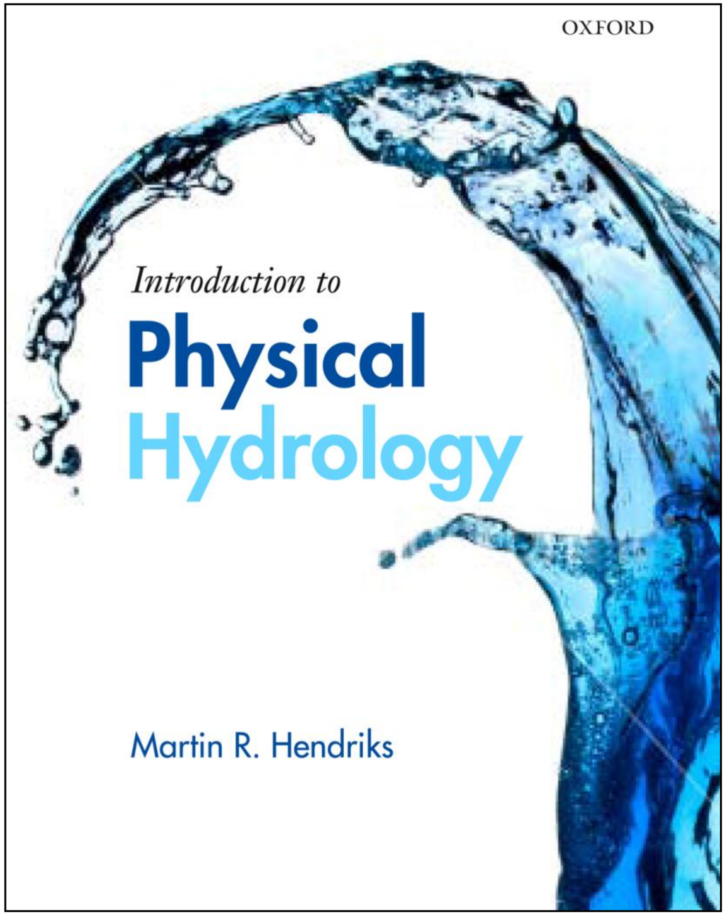
Groundwater hydraulics



Paperback | 351 pages
Follow the book's didactic concept!

- Hydrological cycle
- Drainage basin
- Water balance

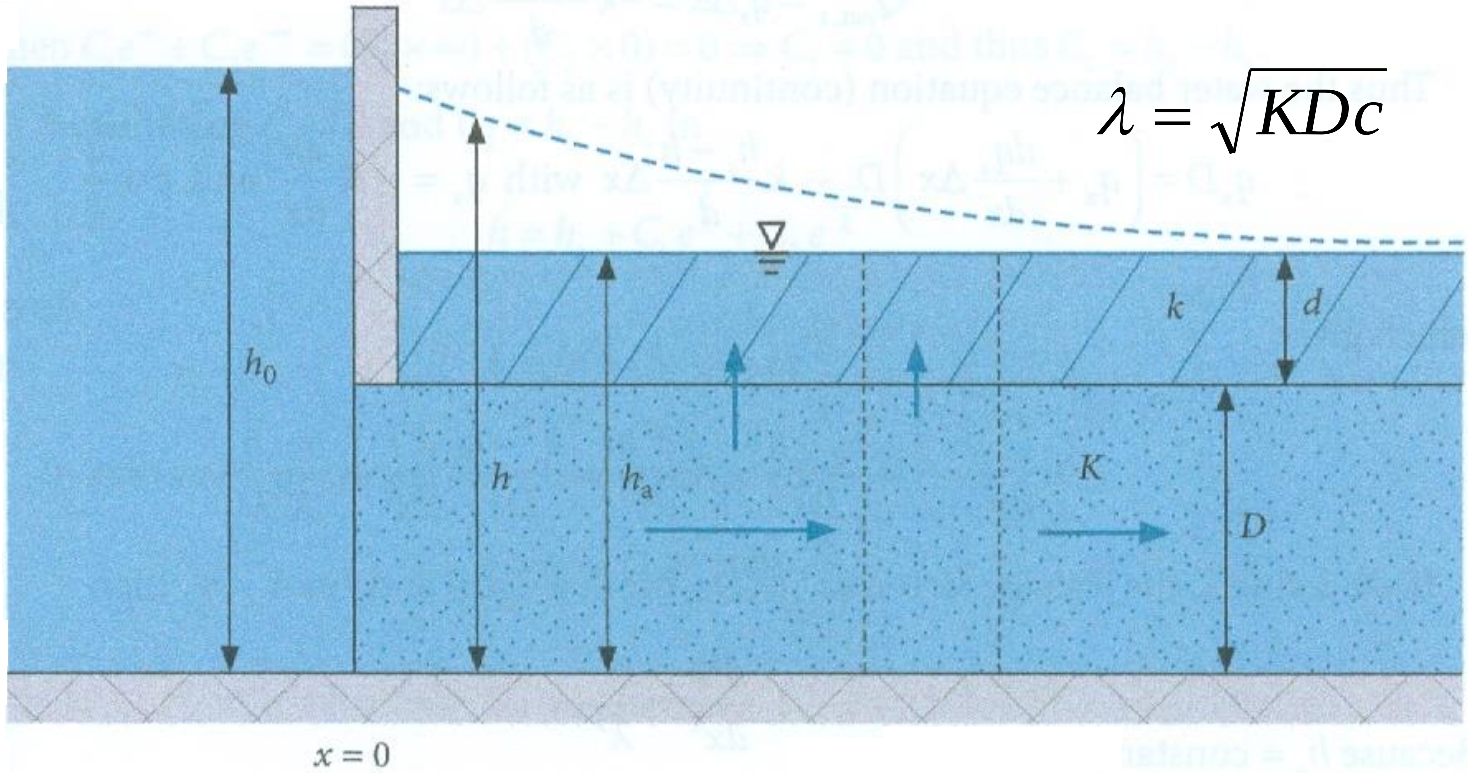
- Energy equation
- Flow equation
- Continuity equation

1. Introduction
2. Atmospheric water
3. Groundwater, including **Section 3.15**
4. Soil water
5. Surface water

Exercises

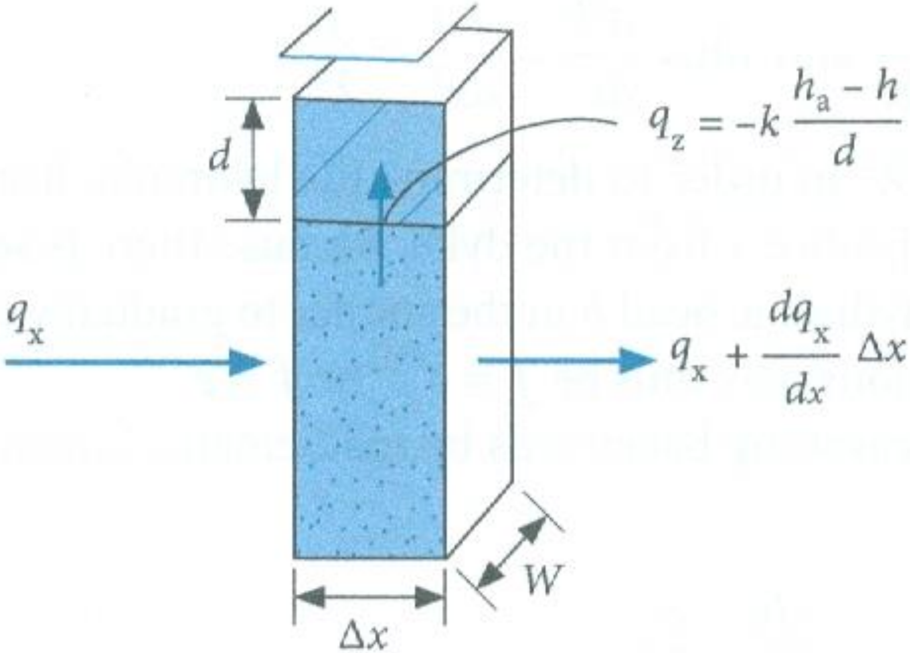
Leaky aquifer

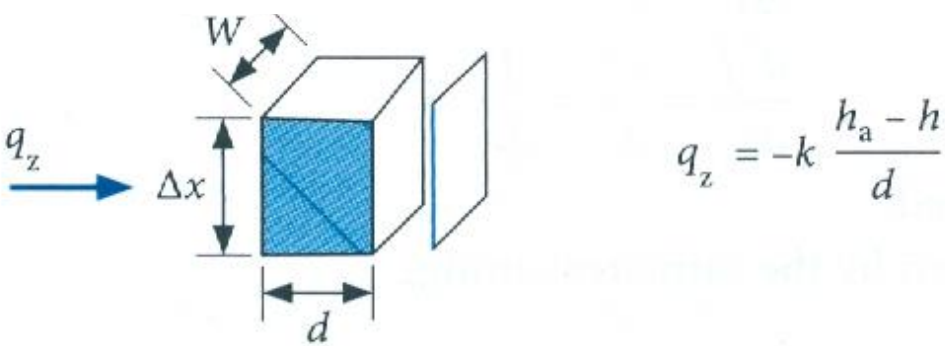
$$\lambda = \sqrt{KDc}$$



$$h = h_a + C_1\, e^{\frac{x}{\lambda}} + C_2\, e^{\frac{-x}{\lambda}}$$

Leaky aquifer

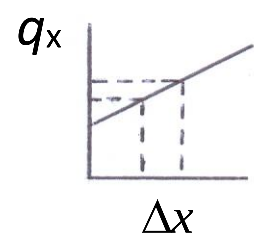




$$Q'_{\text{in, x}} = Q'_{\text{out, x}} + Q'_{\text{out, z}}$$

$$Q'_{\text{in, x}} = q_x D$$

$$Q'_{\text{out, x}} = \left(q_x + \frac{dq_x}{dx} \Delta x \right) D$$



$$Q'_{\text{out, z}} = q_z \Delta x = -k \frac{h_a - h}{d} \Delta x$$

Table 3.3 - Starting point of the exercises

One-dimensional steady groundwater flow

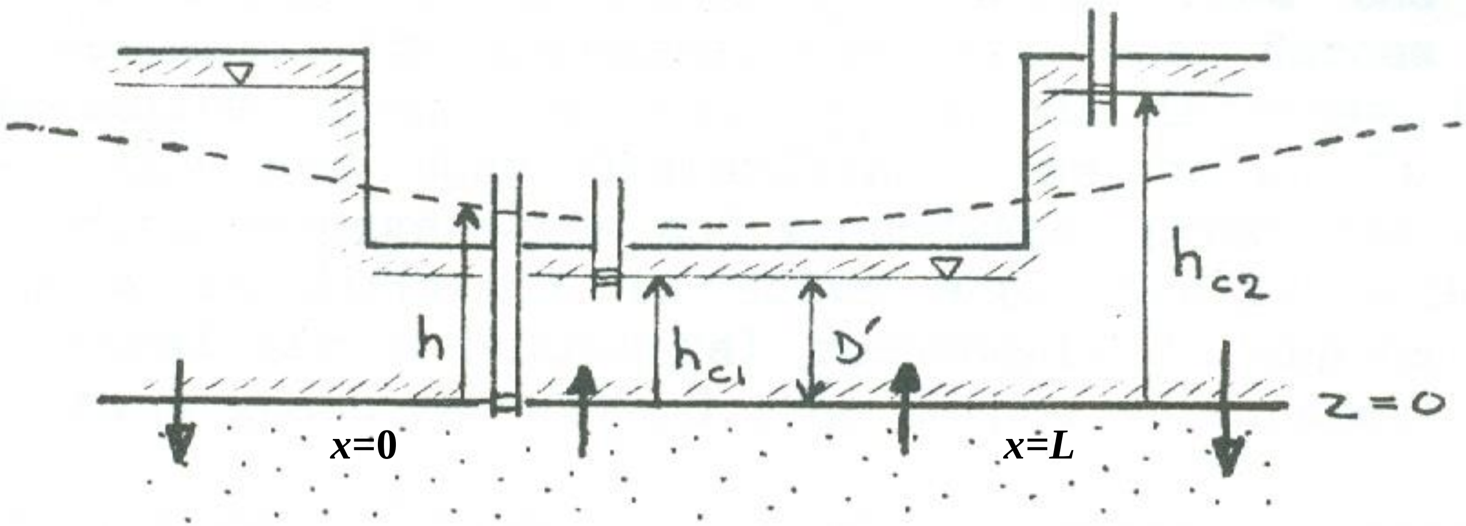
Confined $$h = C_1 x + C_2$$

Unconfined $$h^2 = C_1 x + C_2$$

Leaky $$h = h_a + C_1 e^{\frac{x}{\lambda}} + C_2 e^{\frac{-x}{\lambda}} \quad \text{with} \quad \lambda = \sqrt{KDc}$$

Finite polder

$$h = h_a + C_1 e^{\frac{x}{\lambda}} + C_2 e^{\frac{-x}{\lambda}}$$

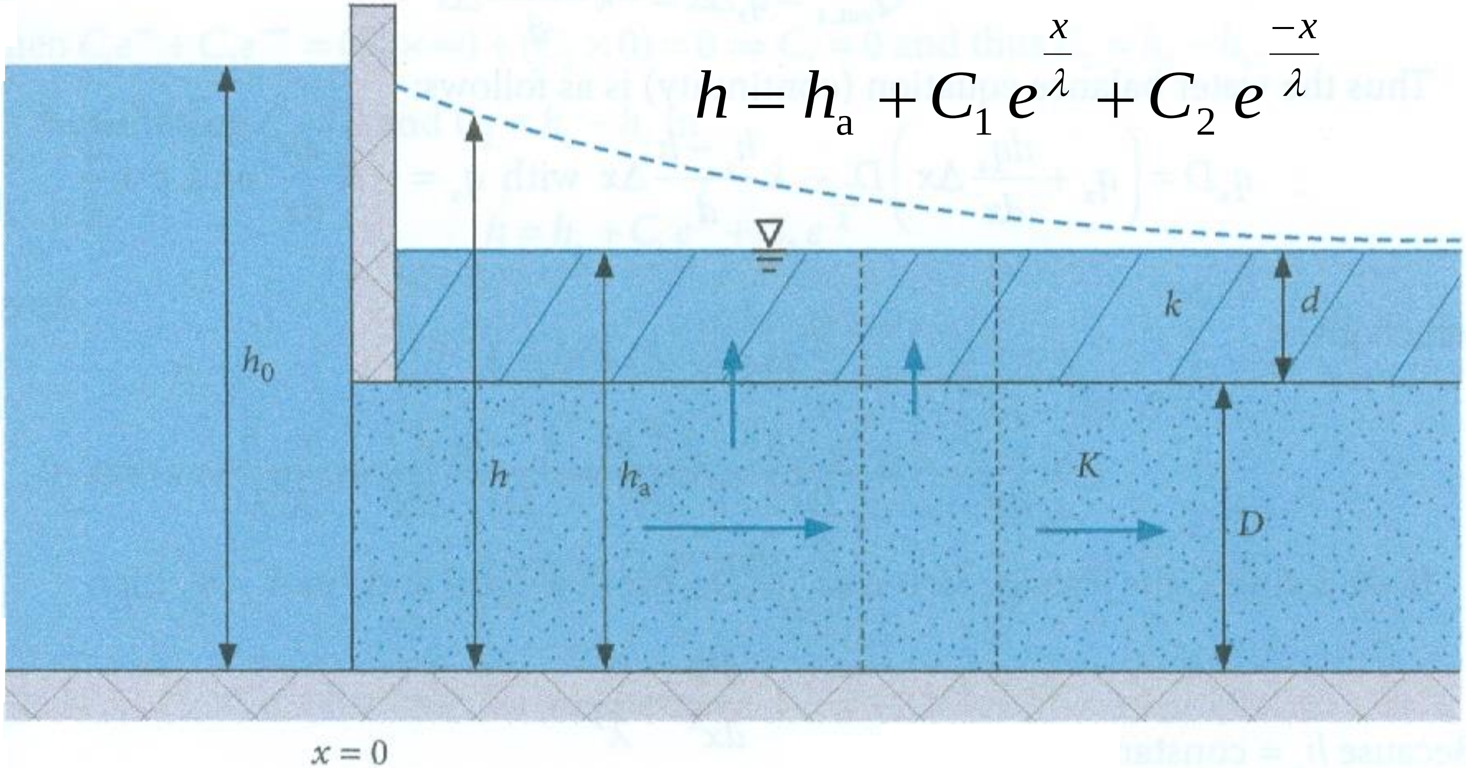


Source: De Vries and Cortel (1990)

$x = 0$, then $h = h_0$: $h_0 = h_a + C_1 e^0 + C_2 e^0 = h_a + C_1 + C_2$; thus $C_1 + C_2 = h_0 - h_a$

$x = L$, then $h = h_L$: $h_L = h_a + C_1 e^{L/\lambda} + C_2 e^{-L/\lambda}$; thus $C_1 e^{L/\lambda} + C_2 e^{-L/\lambda} = h_L - h_a$

Infinite polder



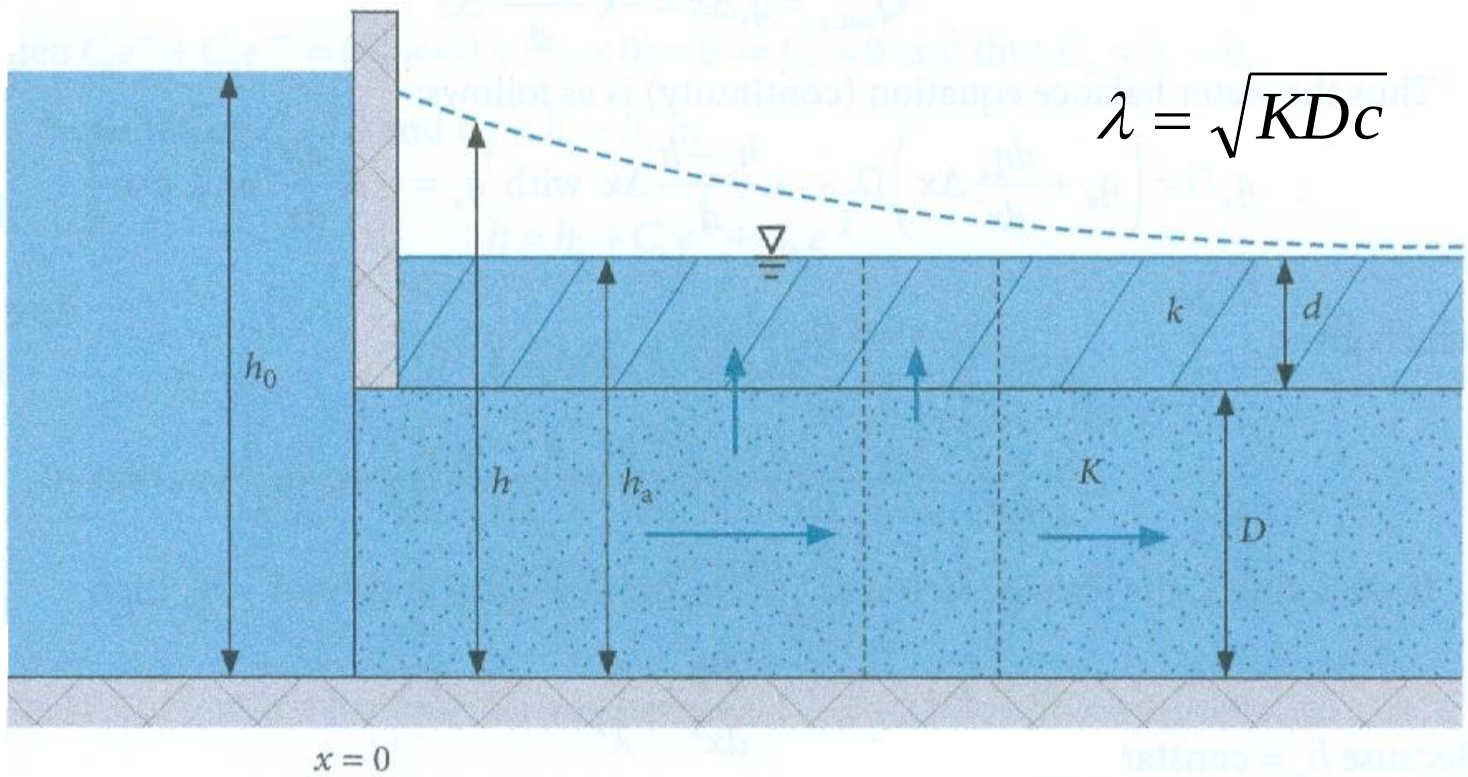
$$h = h_a + C_1 e^{\frac{x}{\lambda}} + C_2 e^{\frac{-x}{\lambda}}$$

$x = 0$, then $h = h_0 : h_0 = h_a + C_1 e^0 + C_2 e^0 = h_a + C_1 + C_2$; thus $C_1 + C_2 = h_0 - h_a$

$x = \infty$, then $h = h_a : h_a = h_a + C_1 e^{\infty} + C_2 e^{-\infty}$; thus $C_1 e^{\infty} + C_2 e^{-\infty} = h_a - h_a = 0$

$C_1 e^{\infty} + C_2 e^{-\infty} = (C_1 \times \infty) + (C_2 \times 0) = 0 \Rightarrow C_1 = 0$ and thus $C_2 = h_0 - h_a$

Infinite polder



$$\lambda = \sqrt{KDc}$$

$$h = h_a + C_1 e^{\frac{x}{\lambda}} + C_2 e^{\frac{-x}{\lambda}}$$

$$x = 0 \rightarrow \infty, \text{ then } h = h_a + \left(h_0 - h_a\right) e^{\frac{-x}{\lambda}}$$

Seepage in a finite polder

'Horizontal solution'

$$\lambda = \sqrt{KDc} \Rightarrow \lambda^2 = KDc \Rightarrow \frac{\lambda}{c} = \frac{KD}{\lambda}$$

$$h = h_a + C_1 e^{\frac{x}{\lambda}} + C_2 e^{\frac{-x}{\lambda}} \text{ with } \lambda = \sqrt{KDc}$$

$$Q'_{x=0} = -KD\left(\frac{dh}{dx}\right)_{x=0} \; ; \; Q'_{x=L} = -KD\left(\frac{dh}{dx}\right)_{x=L}$$

$$Q'_z = \left|Q'_{x=0}\right| + \left|Q'_{x=L}\right|$$

$$\frac{dh}{dx} = \frac{C_1}{\lambda} e^{\frac{x}{\lambda}} + \frac{C_2}{-\lambda} e^{\frac{-x}{\lambda}}$$

$$Q'_z = -\frac{\lambda}{c}\left(C_1 - C_1 e^{\frac{L}{\lambda}} - C_2 + C_2 e^{\frac{-L}{\lambda}}\right) = -\frac{KD}{\lambda}\left(C_1 - C_1 e^{\frac{L}{\lambda}} - C_2 + C_2 e^{\frac{-L}{\lambda}}\right)$$

Seepage in a finite polder

'Vertical solution'

$$\lambda = \sqrt{KDc} \Rightarrow \lambda^2 = KDc \Rightarrow \frac{\lambda}{c} = \frac{KD}{\lambda}$$

$$h = h_{\mathrm{a}} + C_1 e^{\frac{x}{\lambda}} + C_2 e^{\frac{-x}{\lambda}} \text{ with } \lambda = \sqrt{KDc}$$

$$Q_{\mathrm{z}}' = \int_0^L q_z \, dx$$

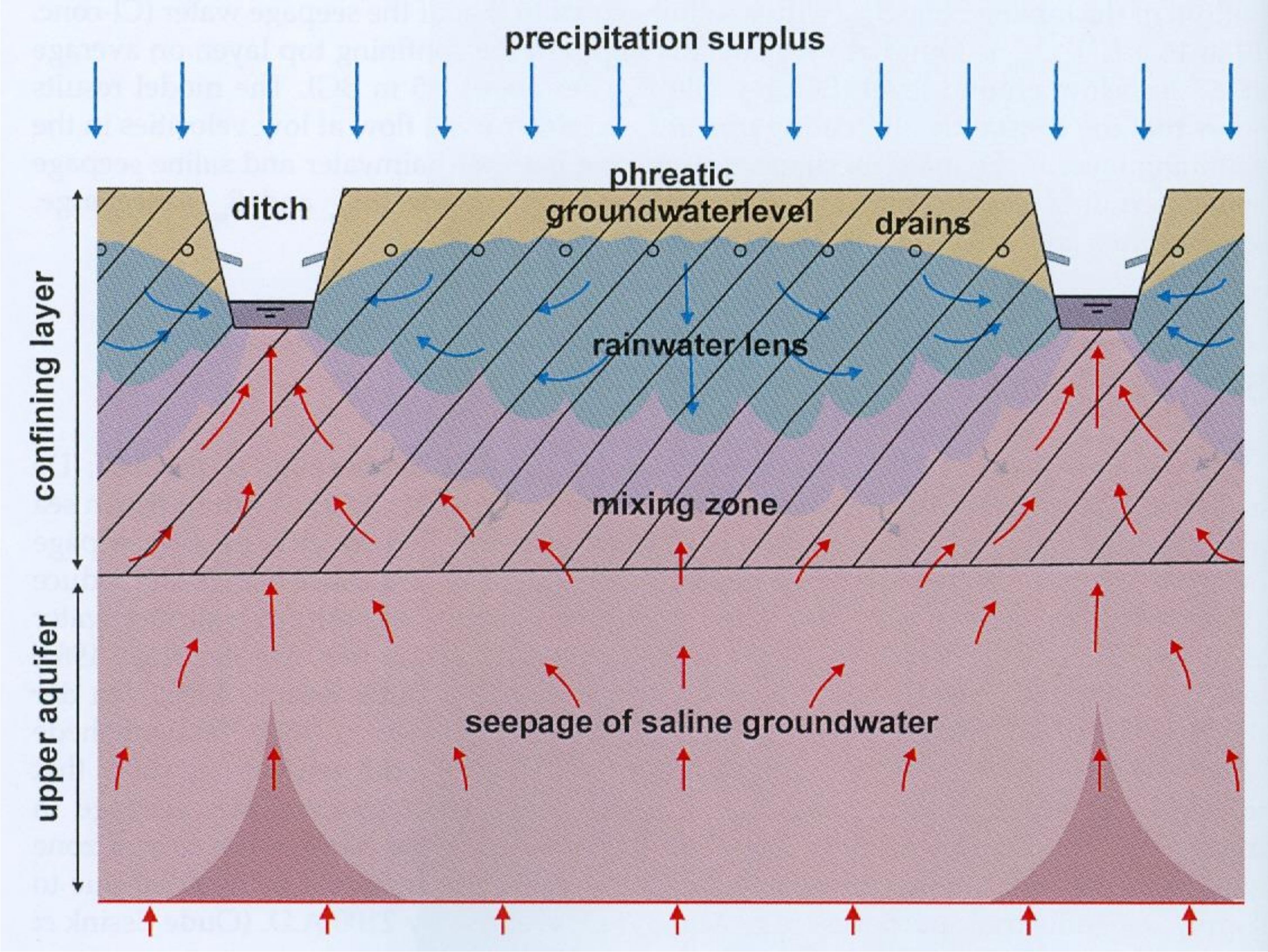
$$q_{\mathrm{z}} = -k \frac{h_{\mathrm{a}} - h}{d}$$

$$Q_{\mathrm{z}}' = \int_0^L -k \frac{h_{\mathrm{a}} - h}{d} \, dx$$

$$h_{\mathrm{a}} - h = -C_1 e^{\frac{x}{\lambda}} - C_2 e^{\frac{-x}{\lambda}}$$

$$Q_{\mathrm{z}}' = -\frac{\lambda}{c} \left(C_1 - C_1 e^{\frac{L}{\lambda}} - C_2 + C_2 e^{\frac{-L}{\lambda}} \right) = -\frac{KD}{\lambda} \left(C_1 - C_1 e^{\frac{L}{\lambda}} - C_2 + C_2 e^{\frac{-L}{\lambda}} \right)$$

Rainwater lens and saline seepage



Source: De Louw (2013)

Boils in deep polders

a pin boil

b sand boil

c boil emitting methane

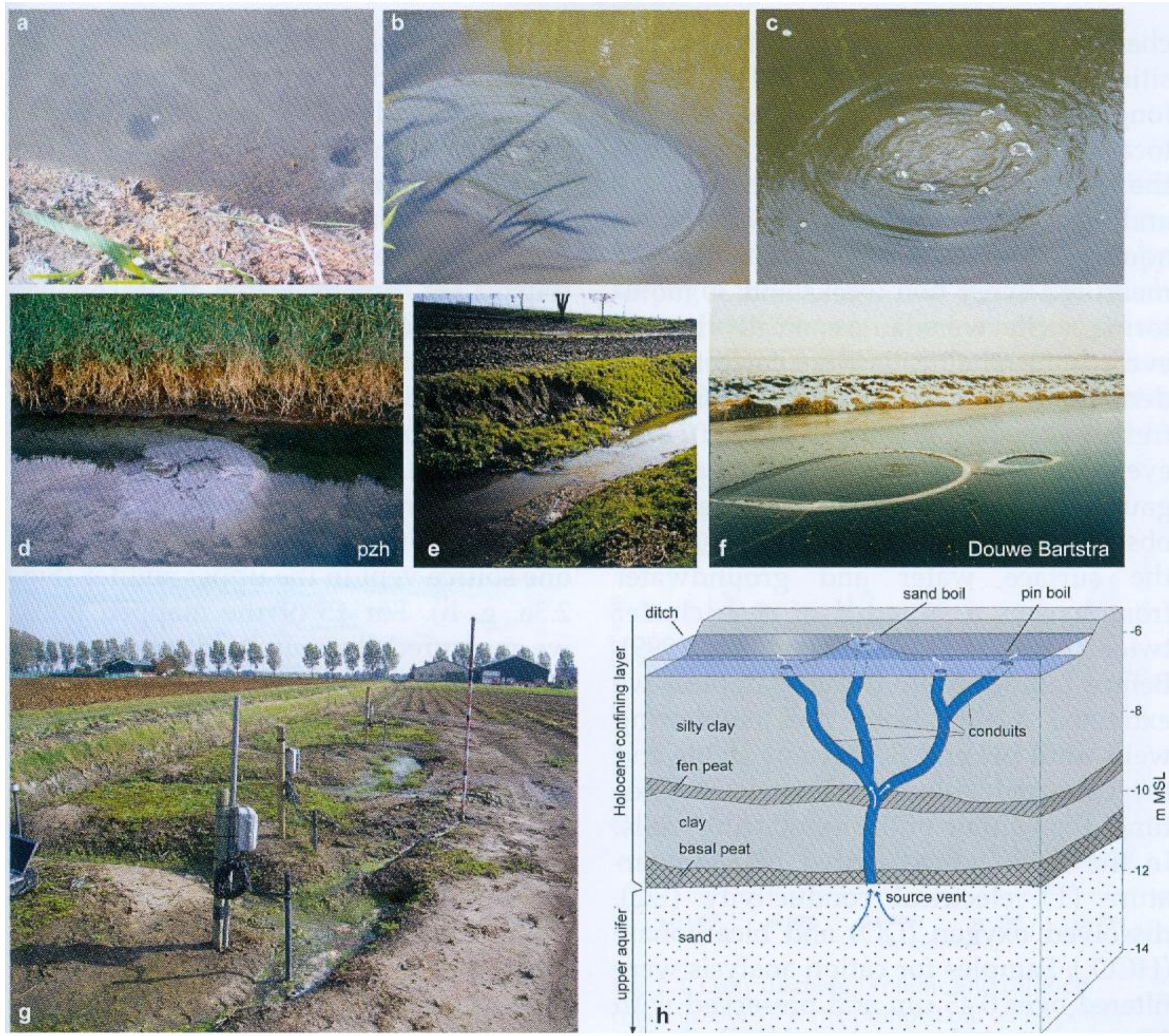
d sand volcano

e collapsed ditch bank

f hole in ice

g sand boils on land

h schematic diagram

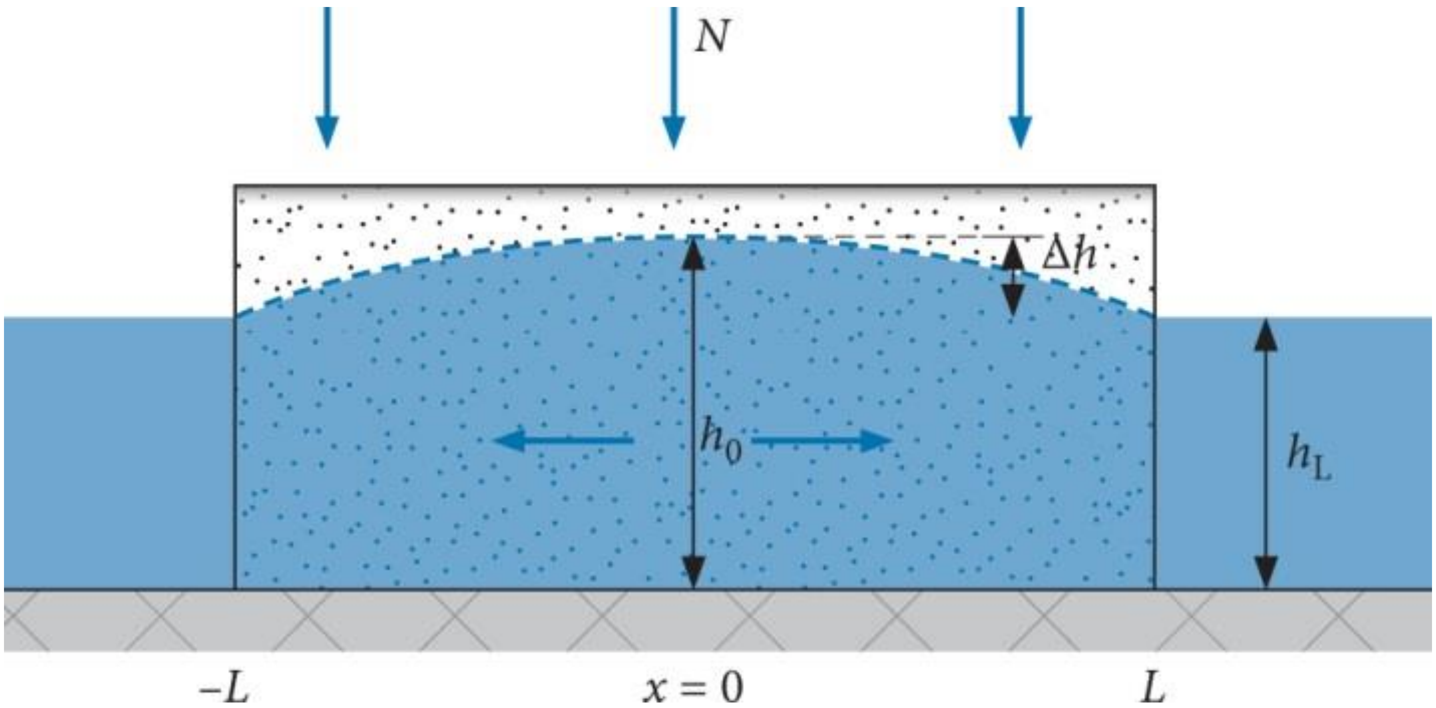


Saline upward seepage through boils

Zoute kwel via wellen

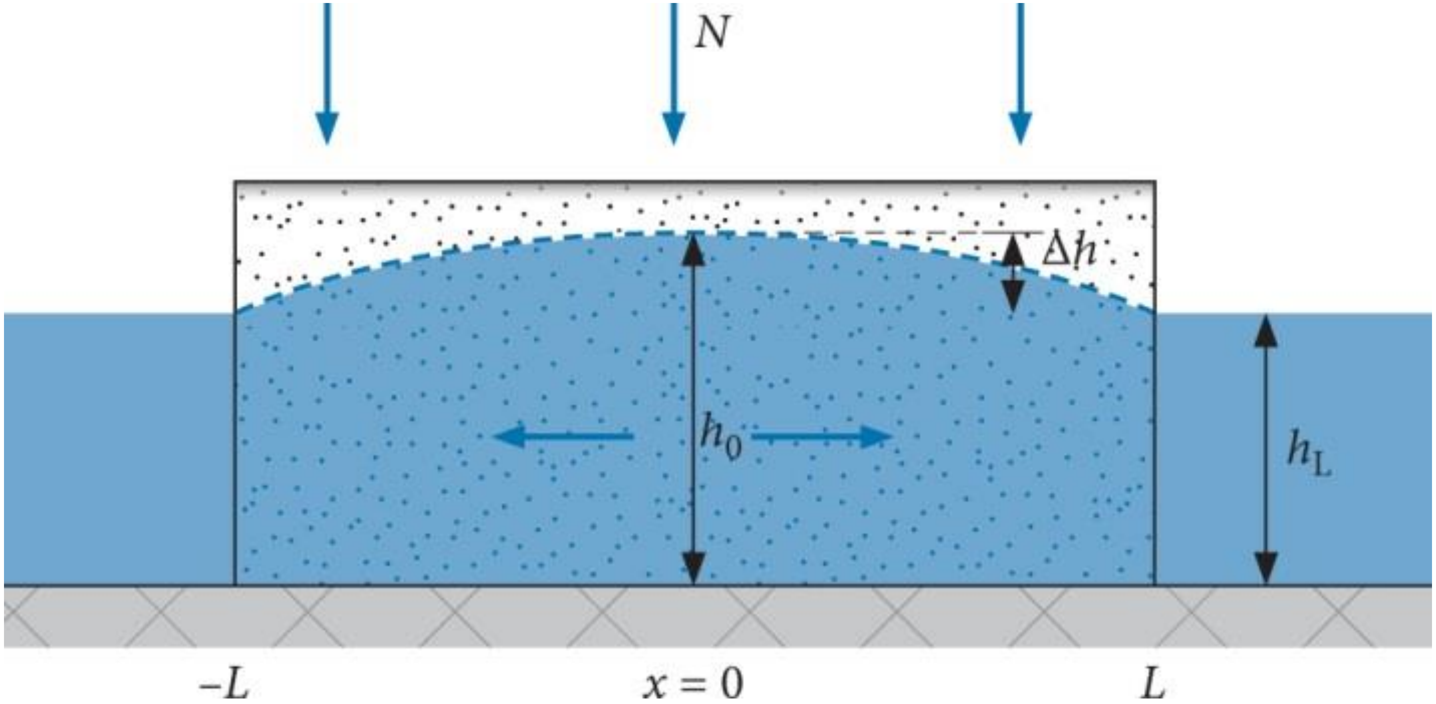
Source: De Louw (2013)

Unconfined aquifer with recharge



$$Q' = -Kh\frac{dh}{dx} \qquad Q' = Nx \qquad h^2 = -\frac{N}{K}x^2 + C$$

~ Hooghoudt equation



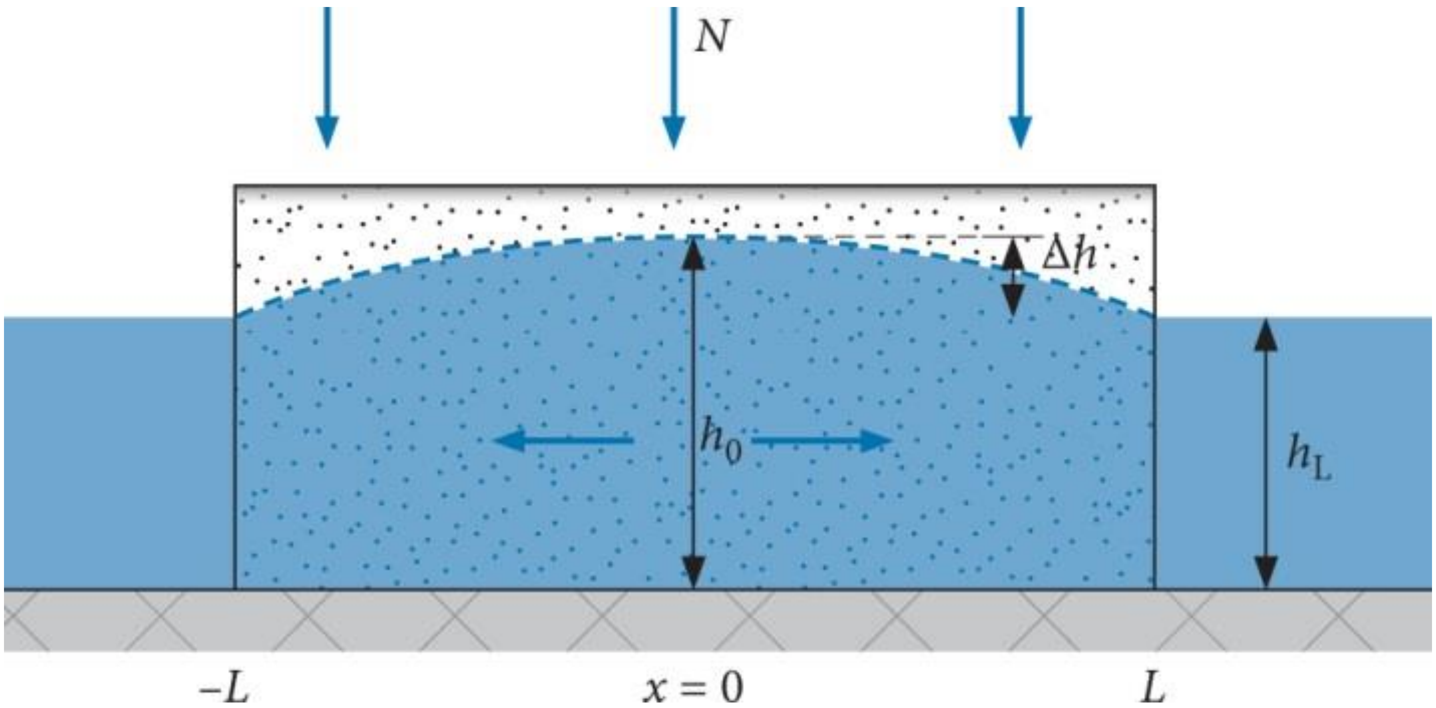
$$\Delta h = h_0 - h_L$$

$$\overline{D} = \frac{h_0 + h_L}{2}$$

$$N = \frac{\Delta h}{\left(\frac{L^2}{2K\overline{D}}\right)}$$

$$h_0^2 - h_L^2 = \left(h_0 + h_L\right)\left(h_0 - h_L\right)$$

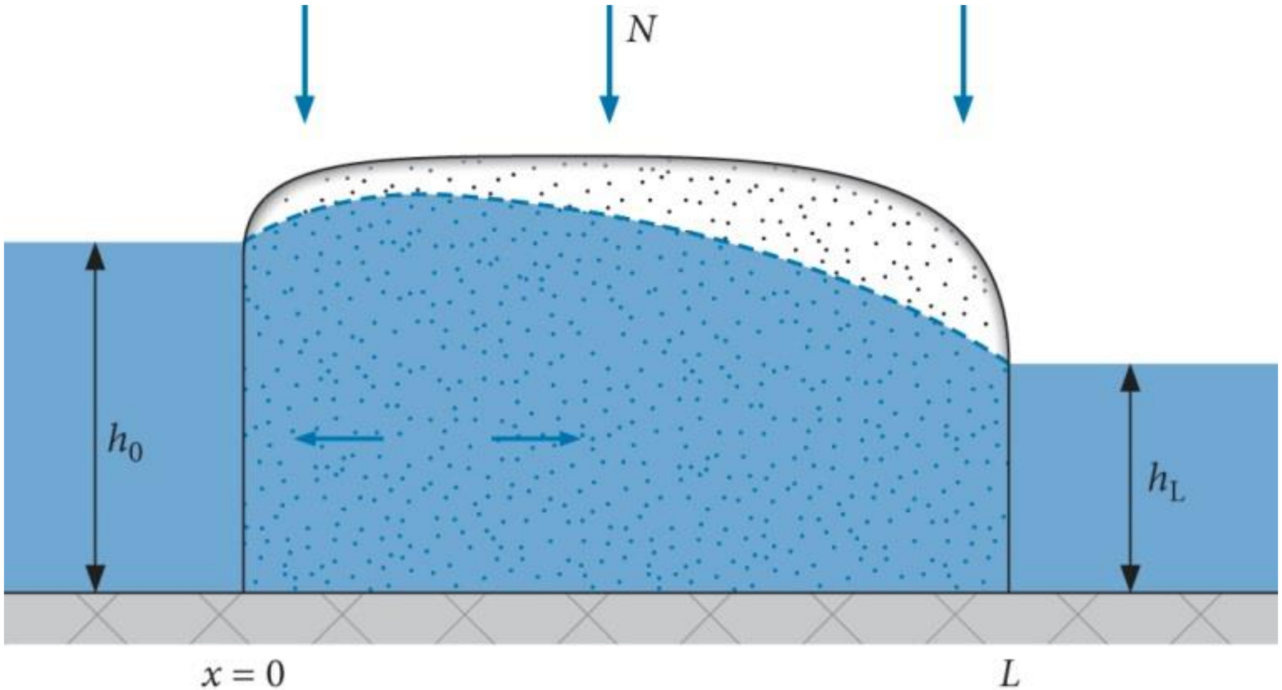
Drain spacing 2L



$$N = \frac{\Delta h}{\left(\dfrac{L^2}{2K\overline{D}}\right)}$$

$$2L = 2\sqrt{\frac{2K\overline{D}\,\Delta h}{N}}$$

Unconfined aquifer with recharge



$$Q'_x = -K\left(h\frac{dh}{dx}\right)_x \qquad Q'_{x+\Delta x} = -K\left(h\frac{dh}{dx}\right)_{x+\Delta x} \qquad Q'_{x+\Delta x} - Q'_x = -K\frac{d\left(h\dfrac{dh}{dx}\right)}{dx}\Delta x$$

$$Q'_{x+\Delta x} - Q'_x = N\Delta x \qquad h^2 = -\frac{N}{K}x^2 + C_1 x + C_2$$

Table 3.3 - Starting point of the exercises

One-dimensional steady groundwater flow

Confined	$h = C_1 x + C_2$
Unconfined	$h^2 = C_1 x + C_2$
Leaky	$h = h_a + C_1 e^{\frac{x}{\lambda}} + C_2 e^{\frac{-x}{\lambda}}$ with $\lambda = \sqrt{KDc}$
Recharge; equal water levels	$h^2 = -\frac{N}{K} x^2 + C$
Recharge; different water levels	$h^2 = -\frac{N}{K} x^2 + C_1 x + C_2$

References

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De Vries, J.J. and Cortel, E.A. (1990). Introduction to Hydrogeology. Lecture notes. Institute of Earth Sciences, VU University Amsterdam, The Netherlands.

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