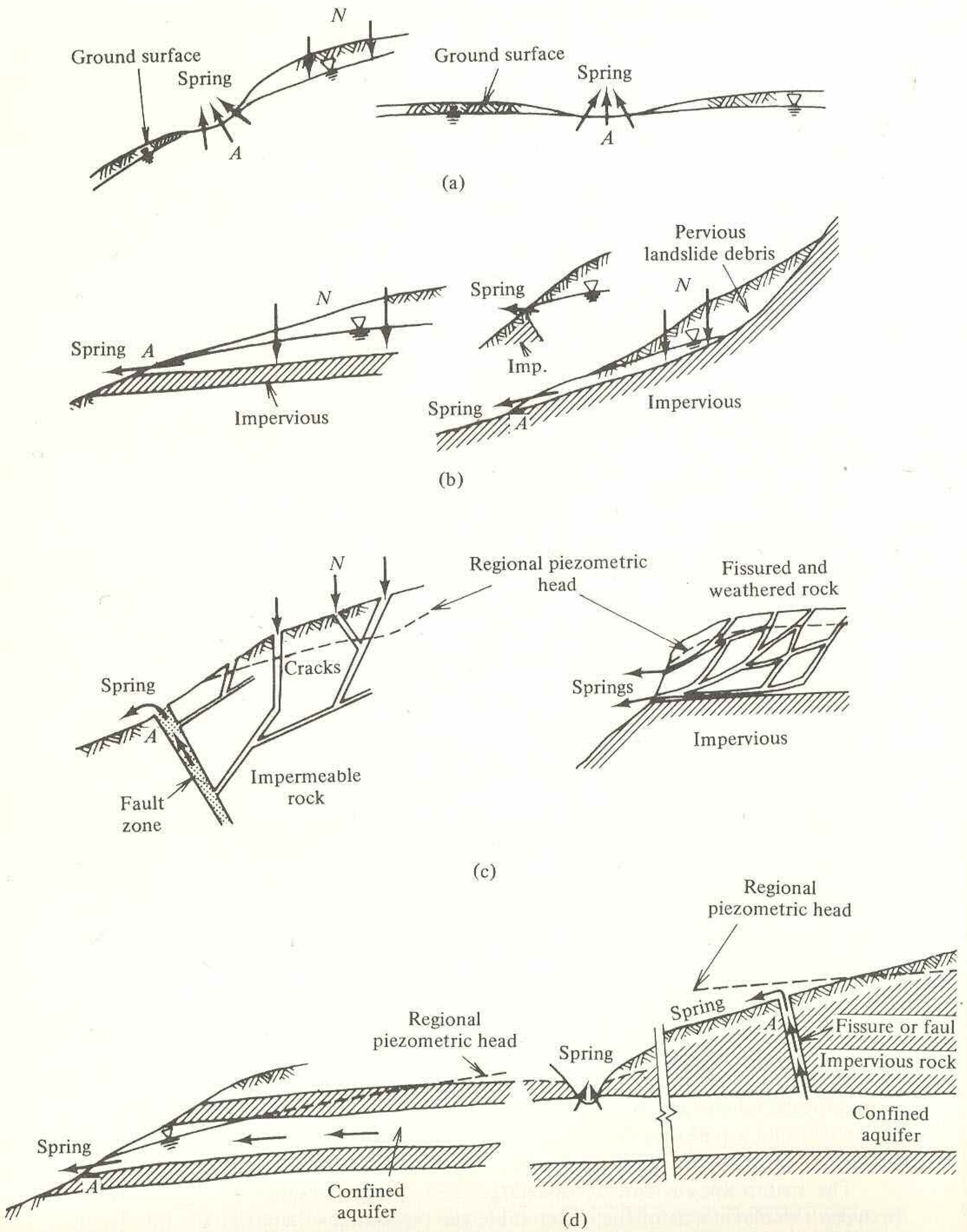
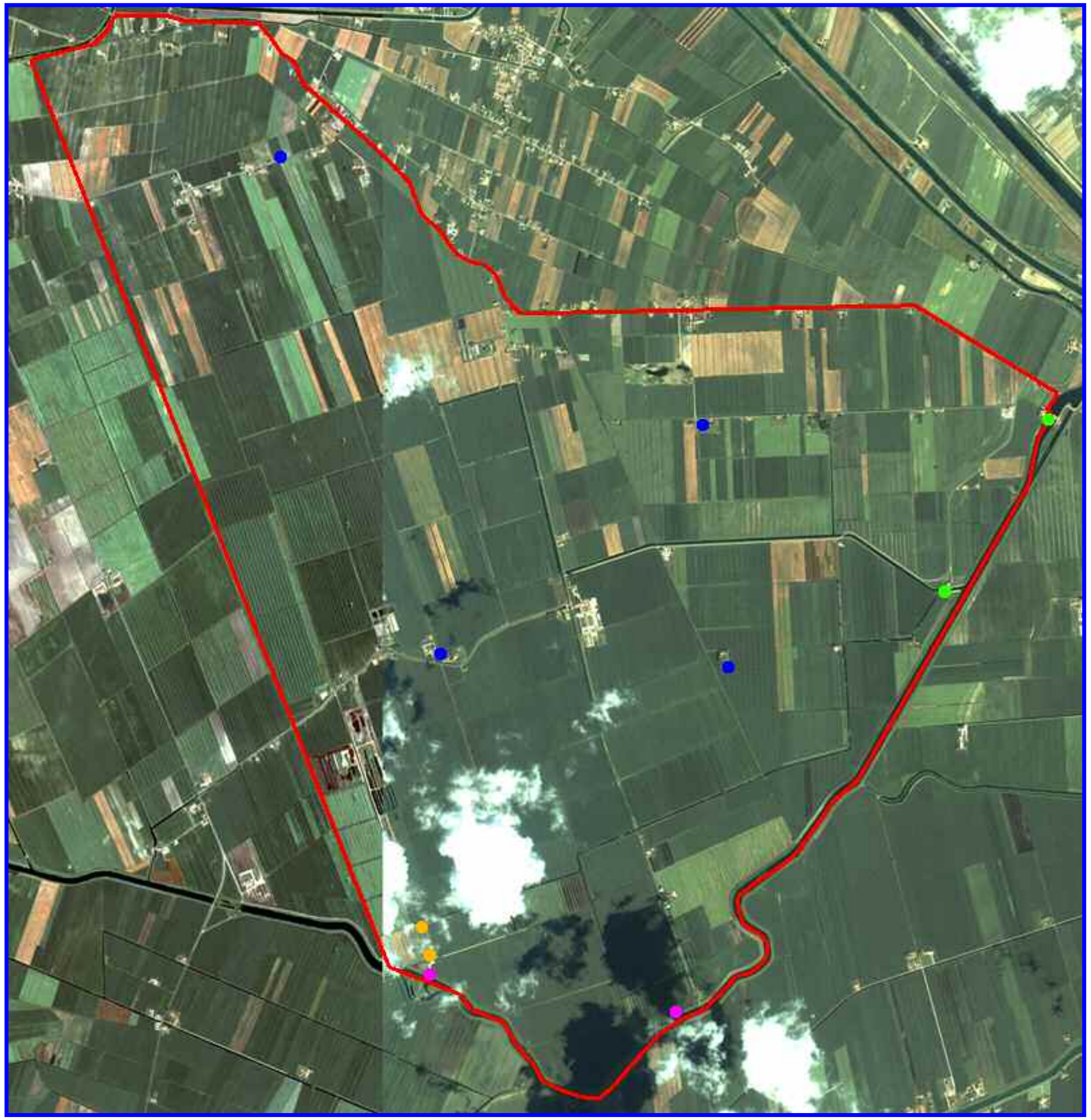
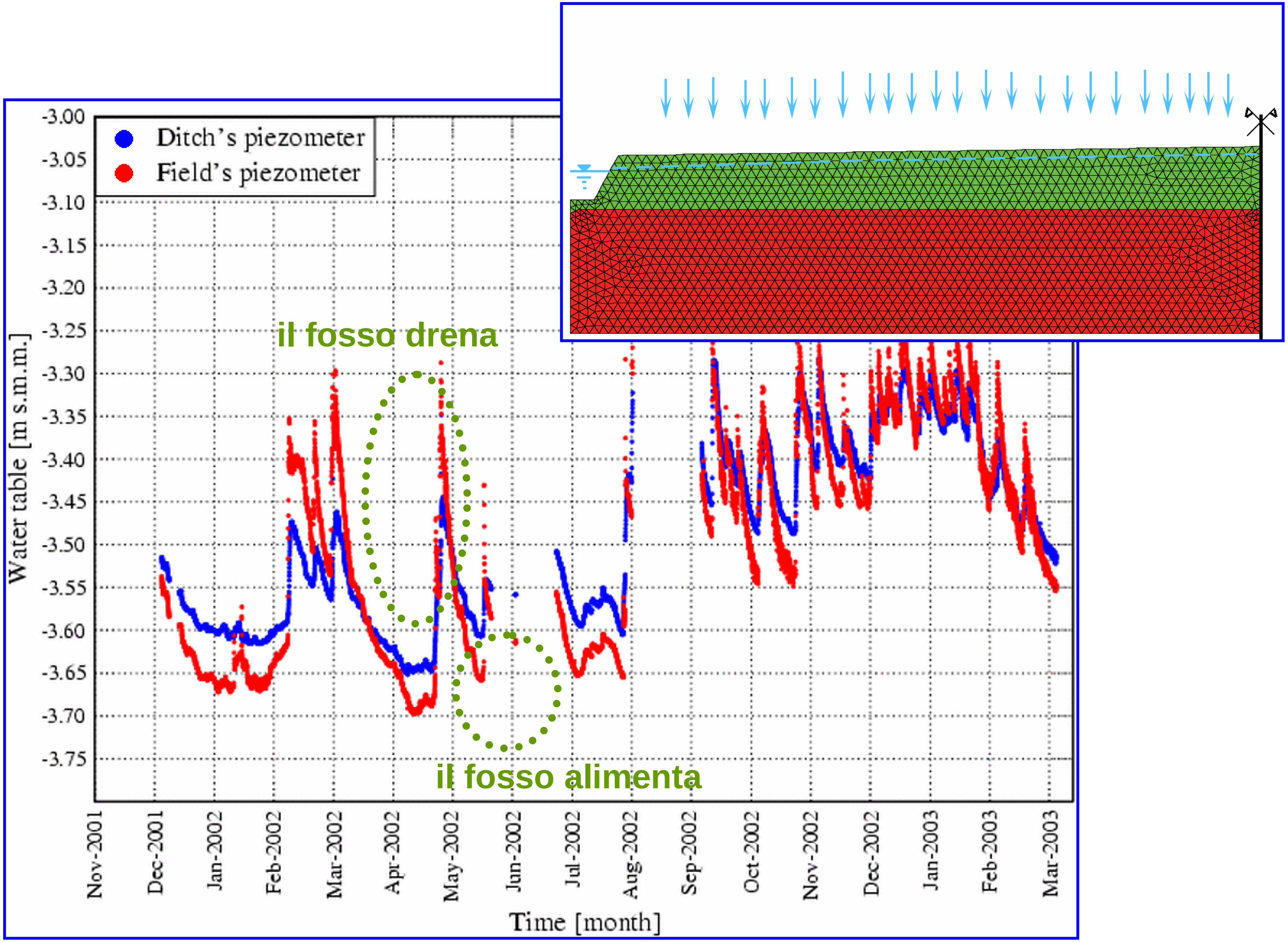
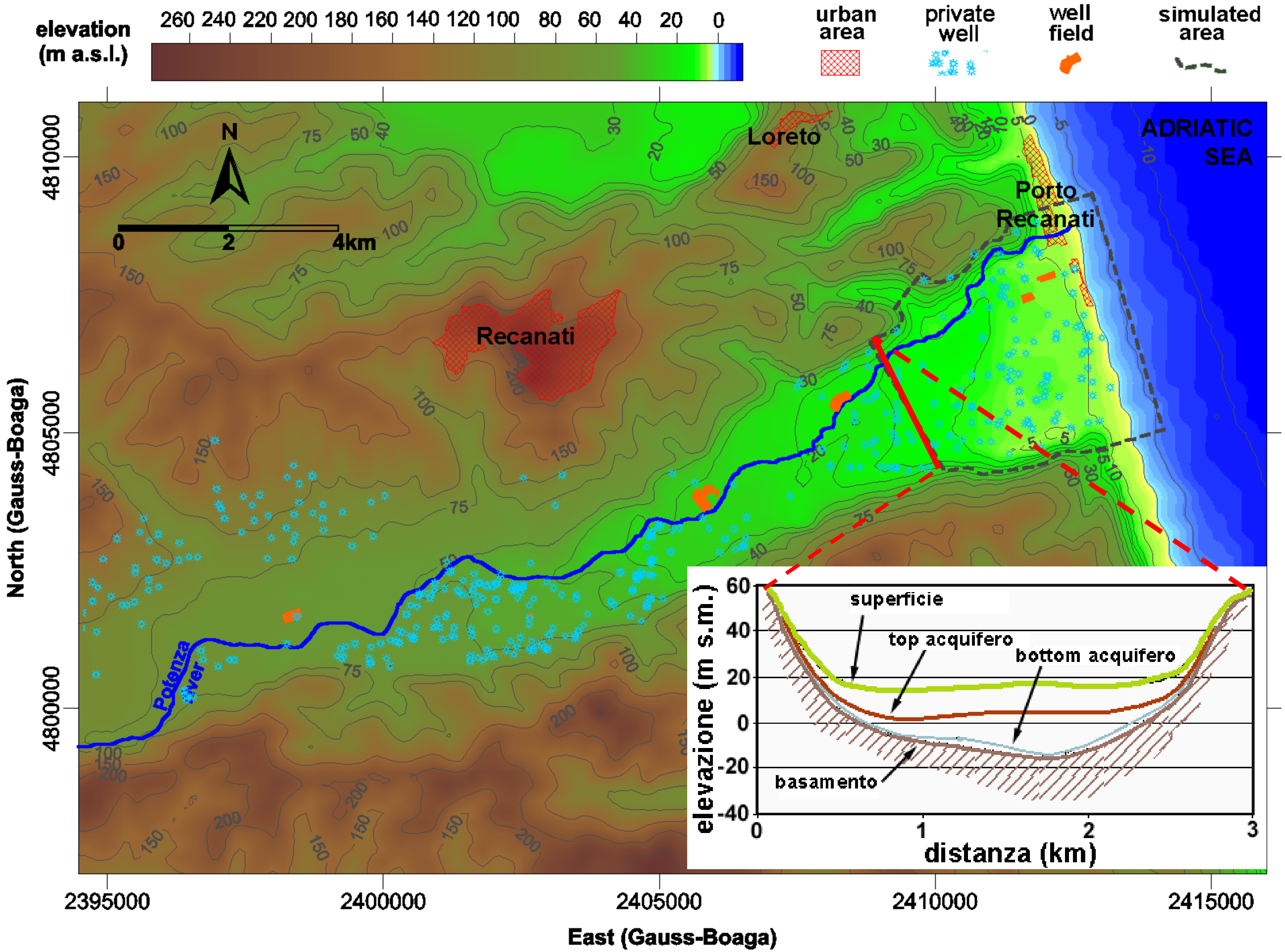


Figure 3-10 Types of springs. (a) Depression springs. (b) Perched springs. (c) Springs in cracked, impermeable rock. (d) Springs in a confined aquifer.

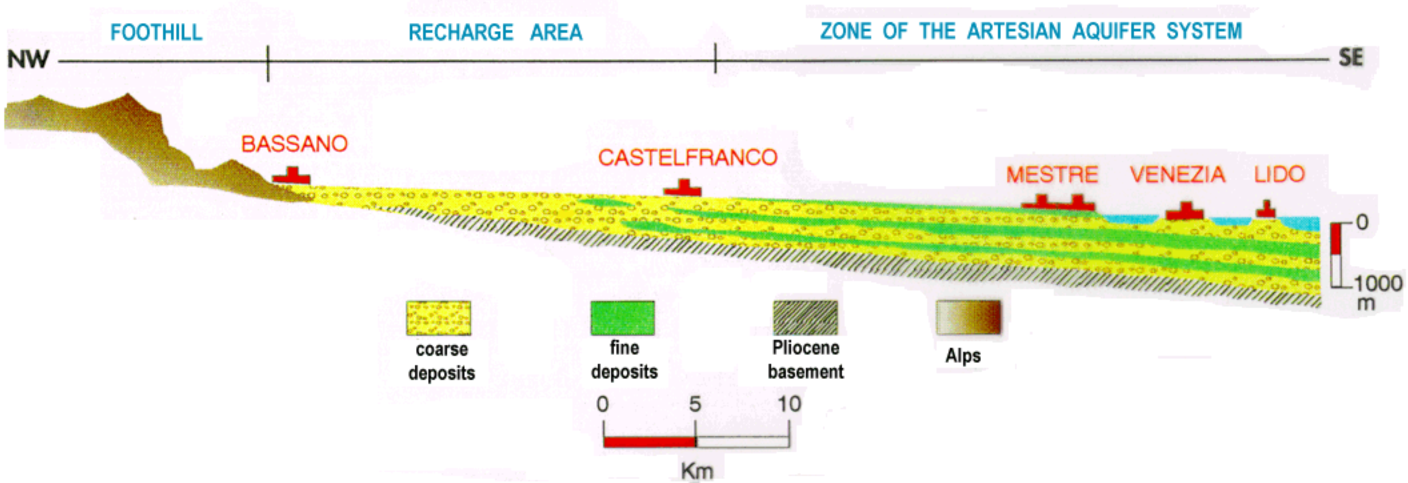
0
5 km
N

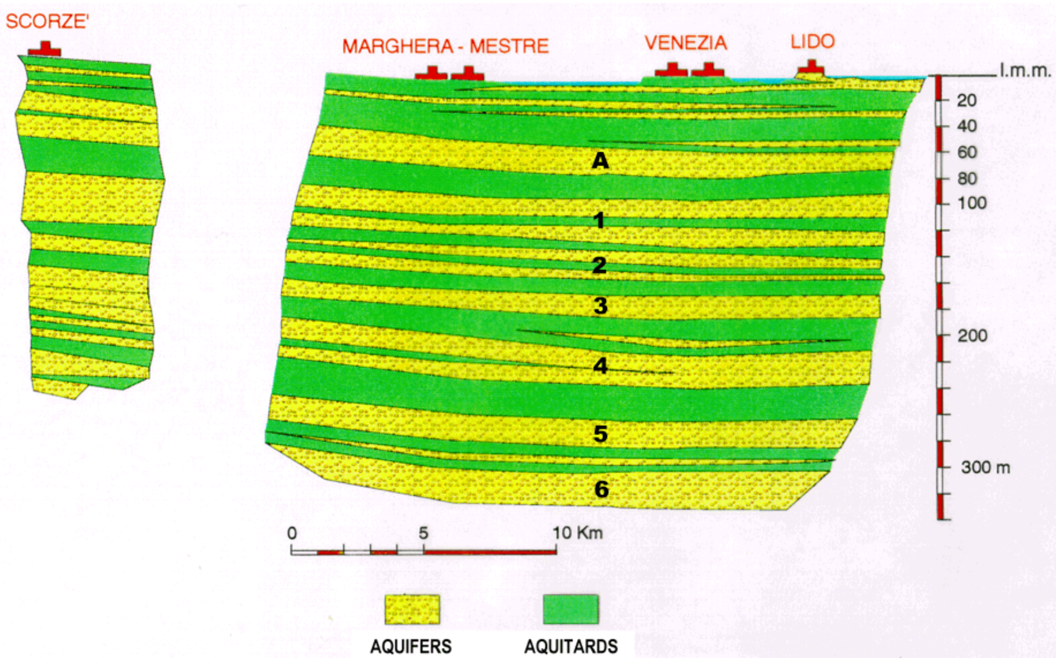


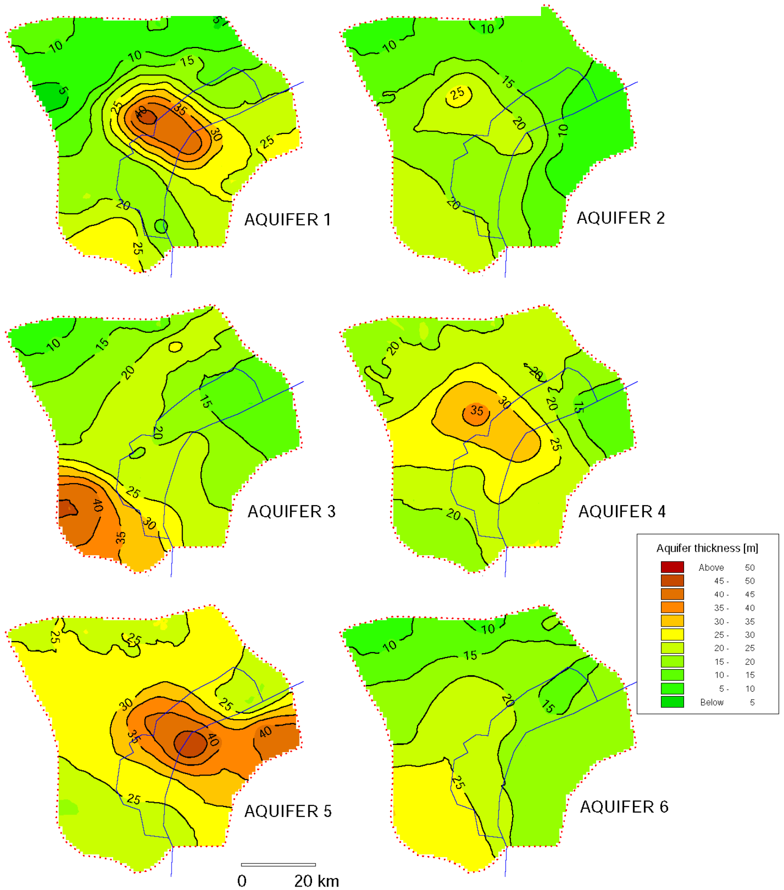

Ditch's piezometer
Field's piezometer
il fosso drena
il fosso alimenta
Water table [m s.m.m.]
Time [month]
-3.00
-3.05
-3.10
-3.15
-3.20
-3.25
-3.30
-3.35
-3.40
-3.45
-3.50
-3.55
-3.60
-3.65
-3.70
-3.75
Nov-2001
Dec-2001
Jan-2002
Feb-2002
Mar-2002
Apr-2002
May-2002
Jun-2002
Jul-2002
Aug-2002
Sep-2002
Oct-2002
Nov-2002
Dec-2002
Jan-2003
Feb-2003
Mar-2003

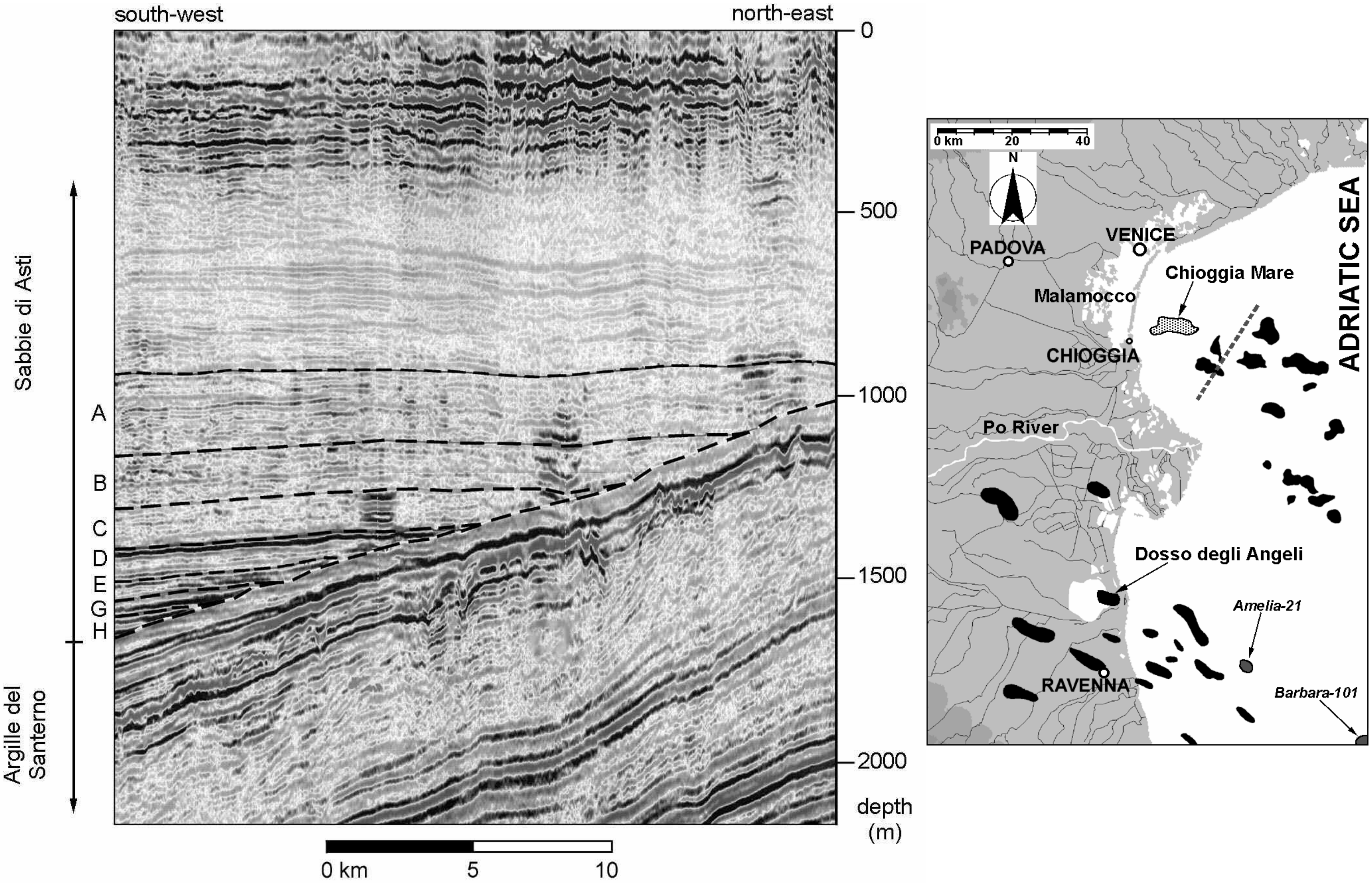


elevation (m a.s.l.)
260 240 220 200 180 160 140 120 100 80 60 40 20 0
urban area
private well
well field
simulated area
ADRIATIC SEA
Loreto
Porto Recanati
Recanati
Potenza river
N
0 2 4km
4810000
4805000
4800000
North (Gauss-Boaga)
2395000 2400000 2405000 2410000 2415000
East (Gauss-Boaga)
superficie
top acquifero
bottom acquifero
basamento
elevazione (m s.m.)
60 40 20 0 -20 -40
0 1 2 3
distanza (km)

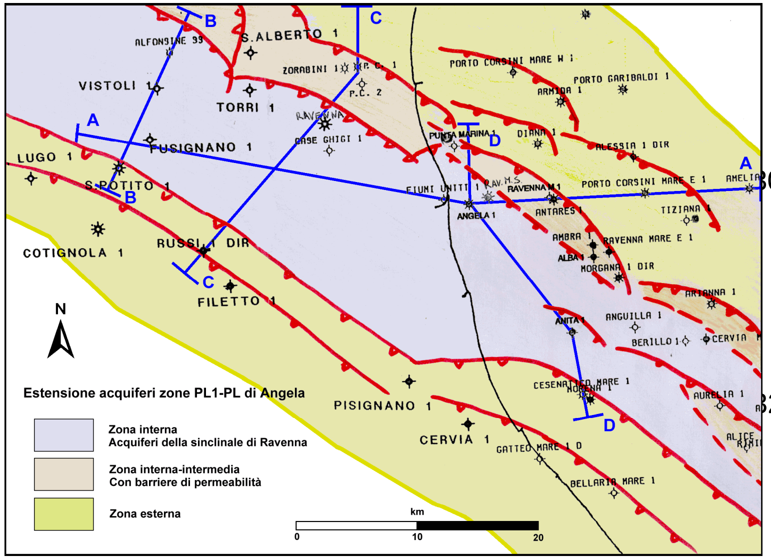

FOOTHILL
RECHARGE AREA
ZONE OF THE ARTESIAN AQUIFER SYSTEM
NW
SE
BASSANO
CASTELFRANCO
MESTRE
VENEZIA
LIDO
0
1000 m
coarse deposits
fine deposits
Pliocene basement
Alps
0
5
10
Km

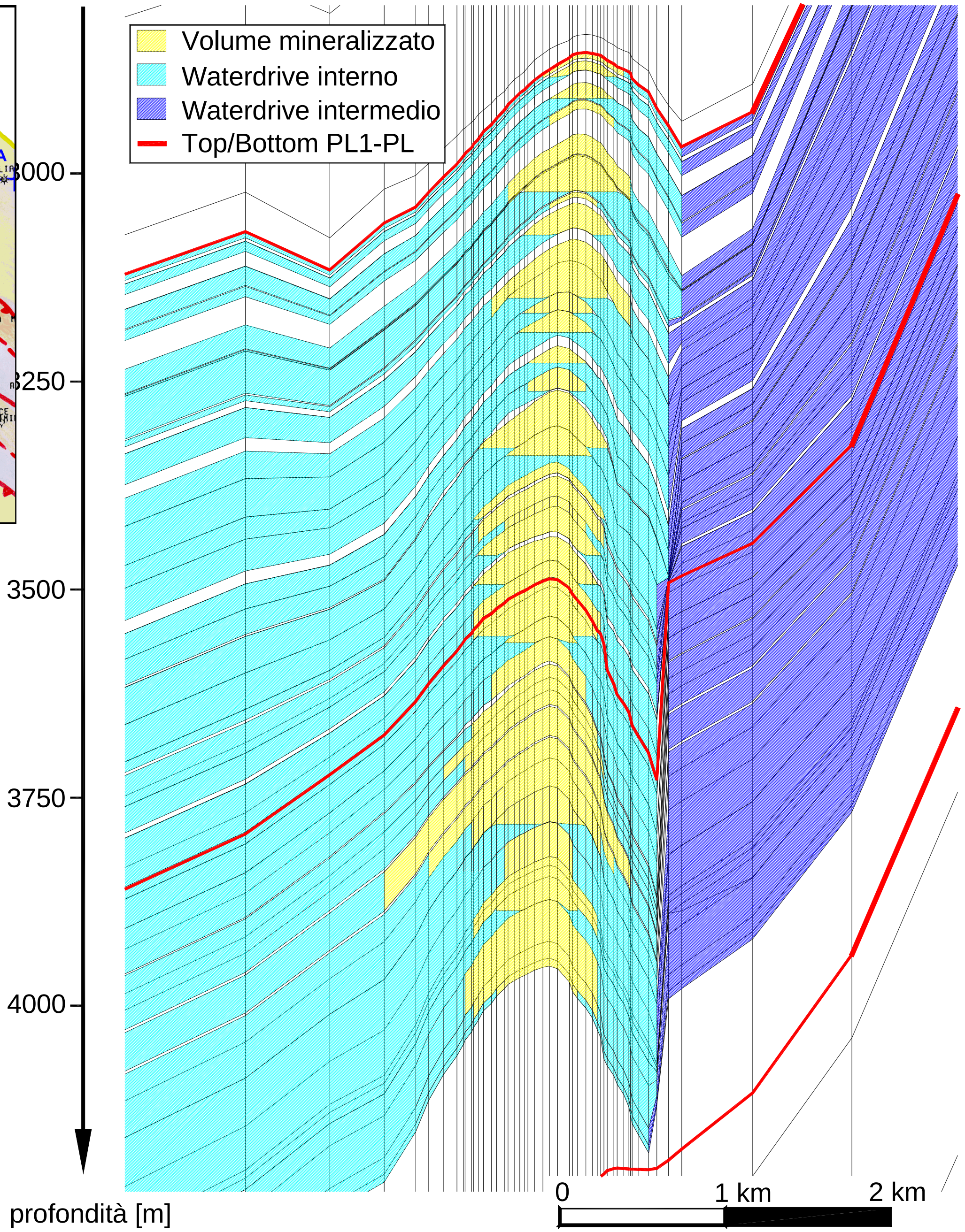

SCORZE'
MARGHERA - MESTRE
VENEZIA
LIDO
l.m.m.
20
40
60
80
100
200
300 m
A
1
2
3
4
5
6
0
5
10 Km
AQUIFERS
AQUITARDS


AQUIFER 1
AQUIFER 2
AQUIFER 3
AQUIFER 4
AQUIFER 5
AQUIFER 6
Aquifer thickness [m]
Above 50
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
Below 5
0
20 km



south-west
north-east
0
500
1000
1500
2000
depth (m)
Sabbie di Asti
Argille del Santerno
A
B
C
D
E
G
H
0 km
5
10
0 km
20
40
N
ADRIATIC SEA
VENICE
PADOVA
Chioggia Mare
Malamocco
CHIOGGIA
Po River
Dosso degli Angeli
Amelia-21
RAVENNA
Barbara-101


Estensione acquiferi zone PL1-PL di Angela
Zona interna
Acquiferi della sinclinale di Ravenna
Zona interna-intermedia
Con barriere di permeabilità
Zona esterna
km
0
10
20
N
A
B
C
D
S.ALBERTO 1
ALFONSINE 35
VISTOLI 1
TORRI 1
FUSIGNANO 1
LUGO 1
S.POTITO 1
COTIGNOLA 1
RUSSI 1 DIR
FILETTO 1
PISIGNANO 1
CERVIA 1
PORTO CORSINI MARE W 1
PORTO GARIBALDI 1
ARMIDA 1
DIANA 1
ALESSIA 1 DIR
PUNTA MARINA 1
ANGELA 1
ANTARES 1
PORTO CORSINI MARE E 1
TIZIANA 1
AMBRA 1
RAVENNA MARE E 1
MORGANA 1 DIR
ARIANNA 1
ANGUILLA 1
BERILLO 1
CERVIA
AURELIA 1
GATTEO MARE 1 D
BELLARIA MARE 1


Volume mineralizzato
Waterdrive interno
Waterdrive intermedio
Top/Bottom PL1-PL
3000
3250
3500
3750
4000
profondità [m]
0
1 km
2 km

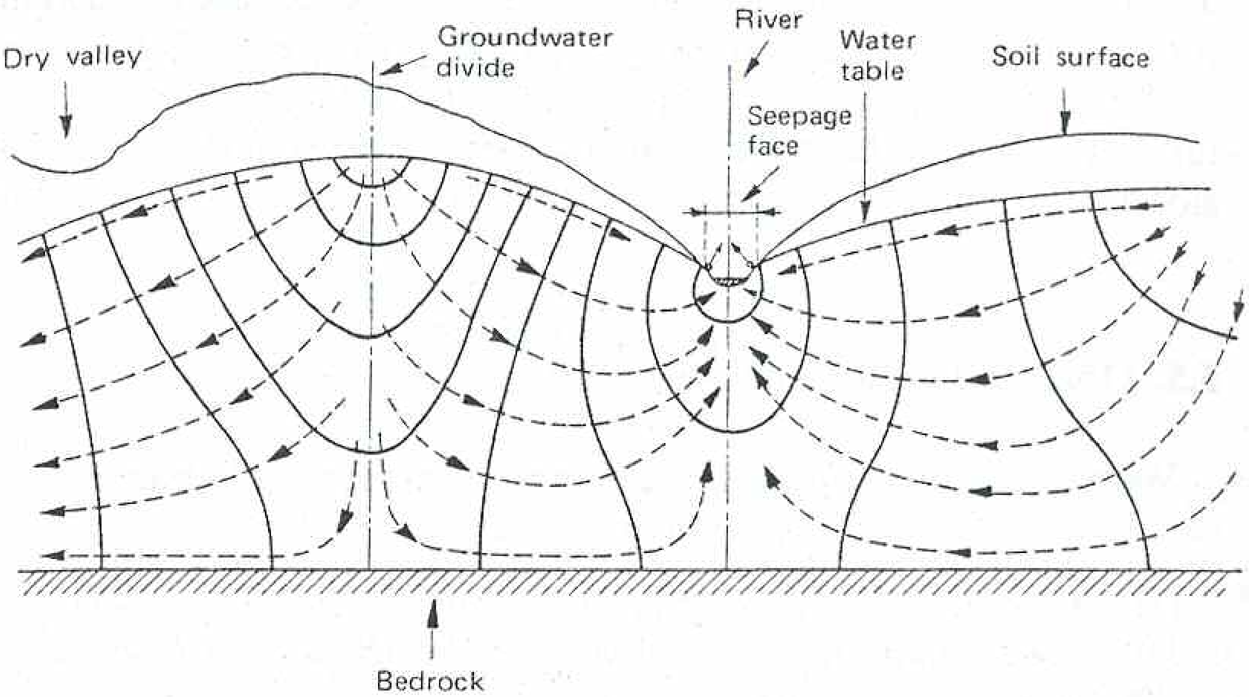


Fig. 6.1. Unconfined valley aquifer.

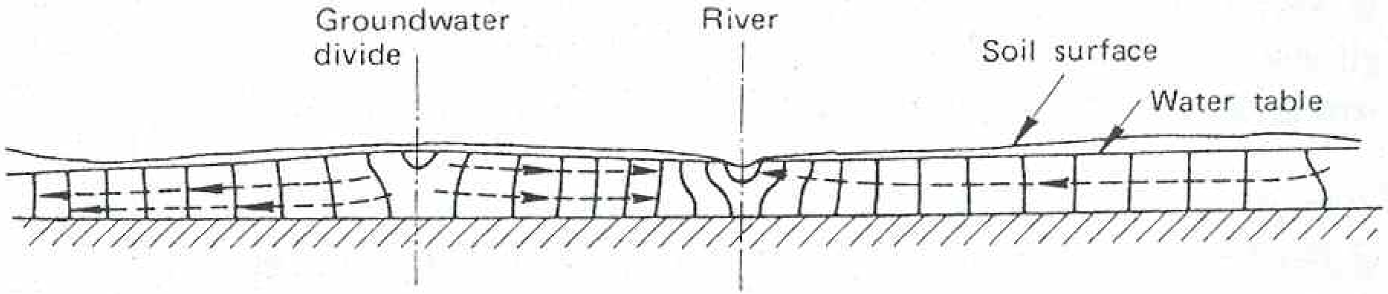


Fig. 6.2. Unconfined valley aquifer without scale distortion.

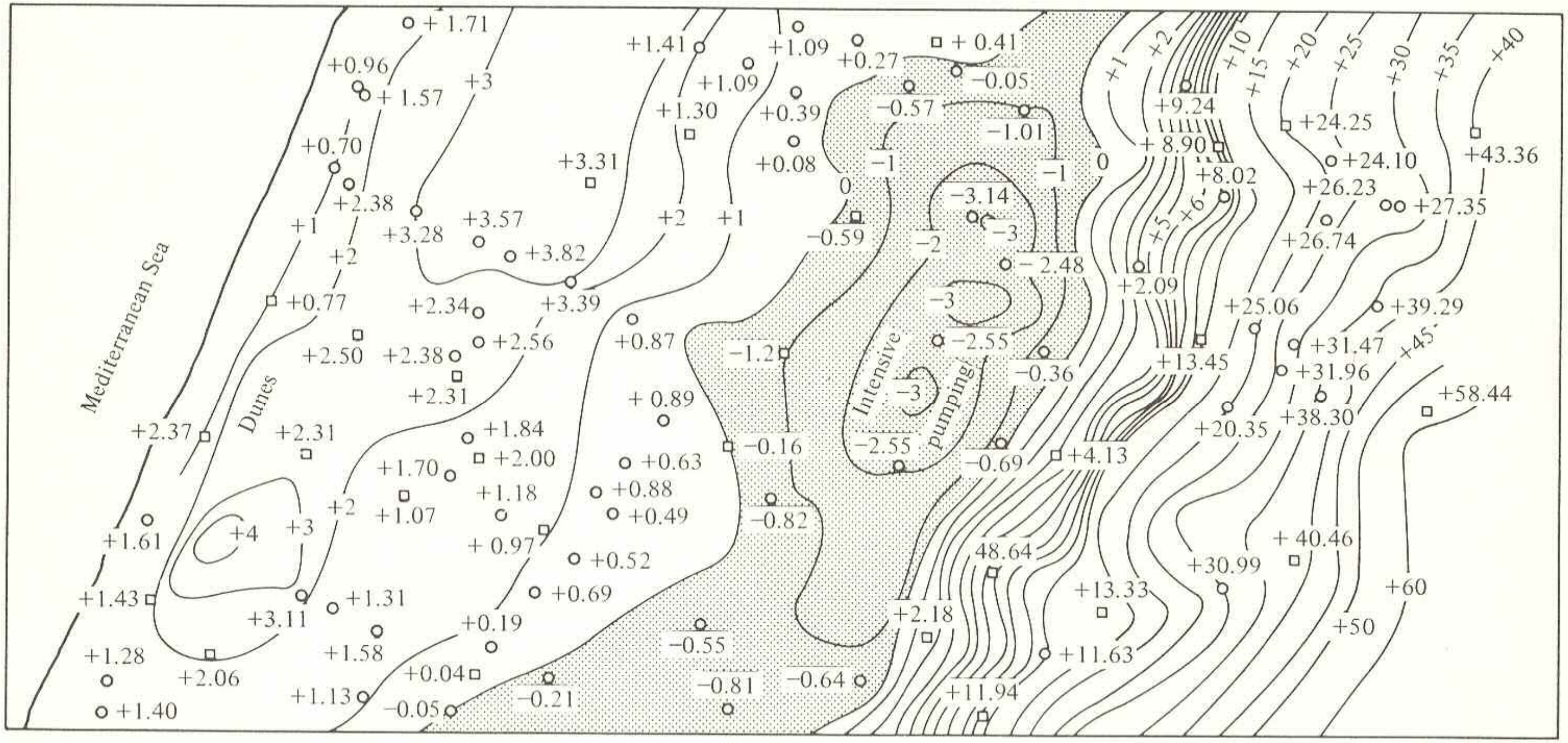
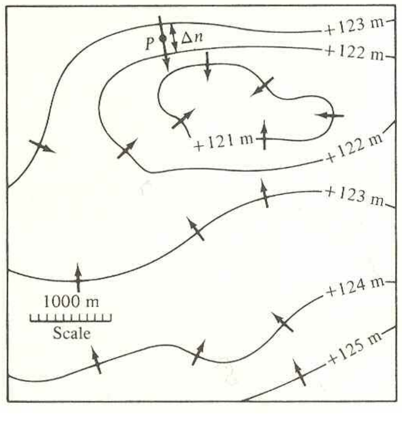


Figure 5-32 A groundwater contour map of a coastal aquifer (Israel) indicating increased recharge in the sand dunes along the coast and an area of intensive pumping. *(Courtesy of Hydrological Service, Israel.)*



Flow Nets

1. Linee di flusso Ψ e linee equipotenziali ϕ sono $\perp$
2. Linee di flusso sono $\parallel$ alla direzione del flusso
3. Due linee di flusso adiacenti individuano un *Tubo di Flusso (o Flux Tube).*
4. Un *reticolato di flusso* (*o Flow Net)* è formato da Ψ e ϕ distanziati tra di loro a passi costanti.
5. All'interno di un tubo di flusso la portata è costante.

$$\Delta q = K \Delta n_1 \frac{\Delta \phi}{\Delta s_1} = K \Delta n_2 \frac{\Delta \phi}{\Delta s_2} \qquad \left[\frac{L^2}{T}\right]$$

Mezzo omogeneo: $$\frac{\Delta n_1}{\Delta s_1} = \frac{\Delta n_2}{\Delta s_2}$$

Mezzo non omogeneo: $$K_1 \Delta n_1 \frac{\Delta \phi}{\Delta s_1} = K_2 \Delta n_2 \frac{\Delta \phi}{\Delta s_2} \qquad K_1 \frac{\Delta n_1}{\Delta s_1} = K_2 \frac{\Delta n_2}{\Delta s_2}$$

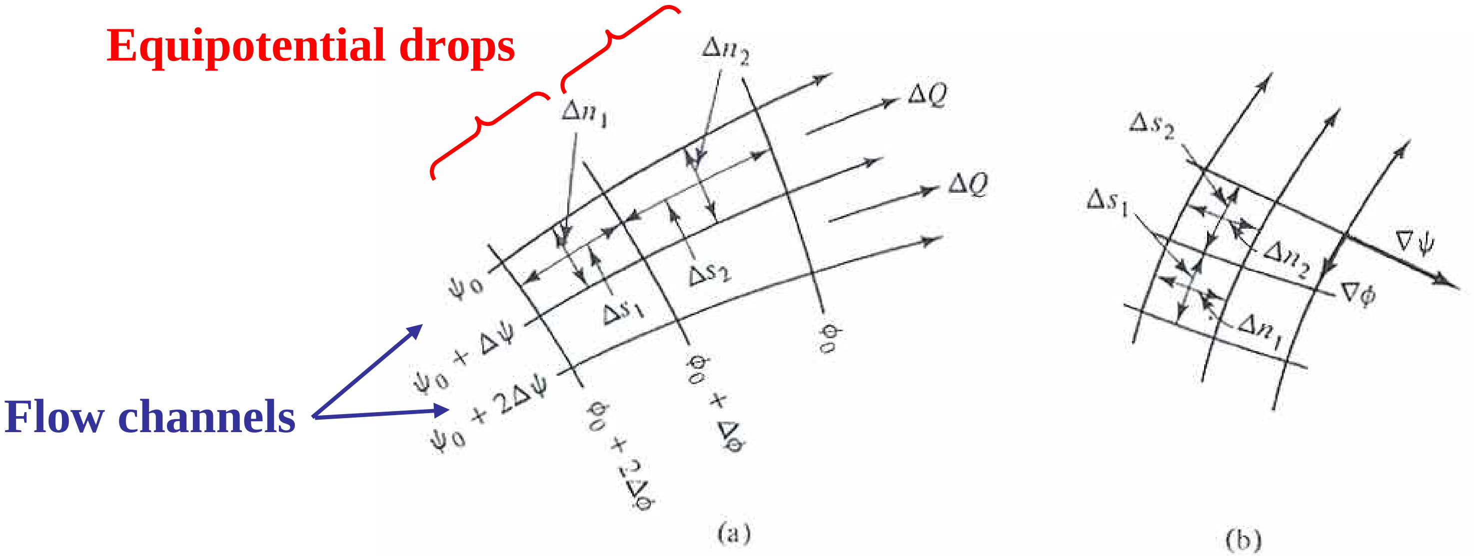


Figure 5-36 A portion of a flow net.

$$q_{total} = m\Delta q = mK\Delta n \frac{\Delta\phi}{\Delta s} = mK\Delta n \frac{\phi_{\max} - \phi_{\min}}{n\Delta s} = \frac{m}{n}\frac{\Delta n}{\Delta s} K\left(\phi_{\max} - \phi_{\min}\right) \quad \left[\frac{L^2}{T}\right]$$

Se le maglie sono quadrate:

$$\Delta q = K\Delta\phi \quad \left[\frac{L^2}{T}\right]$$

$$q_{total} = \frac{m}{n} K\left(\phi_{\max} - \phi_{\min}\right) \quad \left[\frac{L^2}{T}\right]$$

q_{total}: portata specifica per unità di larghezza

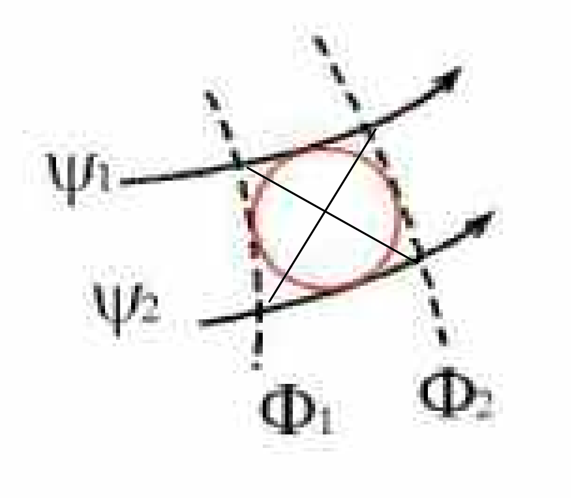
m: numero di tubi di flusso

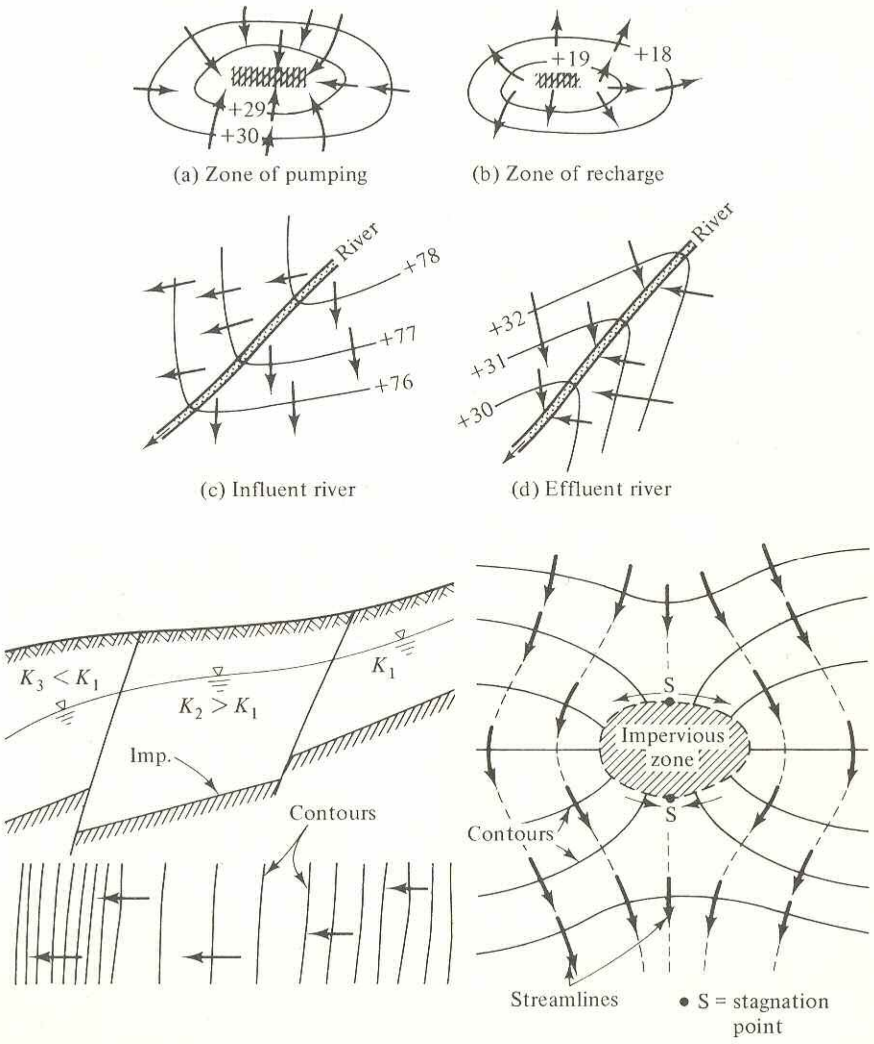
n: numero di $\Delta\Phi$

K: conducibilità idraulica

Per disegnare:

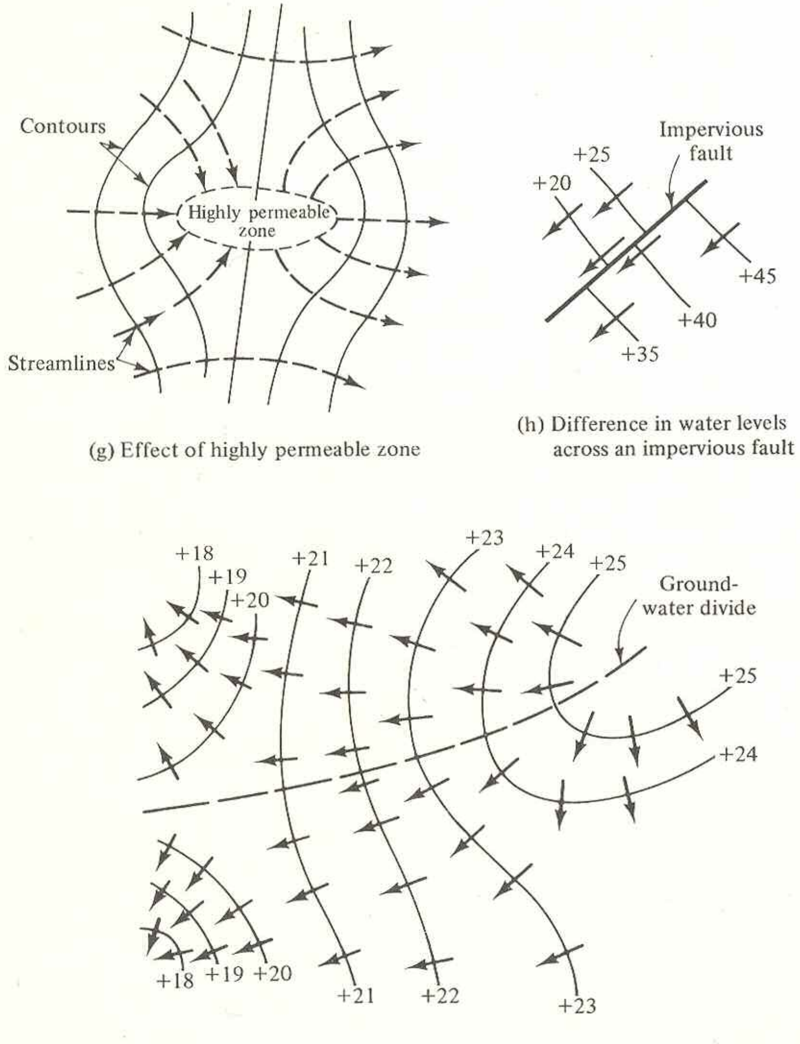
1. Disegnare il dominio in una scala opportuna
2. Imporre le condizioni al contorno e disegnare le linee Ψ e Φ vicino ai contorni
3. Disegnare le altre linee imponendo l'ortogonalità
4. Di solito poche linee sono sufficienti (10)





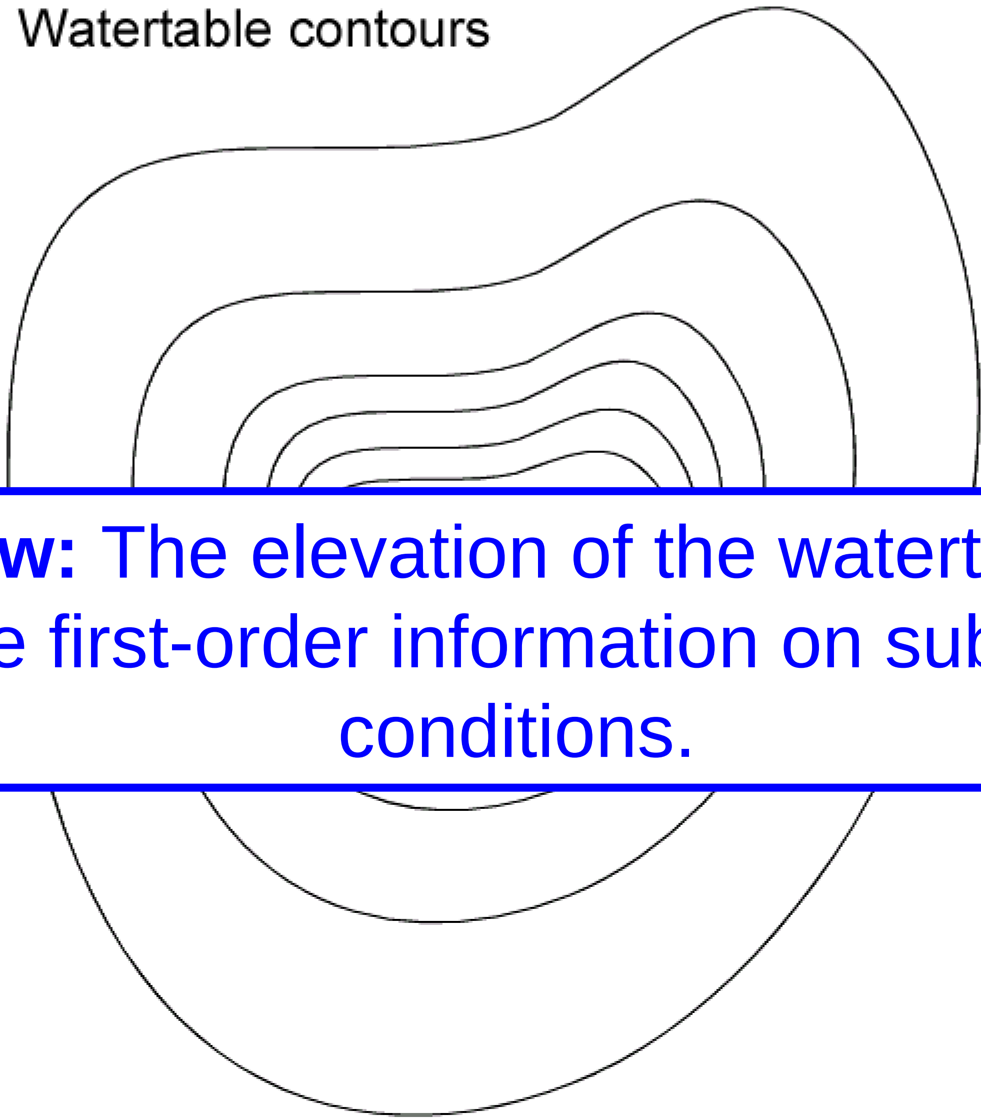
(e) Effect of variable transmissivity (f) Effect of impervious zone

Figure 5-34 Typical features of contour maps.

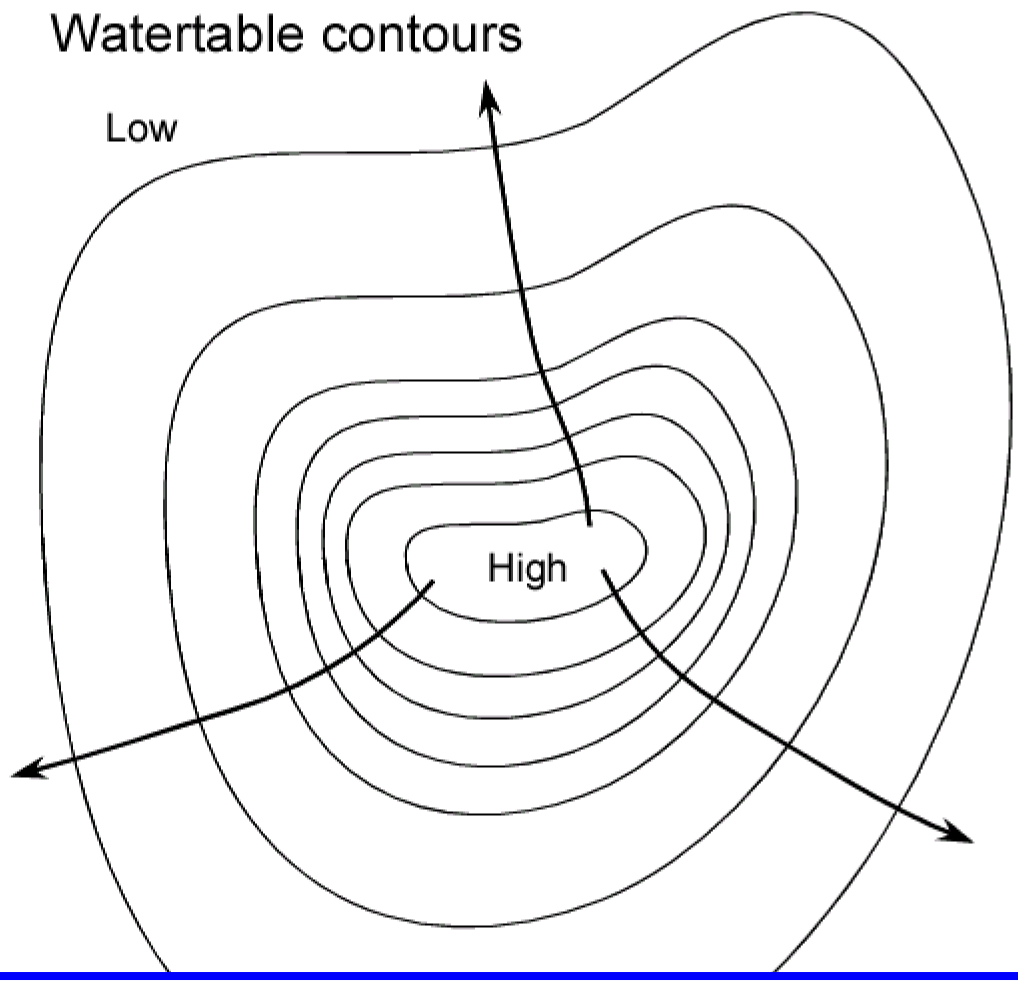


(i) A groundwater divide

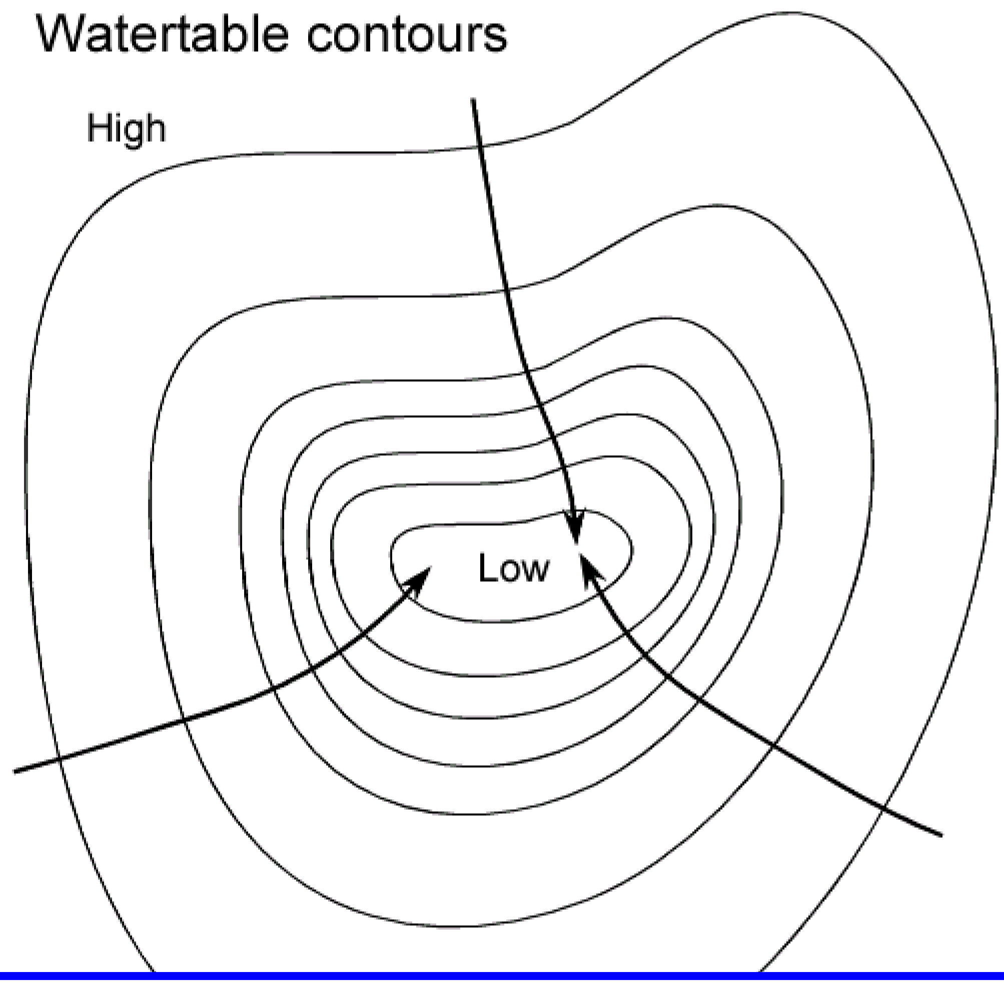
Figure 5-34 (cont.)



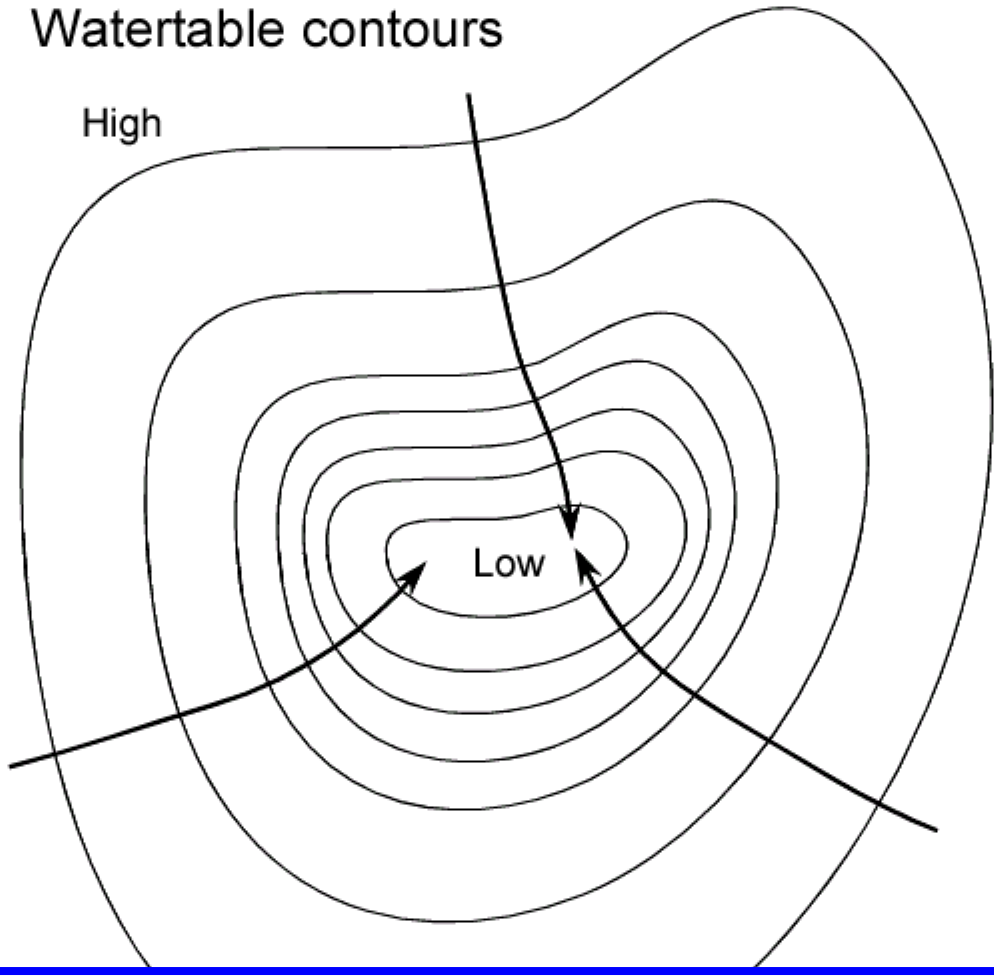
2D Flow: The elevation of the watertable can provide first-order information on subsurface conditions.



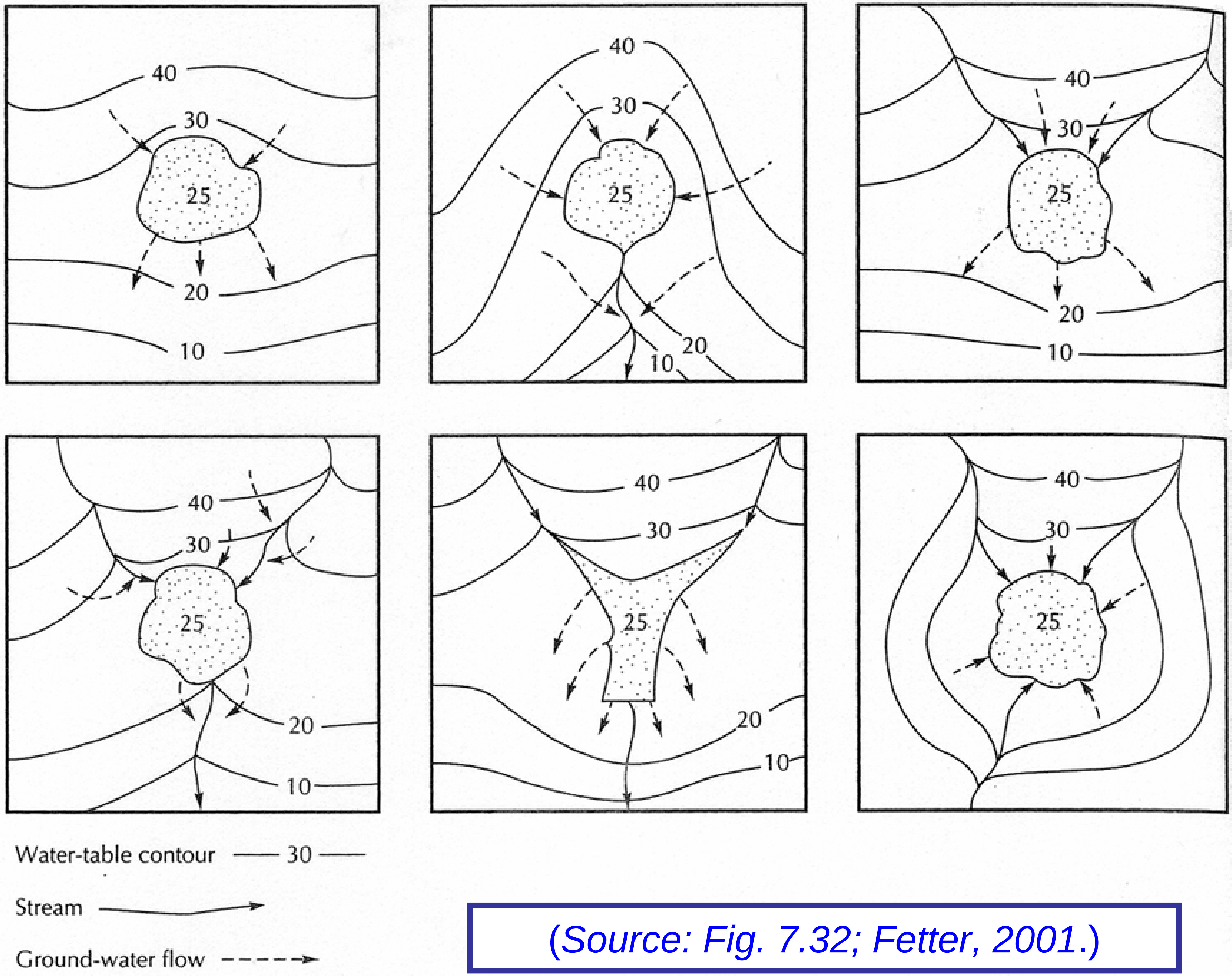
Flow from high elevations to low elevations.
Where's the ***recharge*** area?



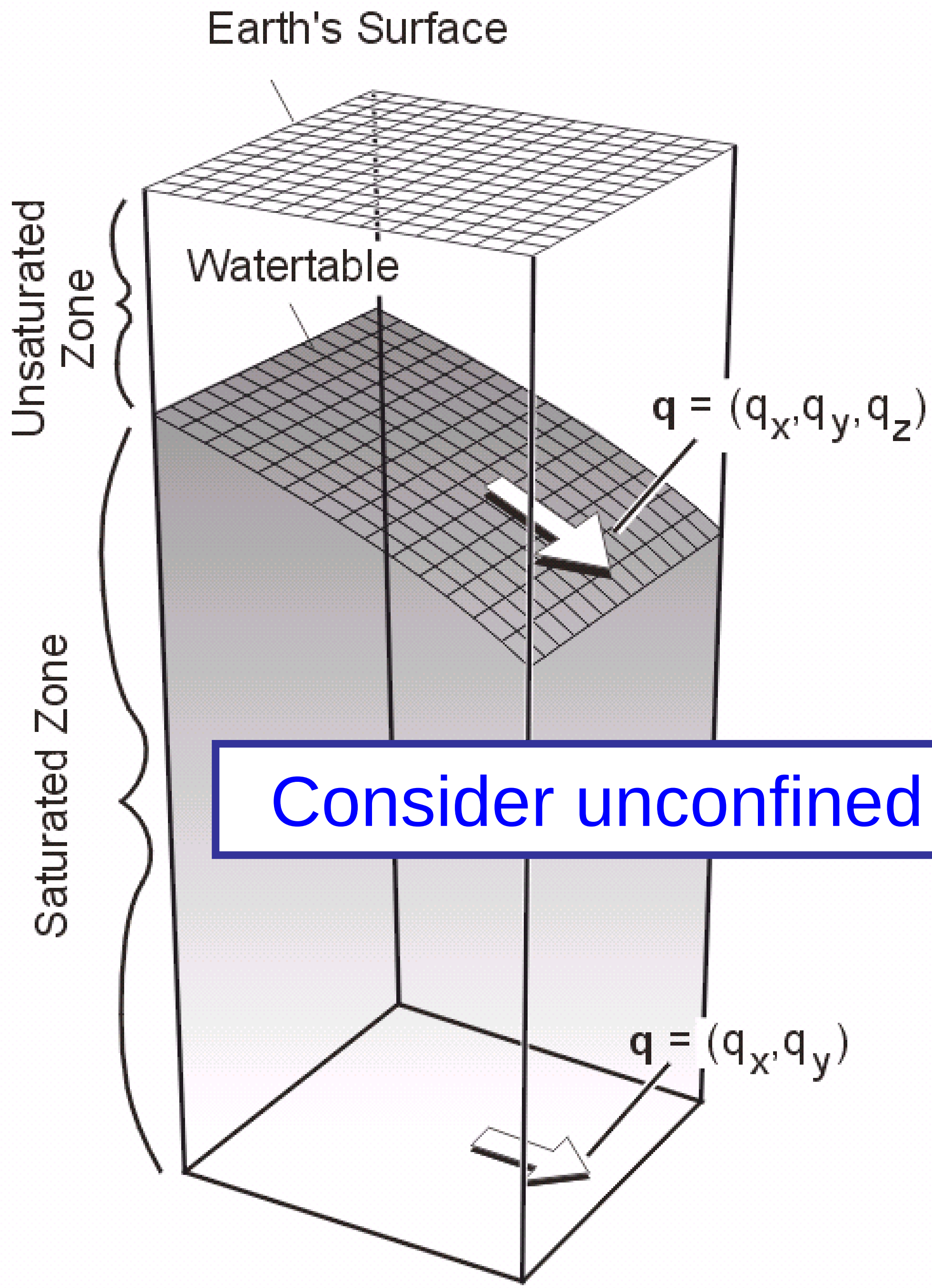
Flow from high elevations to low elevations.
Where’s the ***discharge*** area?



Note that these contours can simulate conditions in *either* the *horizontal* ***or*** the *vertical* plane.

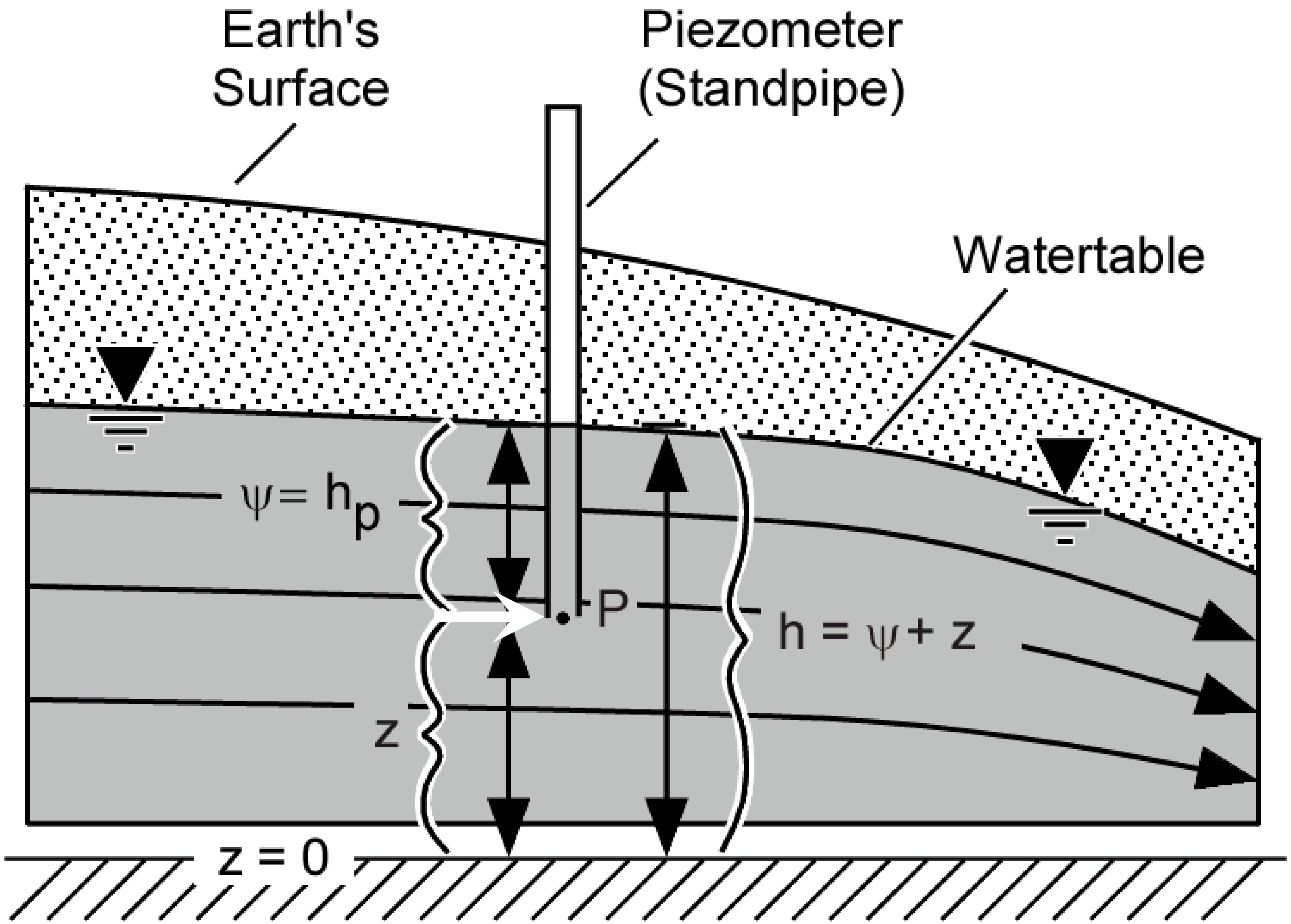


(*Source: Fig. 7.32; Fetter, 2001.*)



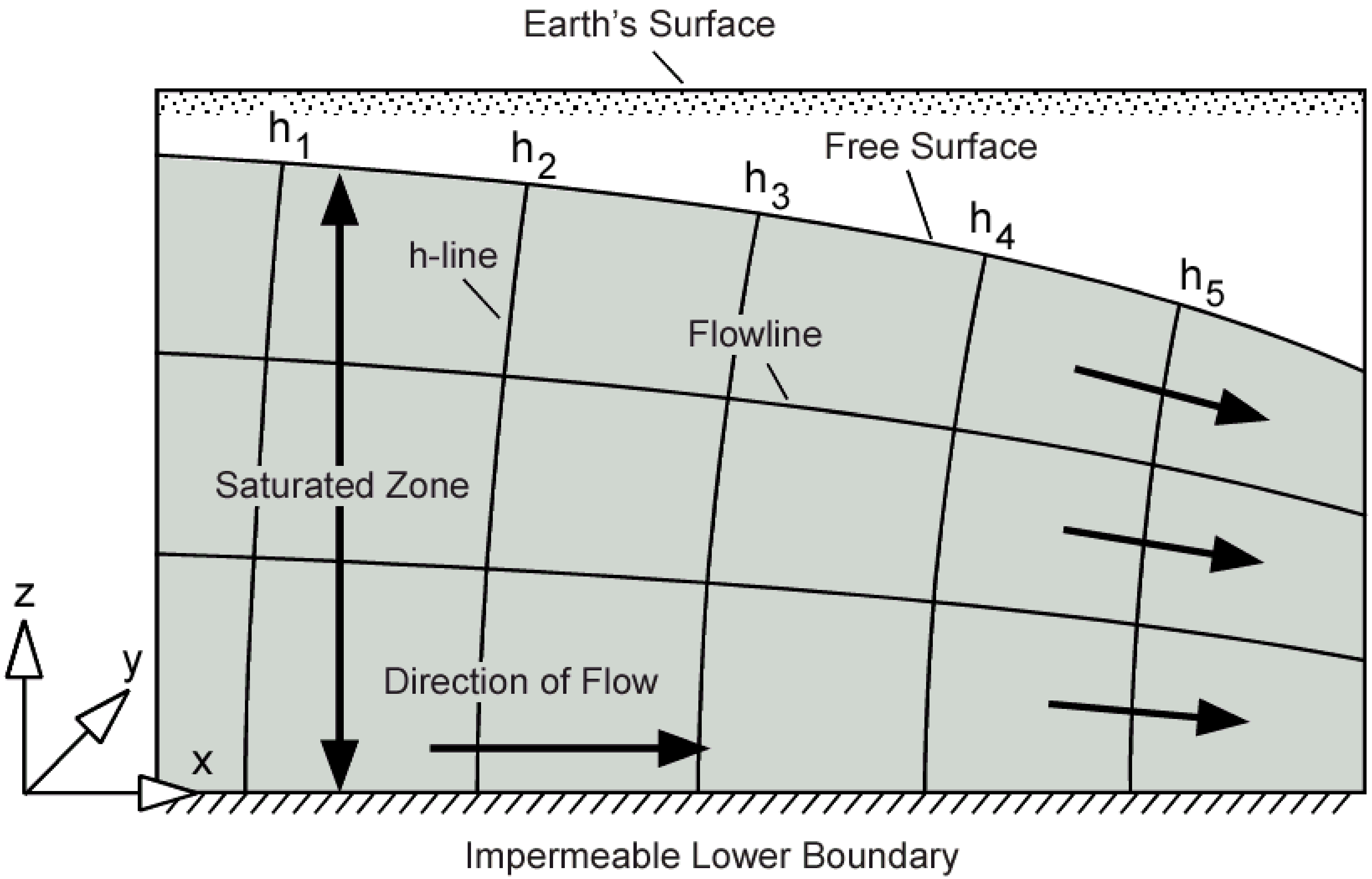
Consider unconfined flow.

***A piezometer in operation*:** The elevation of water in the piezometer provides a measure of $h(P)$.

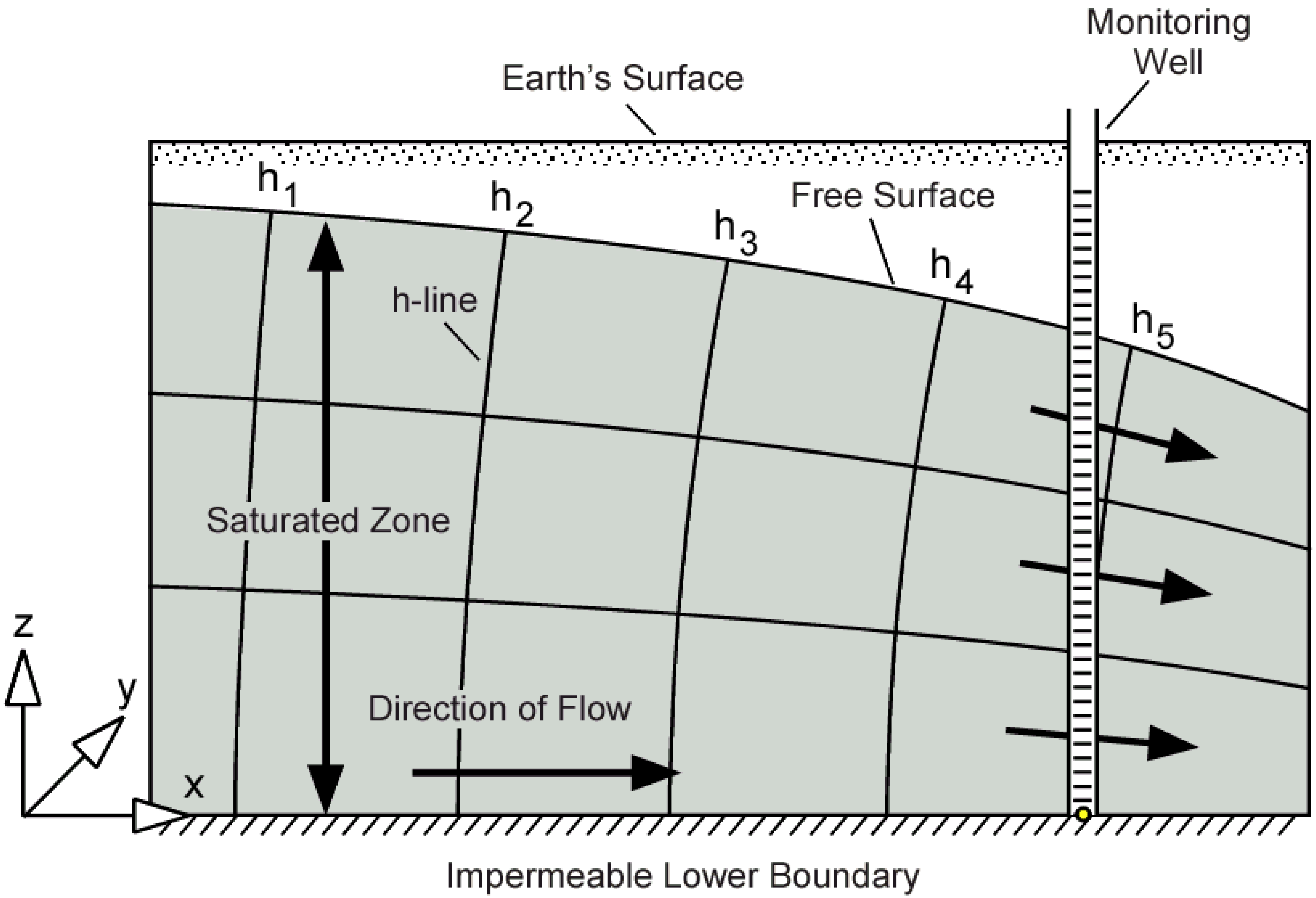


A piezometer measures the hydraulic head at a point.

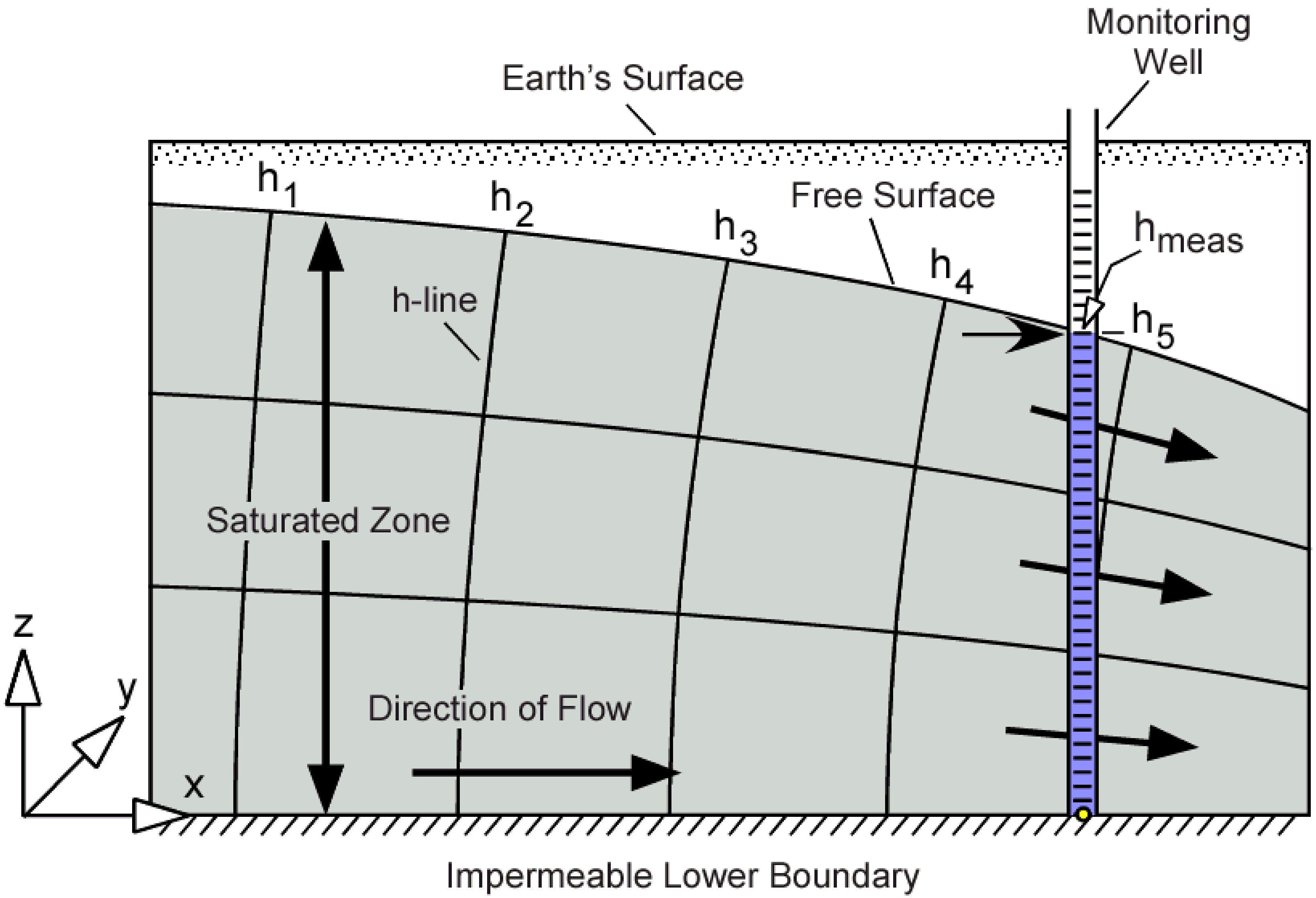
Example: Potentiometric surfaces (h-lines) for unconfined flow.



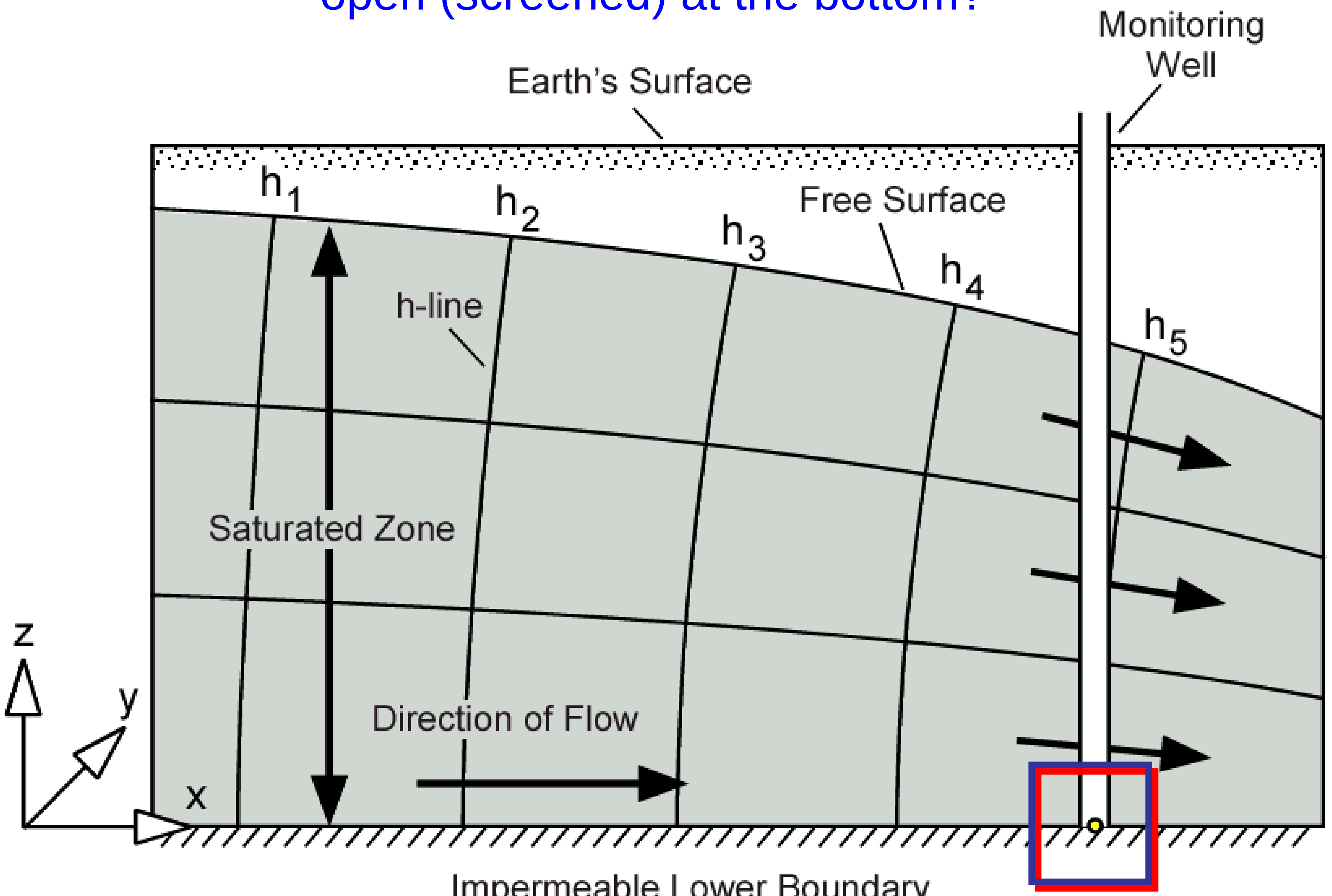
To what level does water rise in a vertical slotted (screened) well?



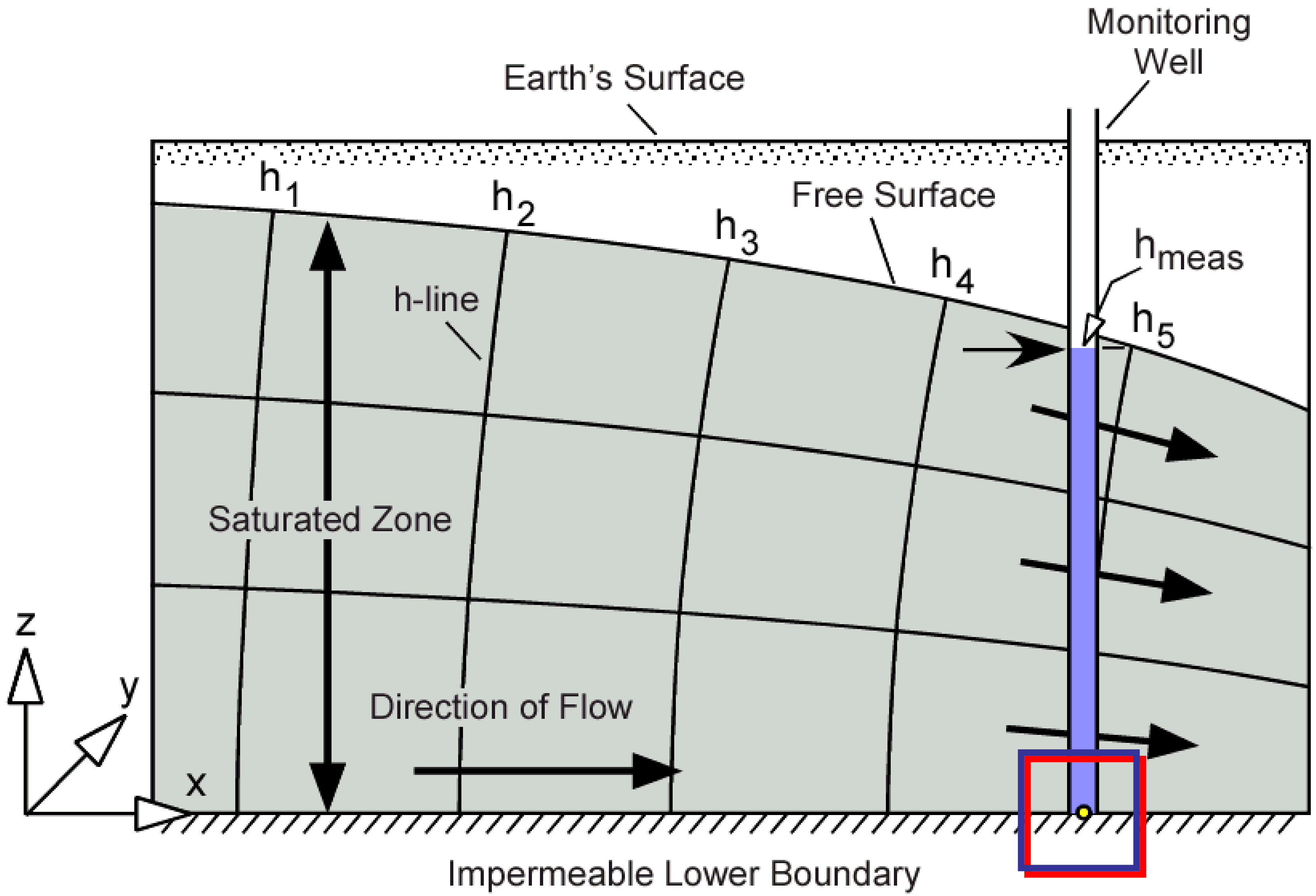
Questions – comments?

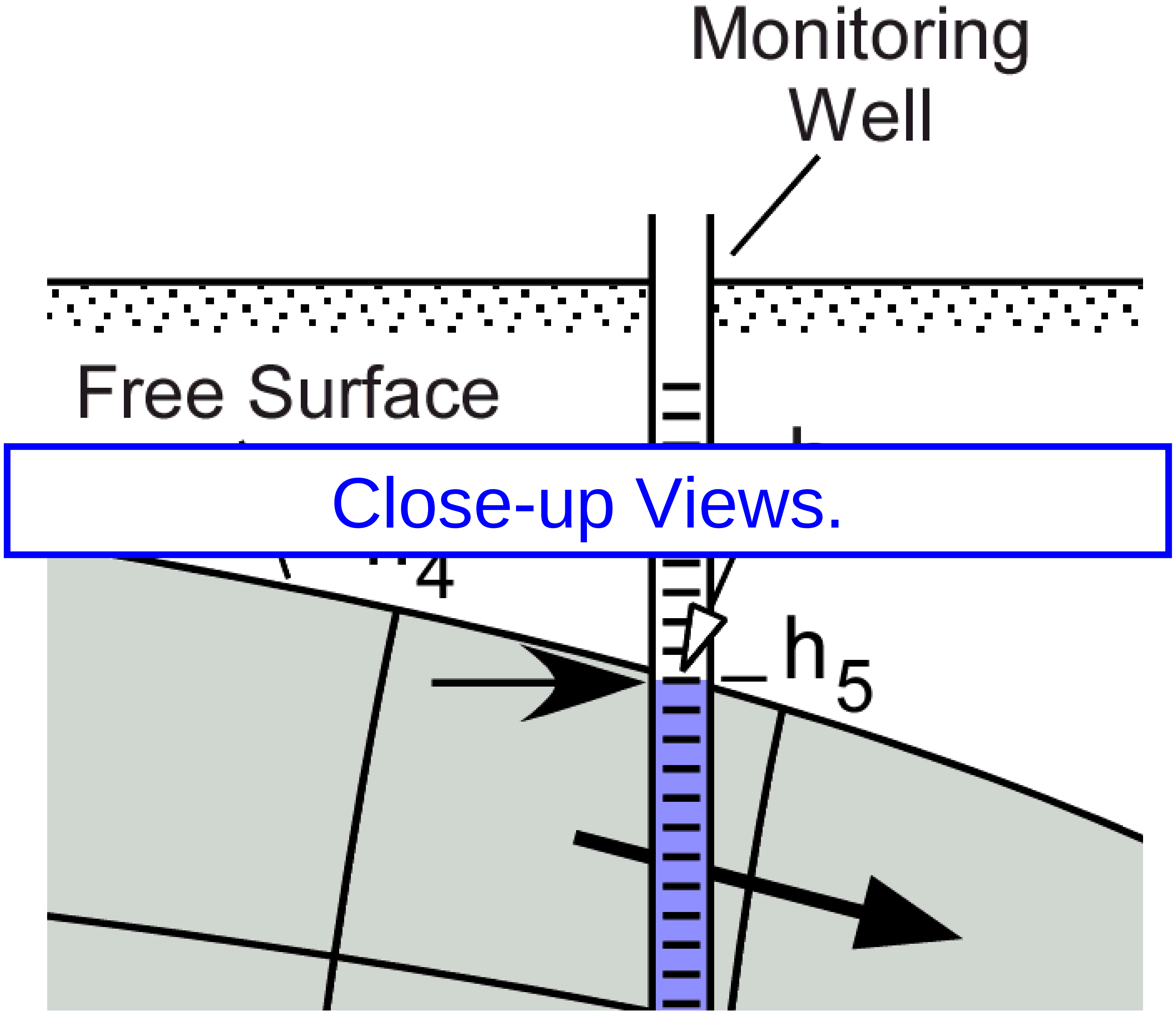


To what level does water rise in a vertical, continuously-cased well, open (screened) at the bottom?

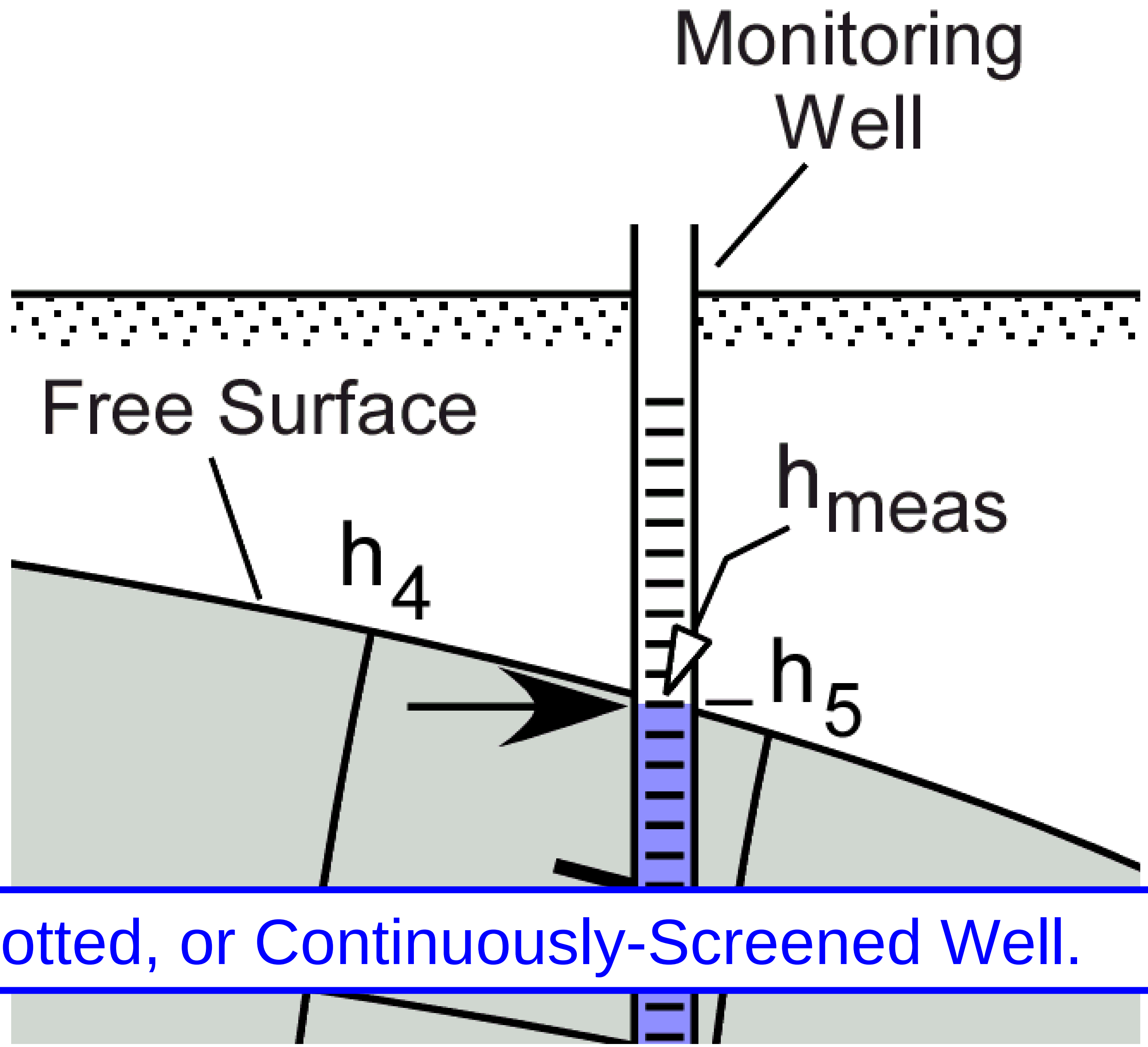


Questions – comments?

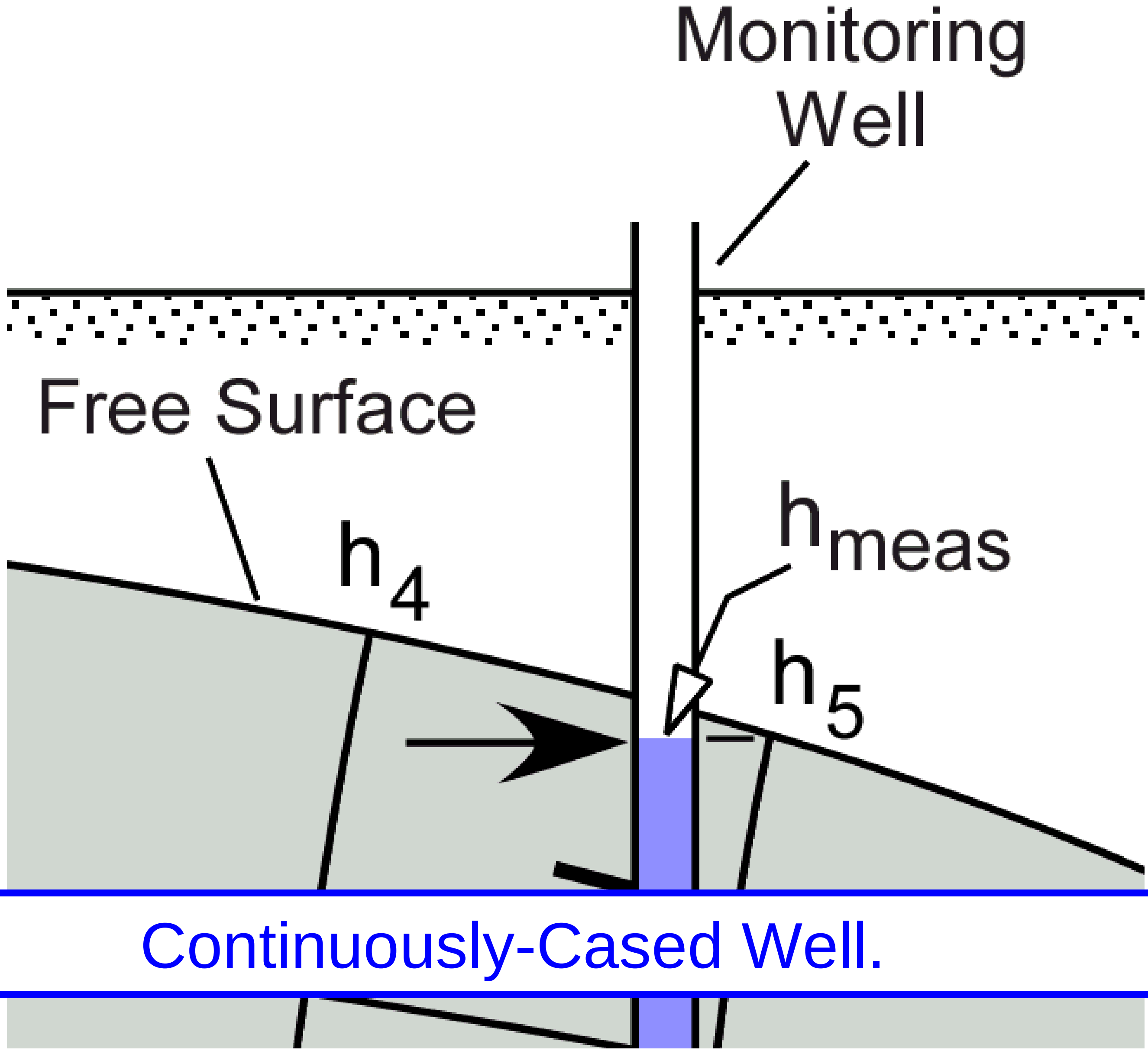




Close-up Views.

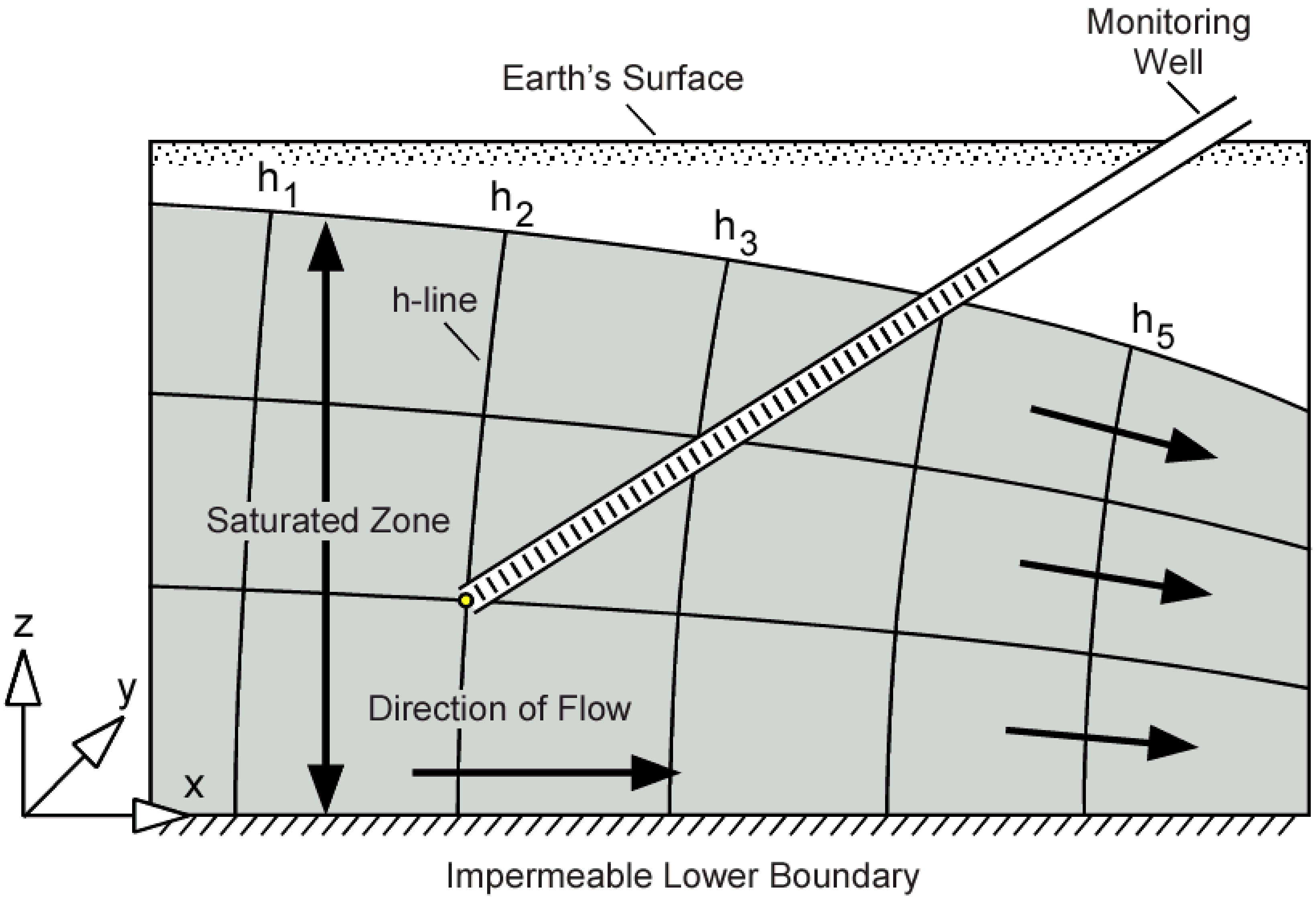


Slotted, or Continuously-Screened Well.

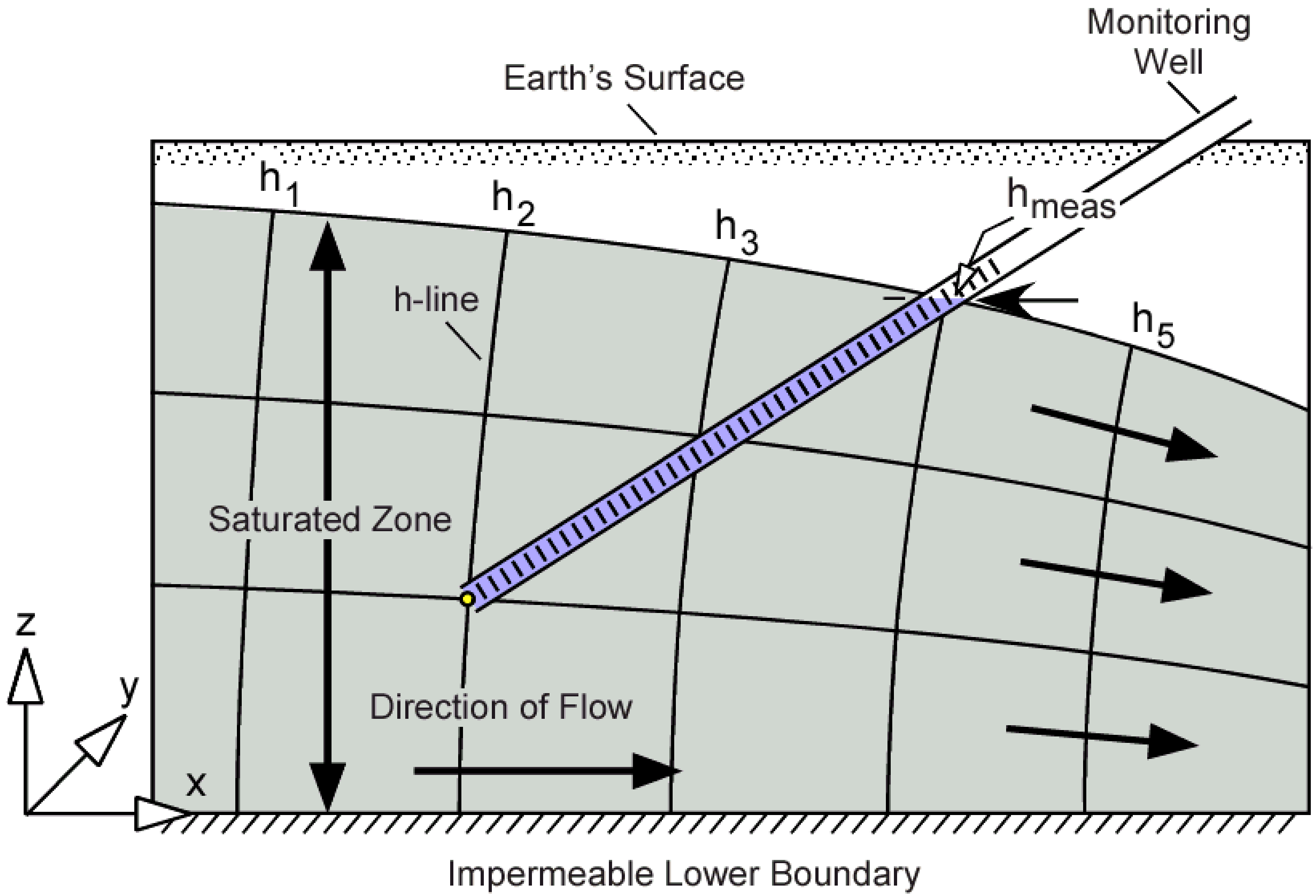


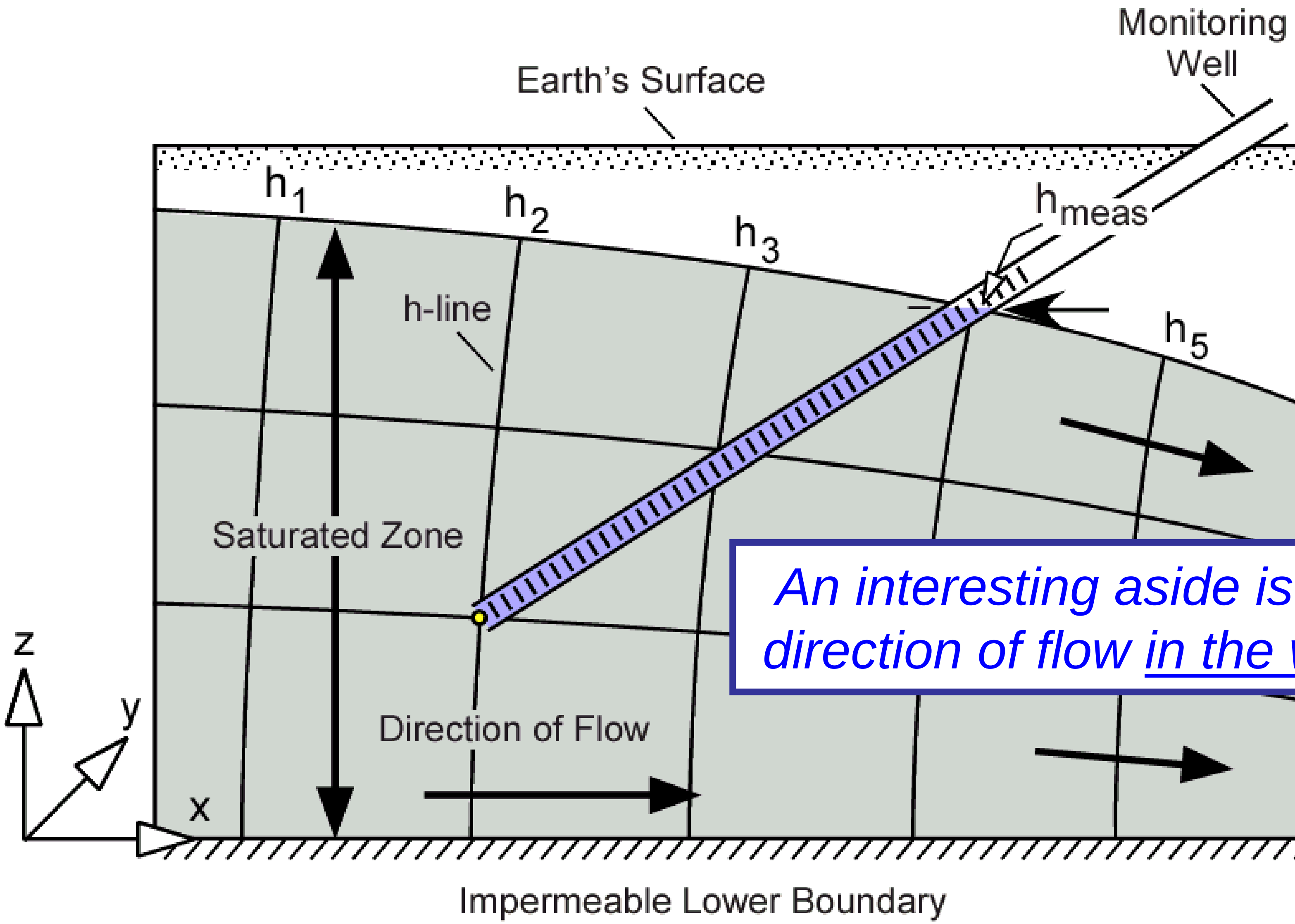
Continuously-Cased Well.

To what level does water rise in a slanted, slotted (screened) well?



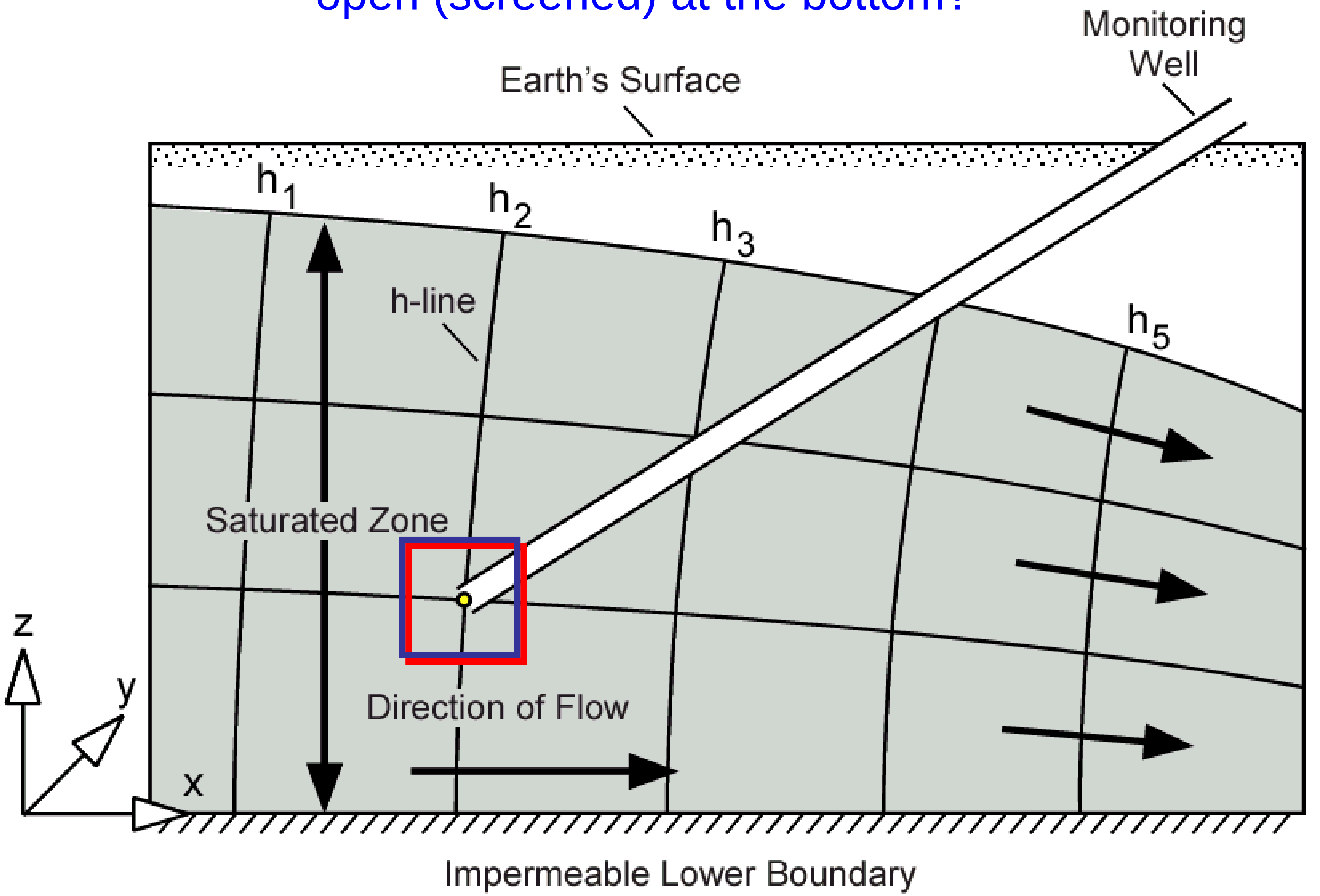
Questions – comments?



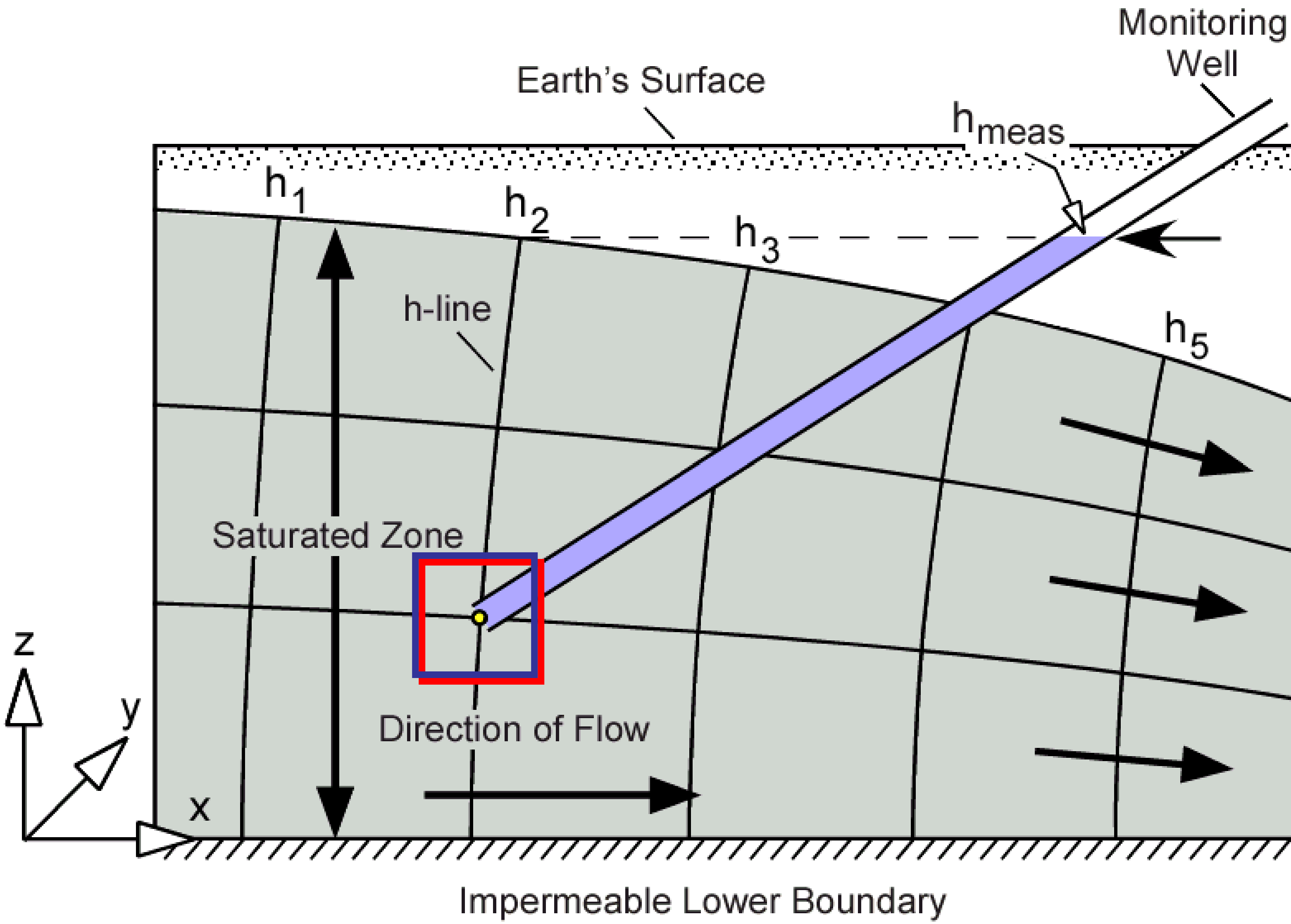


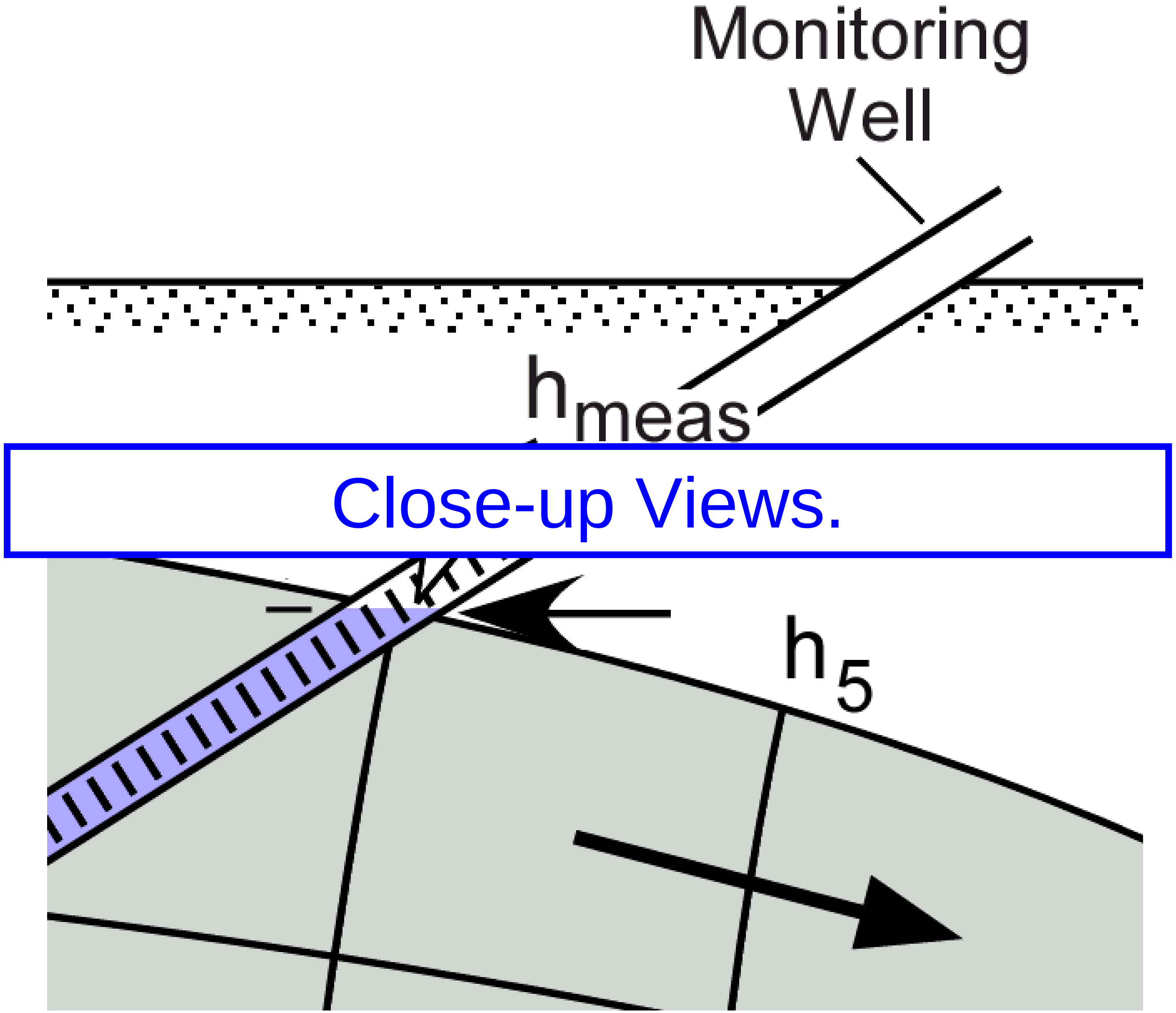
An interesting aside is the direction of flow <u>in the well</u>.

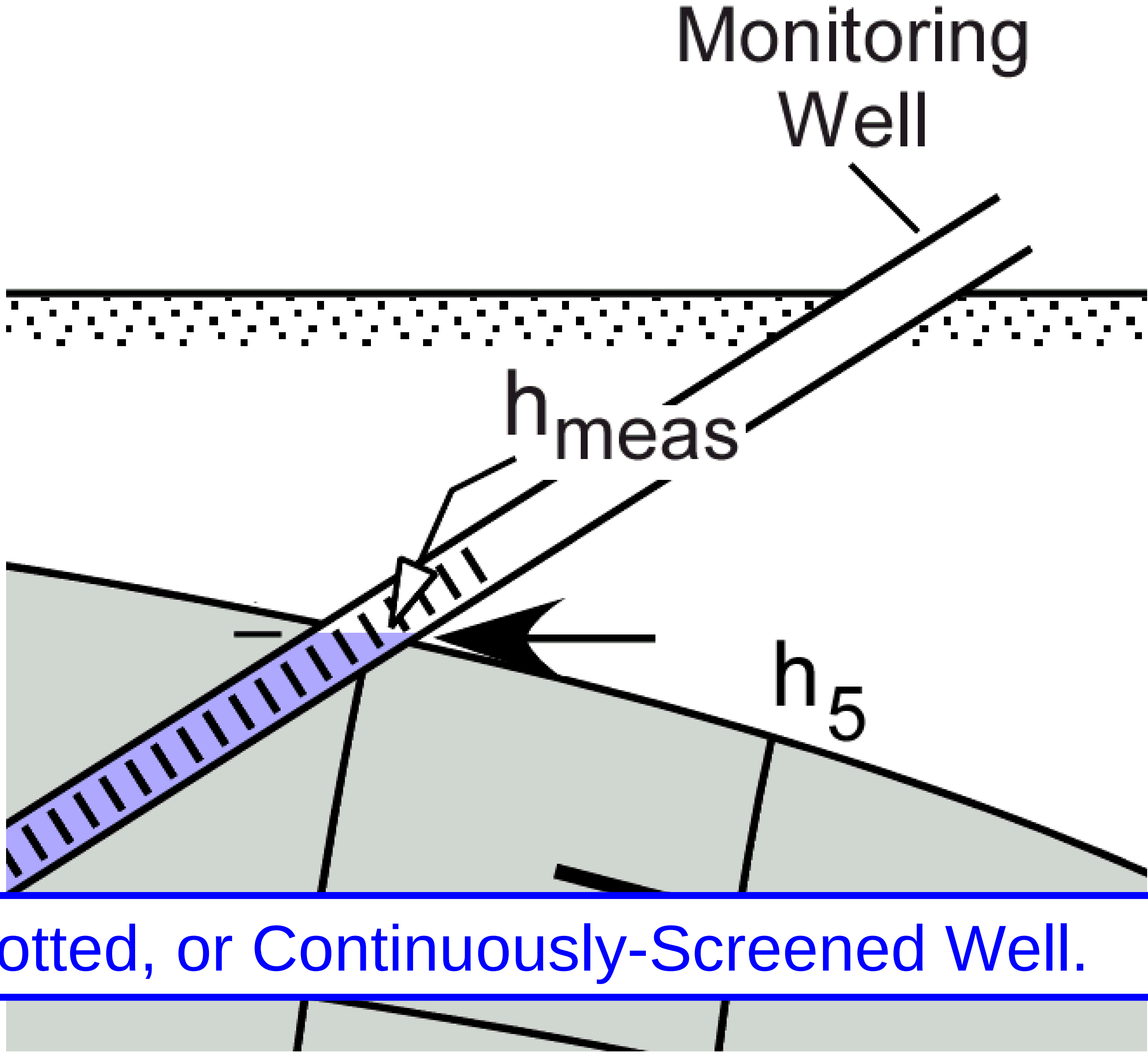
To what level does water rise in a slanted, continuously-cased well, open (screened) at the bottom?



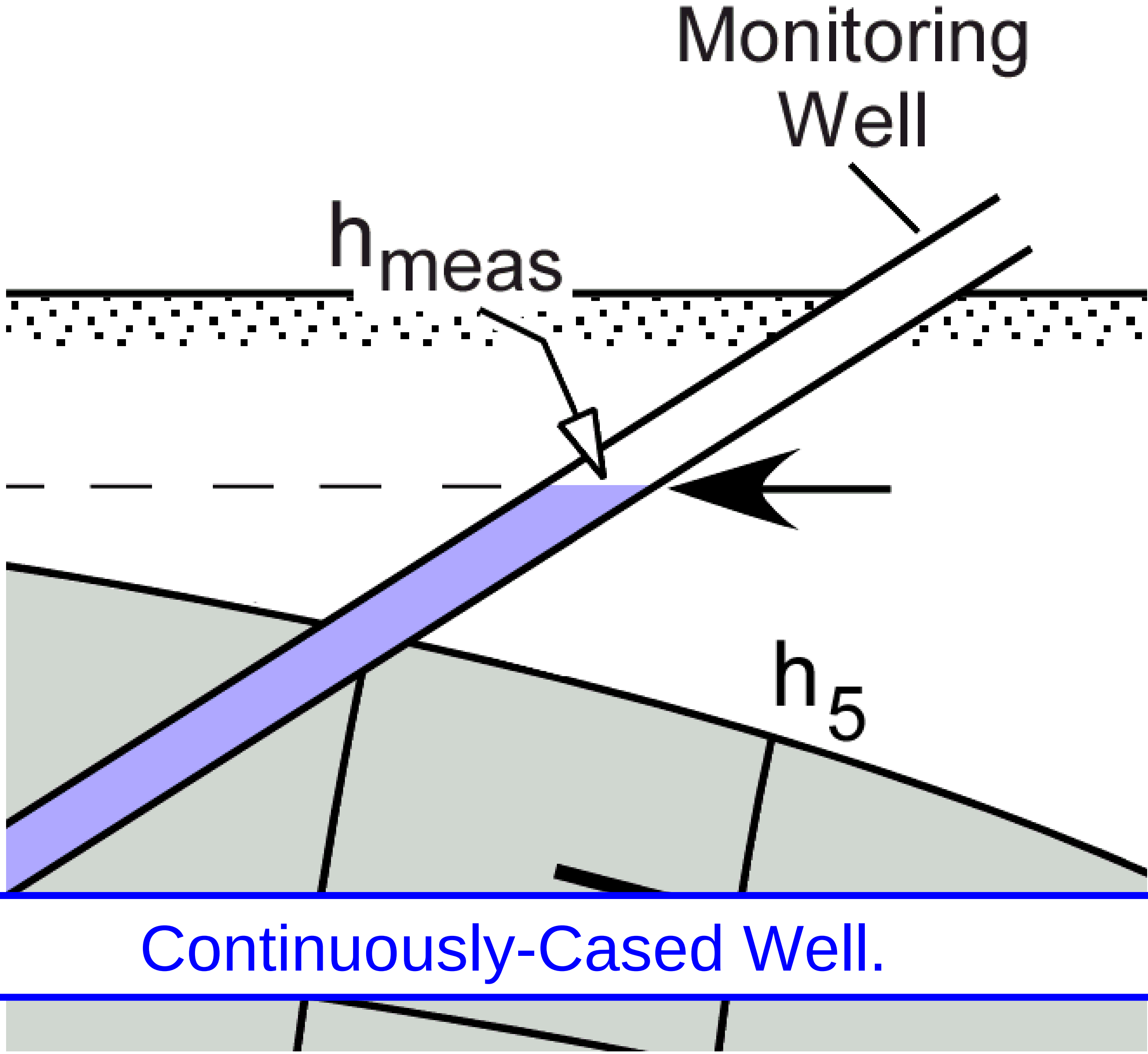
Questions – comments?



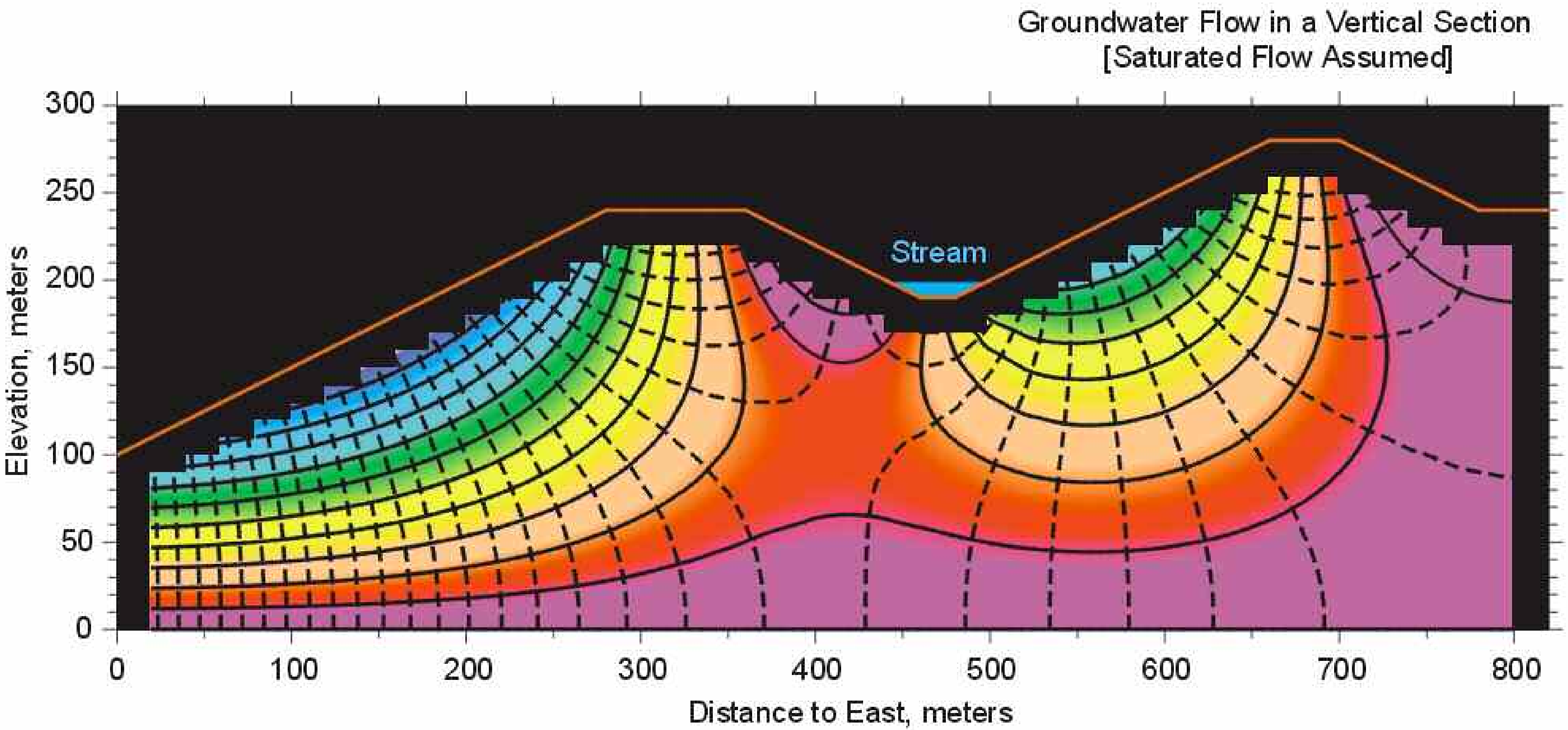

Monitoring
Well
h meas
Close-up Views.
h 5



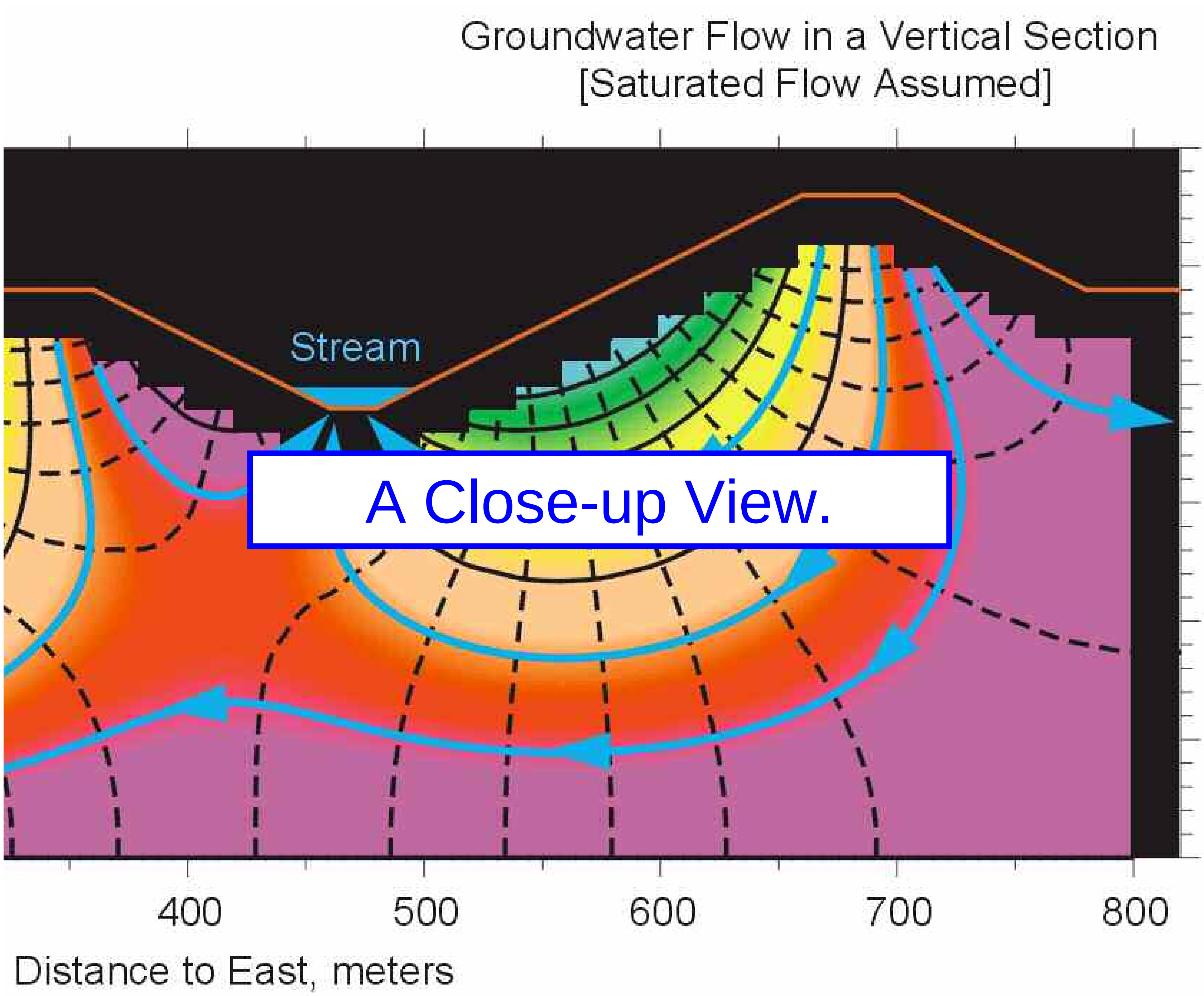
Slotted, or Continuously-Screened Well.



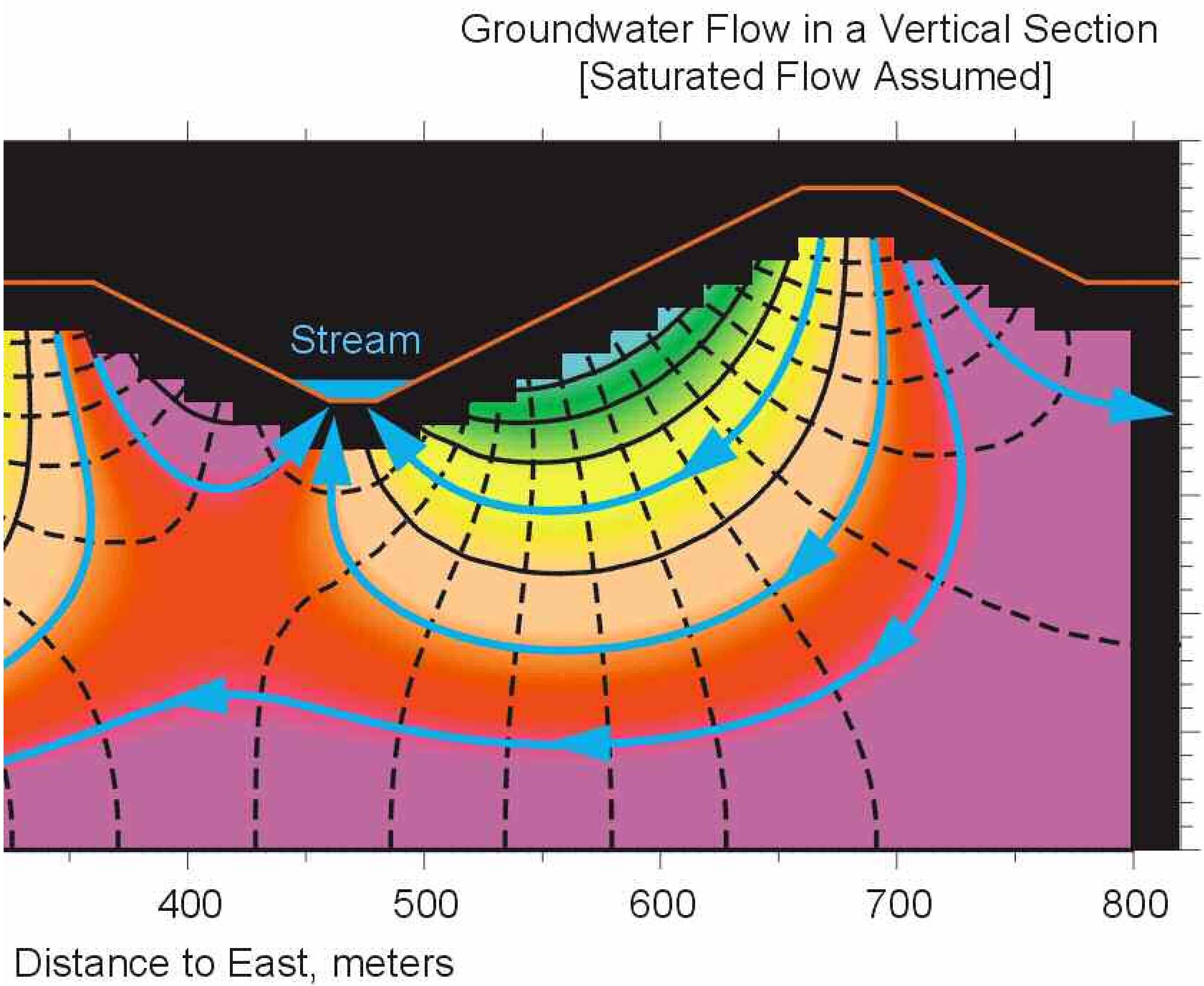
Continuously-Cased Well.



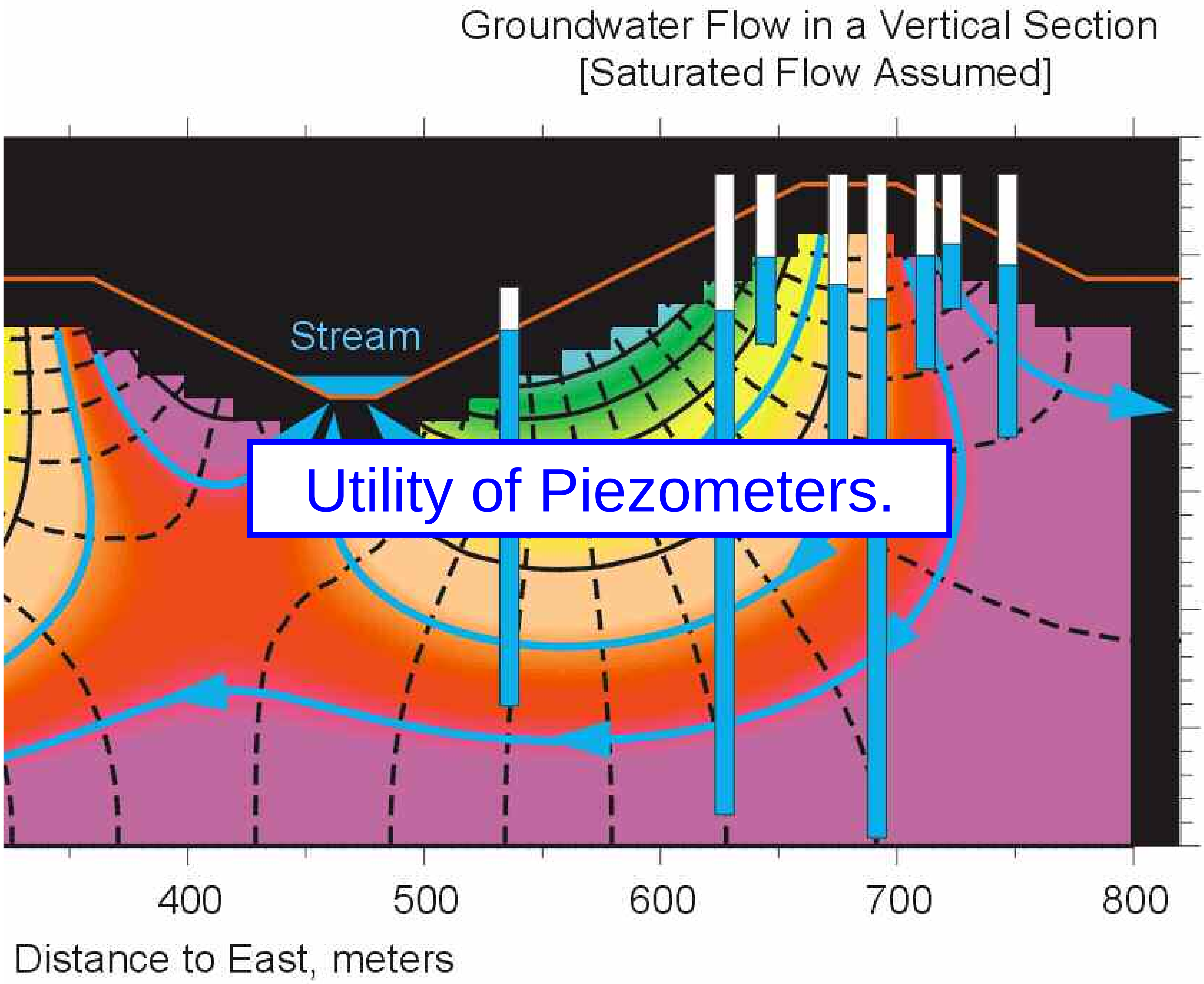
Let’s revisit our numerical model.



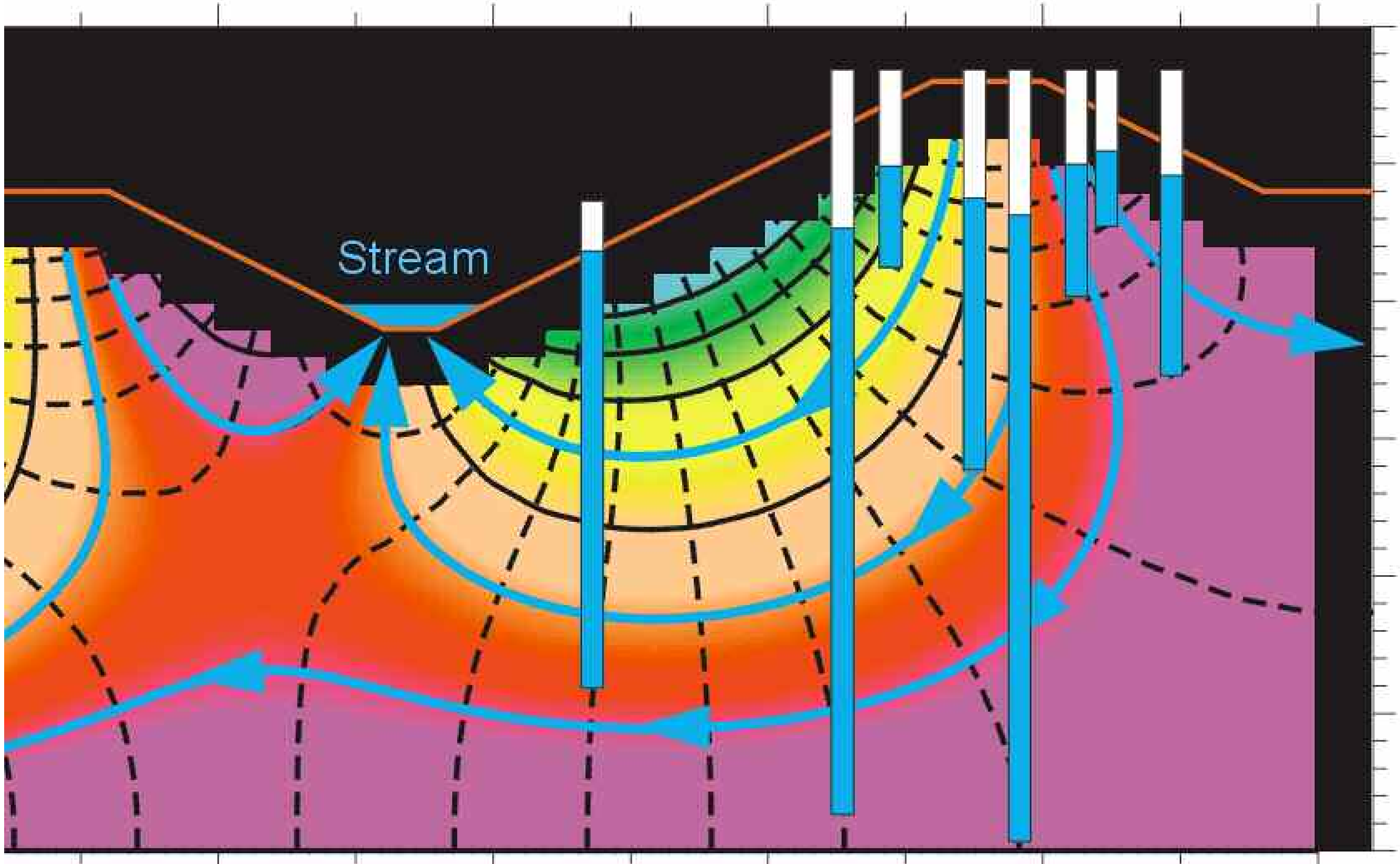
Groundwater Flow in a Vertical Section
[Saturated Flow Assumed]
Stream
A Close-up View.
400
500
600
700
800
Distance to East, meters



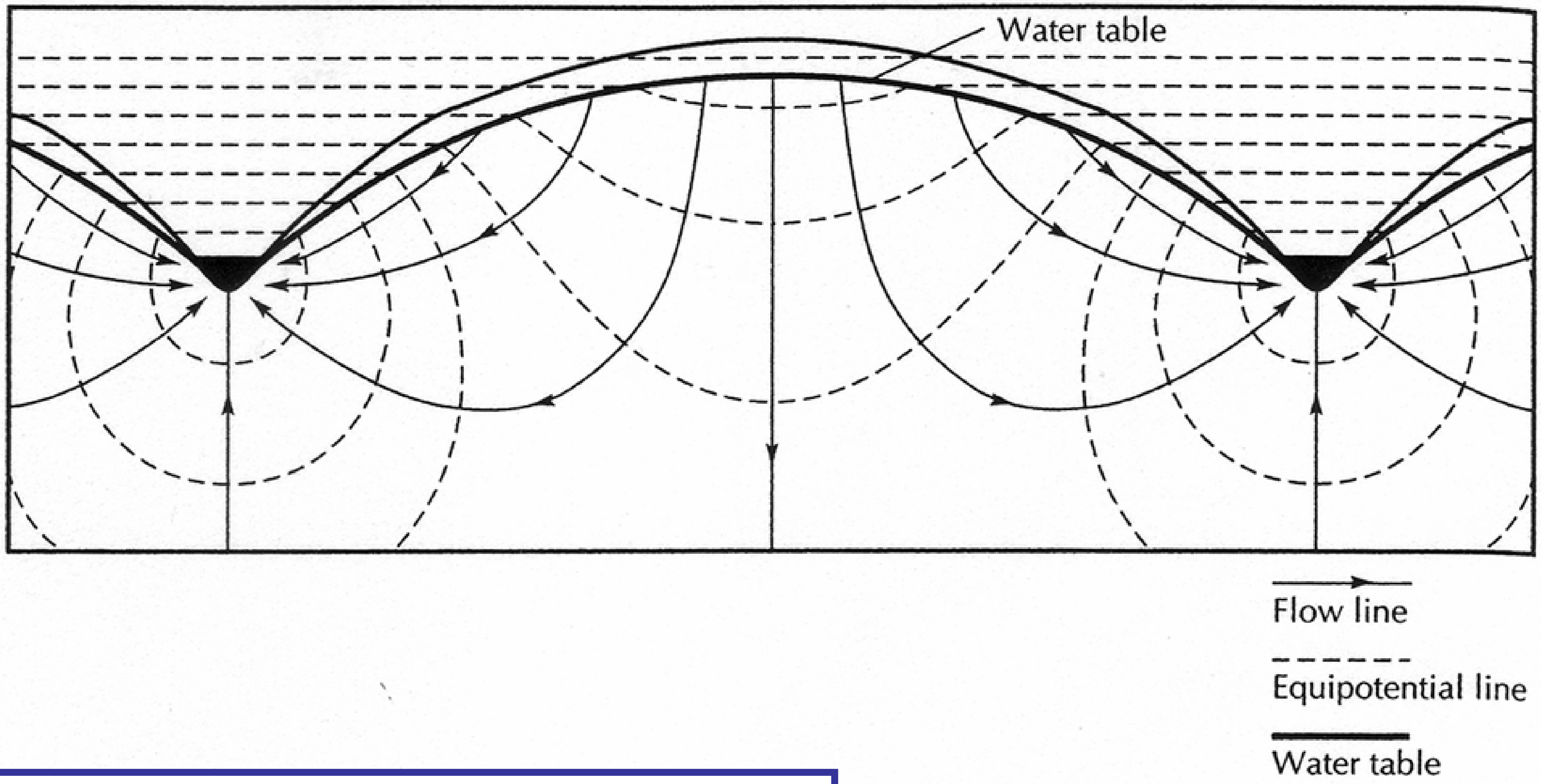
Groundwater Flow in a Vertical Section
[Saturated Flow Assumed]
Stream
400
500
600
700
800
Distance to East, meters


Groundwater Flow in a Vertical Section
[Saturated Flow Assumed]
Stream
Utility of Piezometers.
400
500
600
700
800
Distance to East, meters

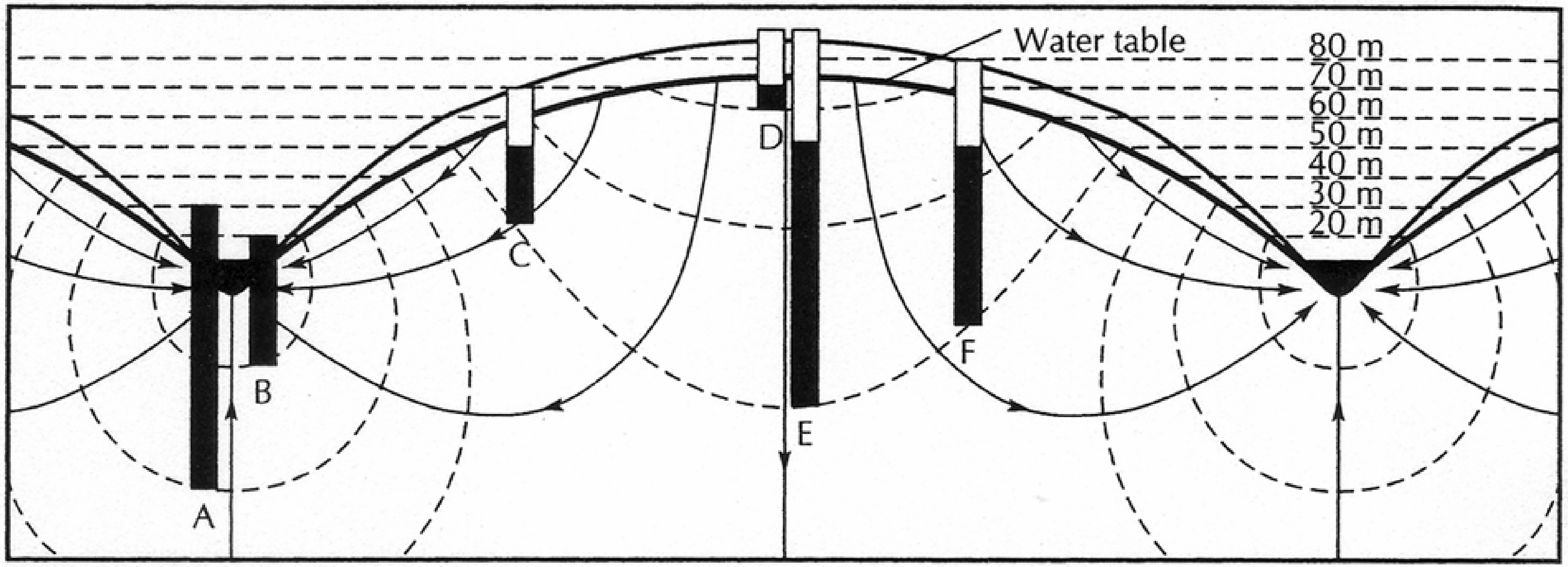
Groundwater Flow in a Vertical Section
[Saturated Flow Assumed]



Regional Ground-Water Flow



(*Source: Fig. 7.1; Fetter, 2001; after Hubbert, 1941.*)



(*Source: Fig. 7.2; Fetter, 2001; modified from Hubbert, 1941.*)

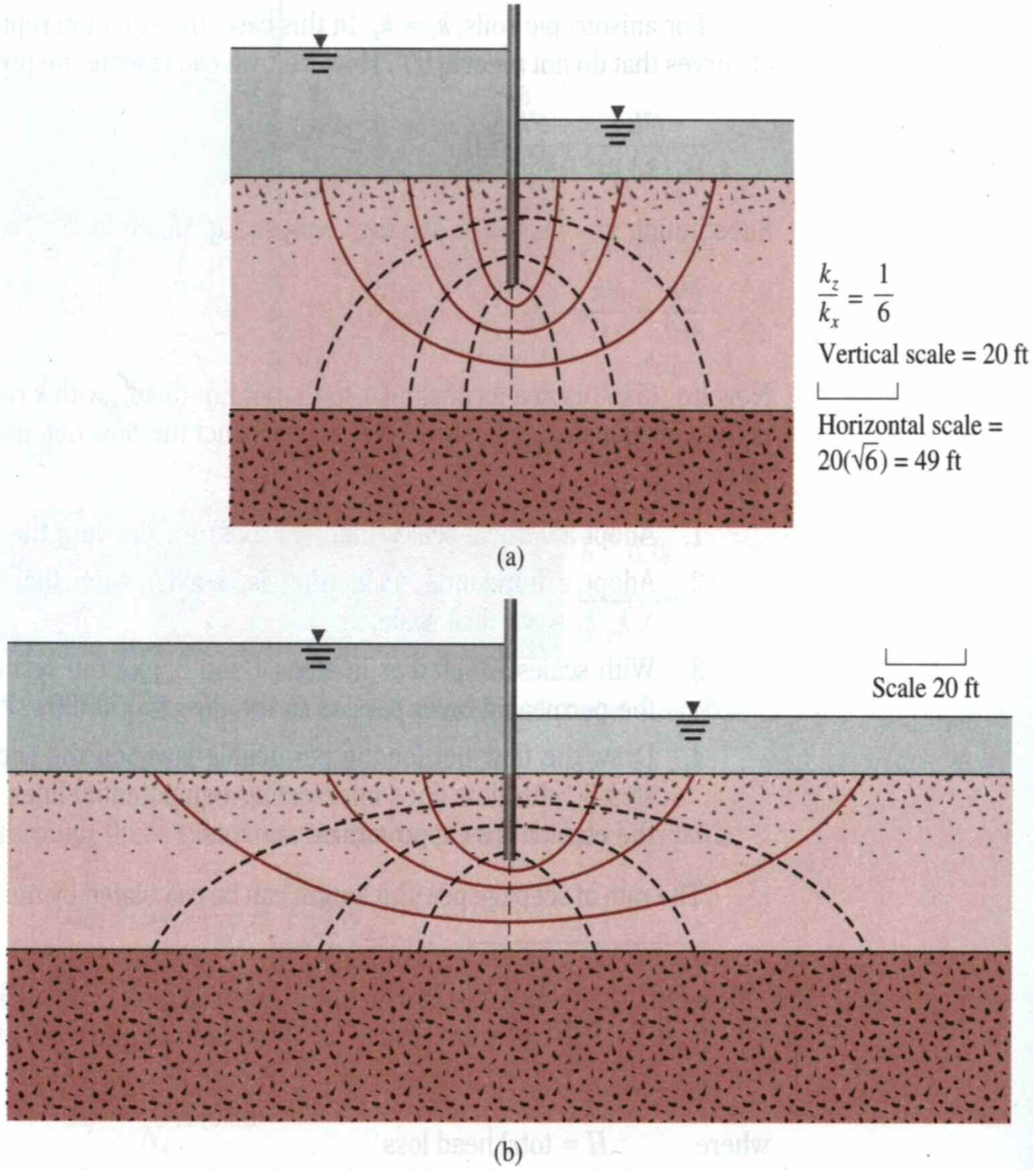
Flow nets in anisotropic soils ($k_x \neq k_z$)

$$k_x \frac{\partial^2 h}{\partial x^2} + k_z \frac{\partial^2 h}{\partial z^2} = 0 \quad \Rightarrow \quad \frac{\partial^2 h}{(k_z / k_x)\partial x^2} + \frac{\partial^2 h}{\partial z^2} = 0$$

Substitute $$x' = \sqrt{k_z / k_x} \cdot x$$

$$\boxed{\frac{\partial^2 h}{\partial x'^2} + \frac{\partial^2 h}{\partial z^2} = 0}$$

$$q = \sqrt{k_x k_z}\,\frac{H N_f}{N_d}$$

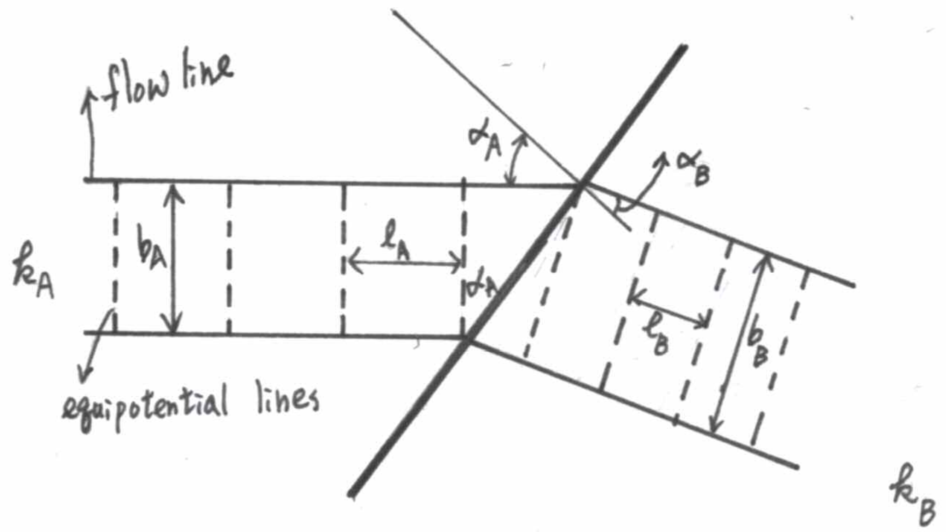


A flow element in anisotropic soil: (a) in transformed section; (b) in true section

Flow nets in nonhomogeneous soils ($k_A \neq k_B$)

$$q_A = k_A \frac{\Delta h}{l_A} b_A$$

$$q_B = k_B \frac{\Delta h}{l_b} b_B$$



$$k_A \frac{\Delta h}{l_A} b_A = k_B \frac{\Delta h}{l_B} b_B$$

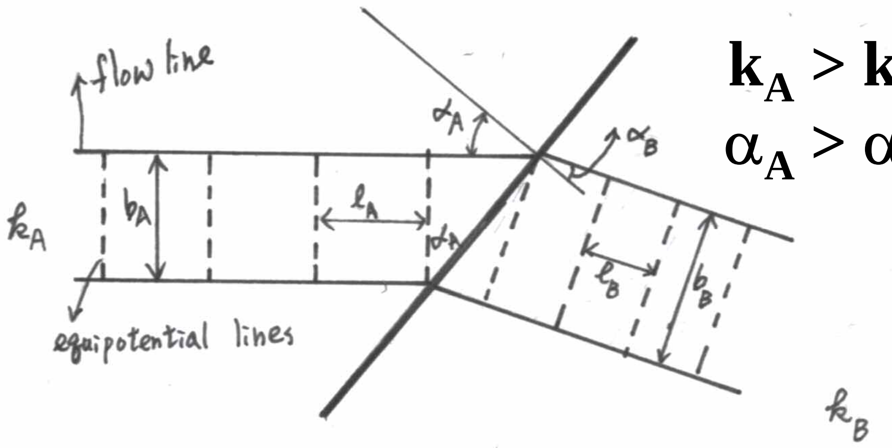
$$\boxed{\frac{k_A}{k_B} = \frac{l_A / b_A}{l_B / b_B}}$$

This equation indicates that the flow element (the cell) cannot be kept square for the soil B since $k_A \neq k_B$ and the flow element in soil A is square.

$$\frac{l_A}{b_A} = \tan \alpha_A$$

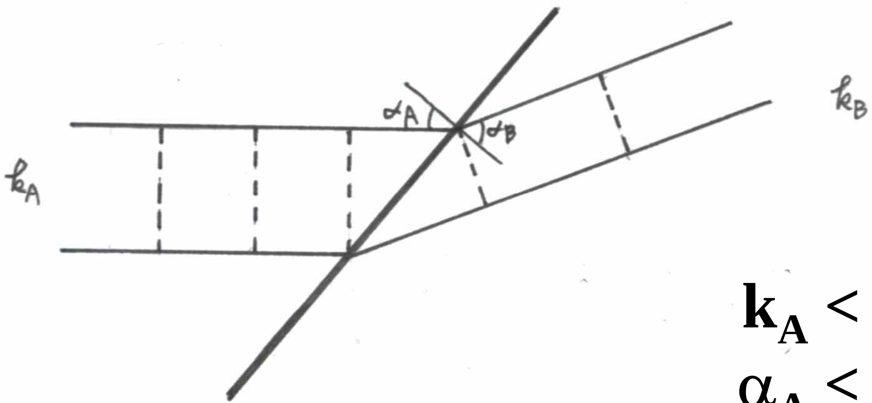
$$\frac{l_B}{b_B} = \tan \alpha_B$$

$$\boxed{\frac{k_A}{k_B} = \frac{\tan \alpha_A}{\tan \alpha_B}}$$



$k_A > k_B$

$\alpha_A > \alpha_B$



$k_A < k_B$

$\alpha_A < \alpha_B$

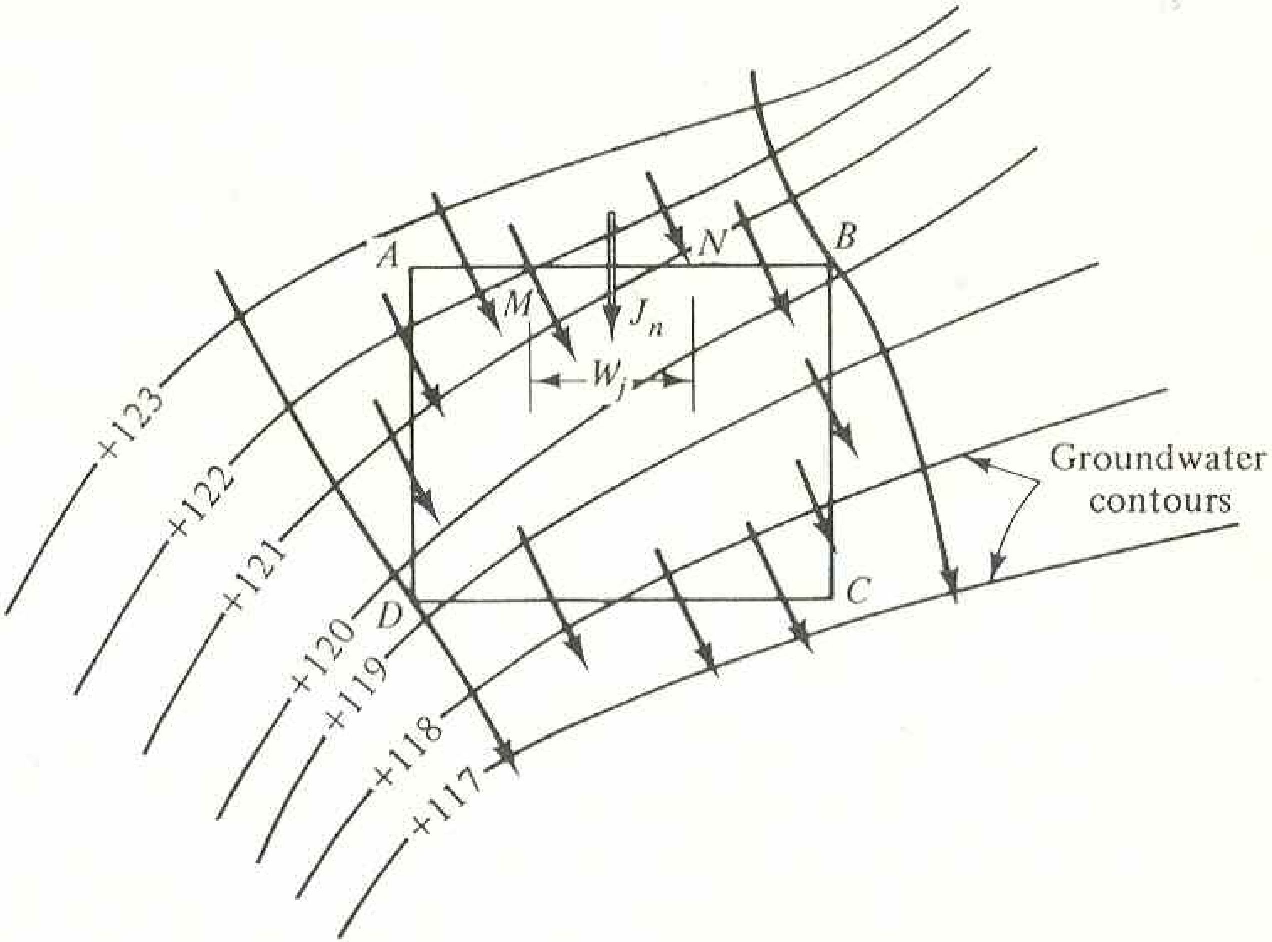


Figure 3-1 Inflow and outflow through aquifer boundary.

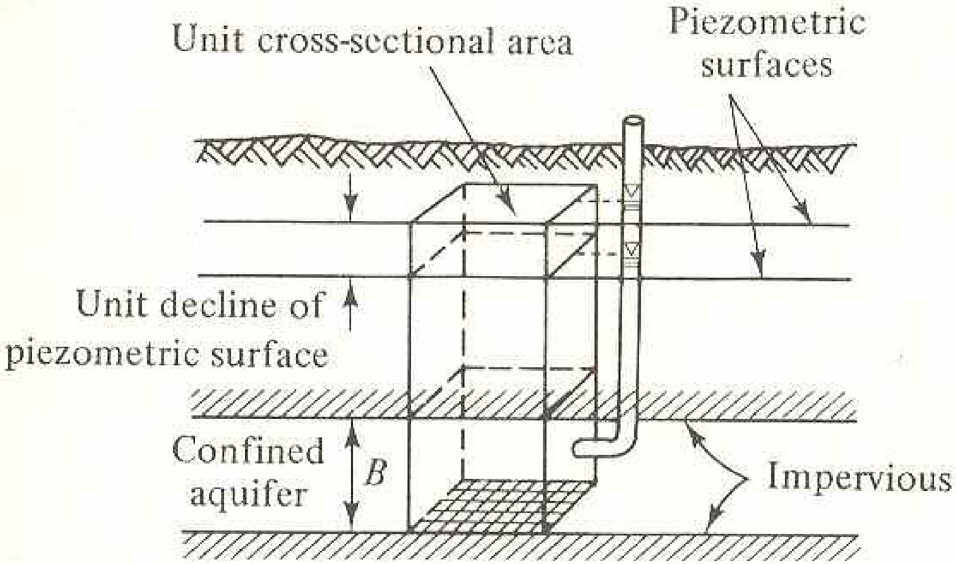


Figure 5-2 Definition sketch for storativity in a confined aquifer.

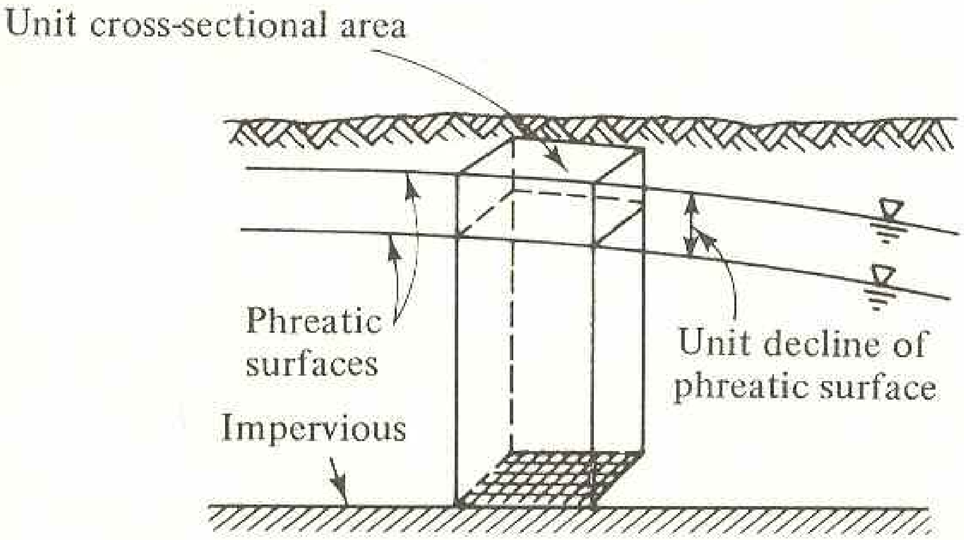


Figure 5-3 Definition sketch for storativity in a phreatic aquifer.