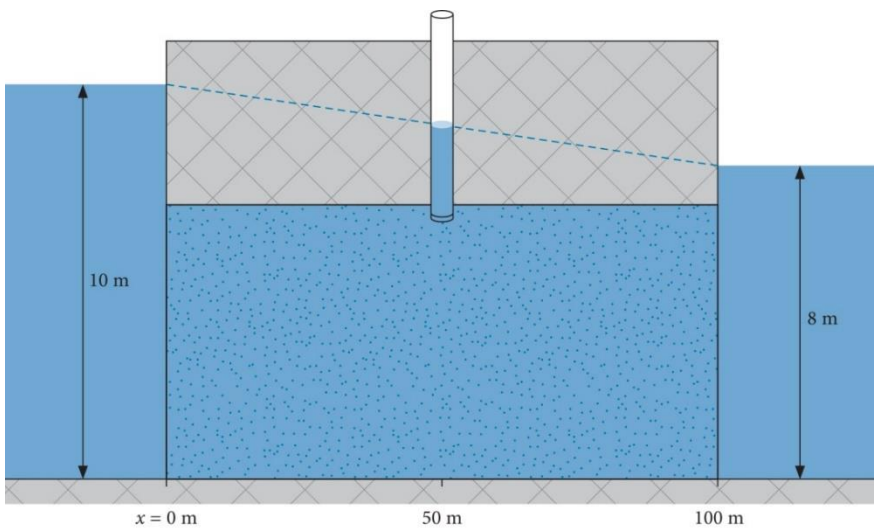
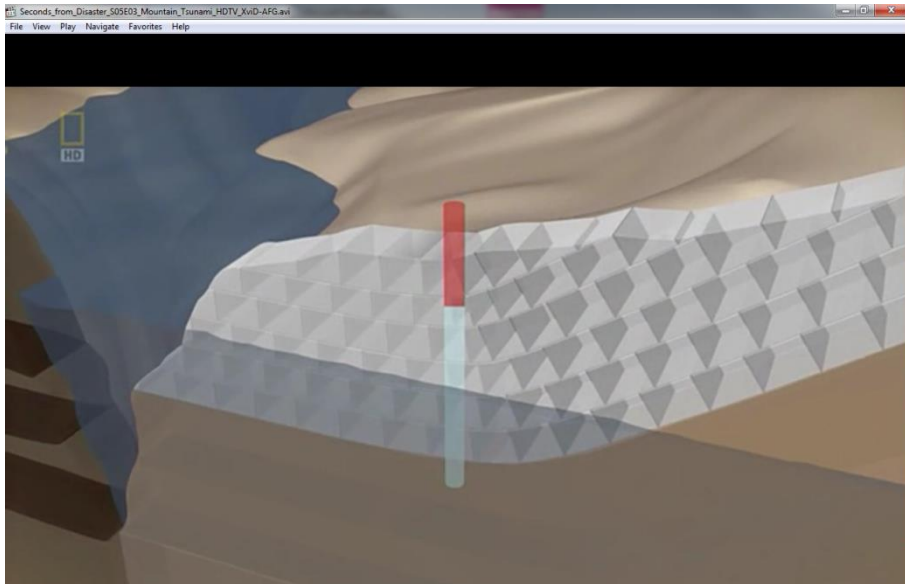
Vaiont Dam Disaster

National Geographic Channel (2012)

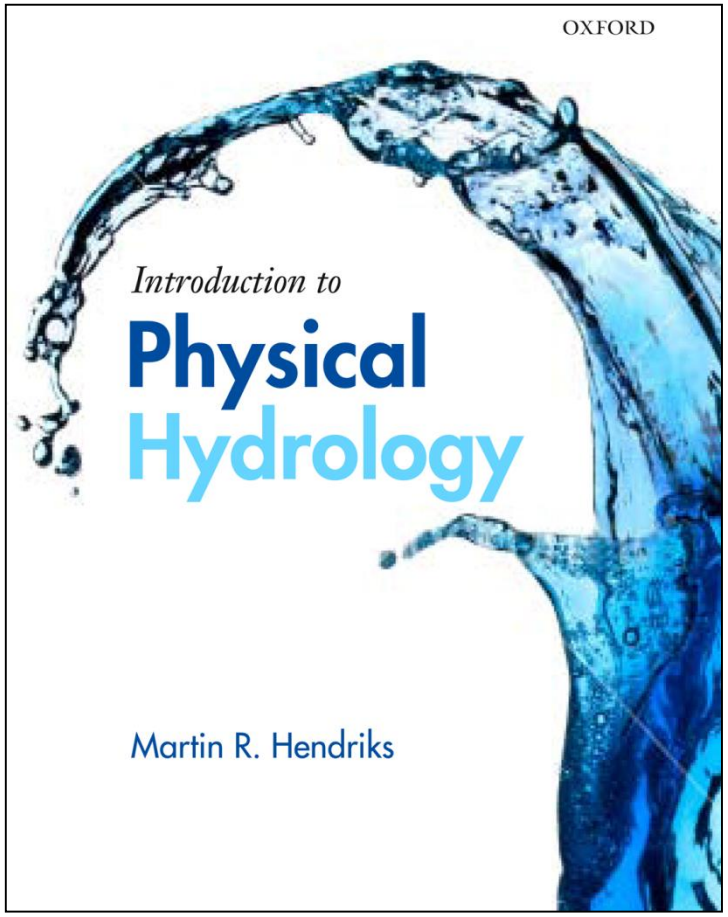
One piezometer always gave a high water level reading!

Evidence of confined groundwater, groundwater trapped at high pressure underneath the landslide mass!





Groundwater hydraulics



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

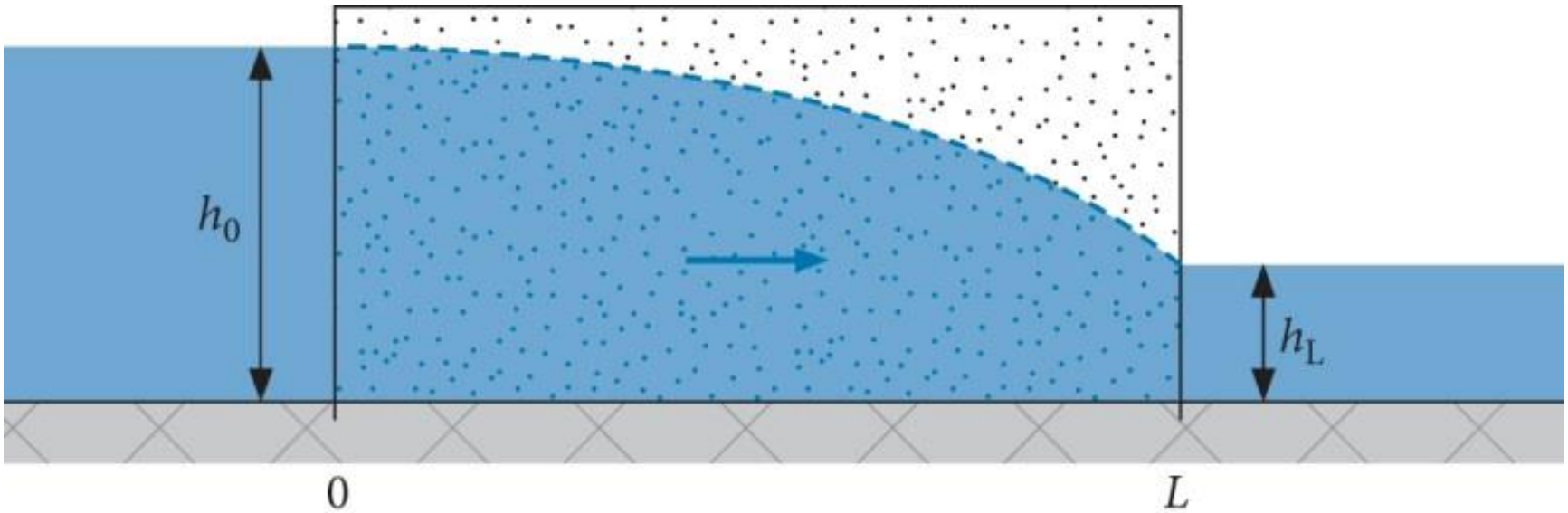
- Hydrological cycle
- Drainage basin
- Water balance

- Energy equation
- Flow equation
- Continuity equation

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

Exercises

Unconfined aquifer

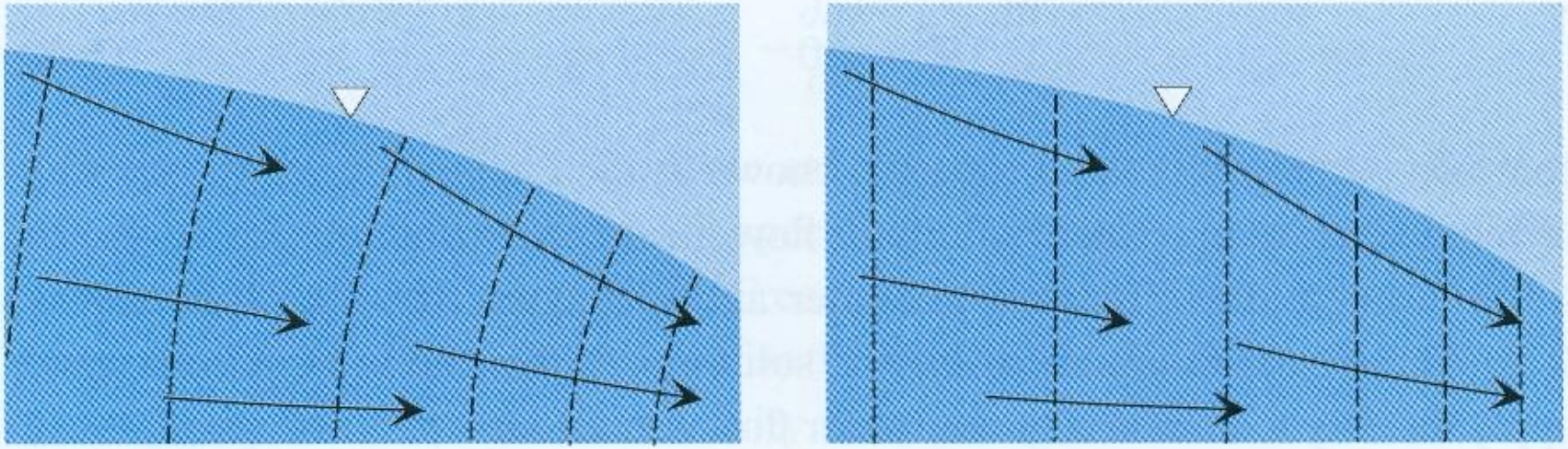


$Q' = \text{constant}$

$$Q' = -Kh\frac{dh}{dx}$$

$$Q' = \text{constant} \Rightarrow -Kh\frac{dh}{dx} = \text{constant}$$

Unconfined aquifer

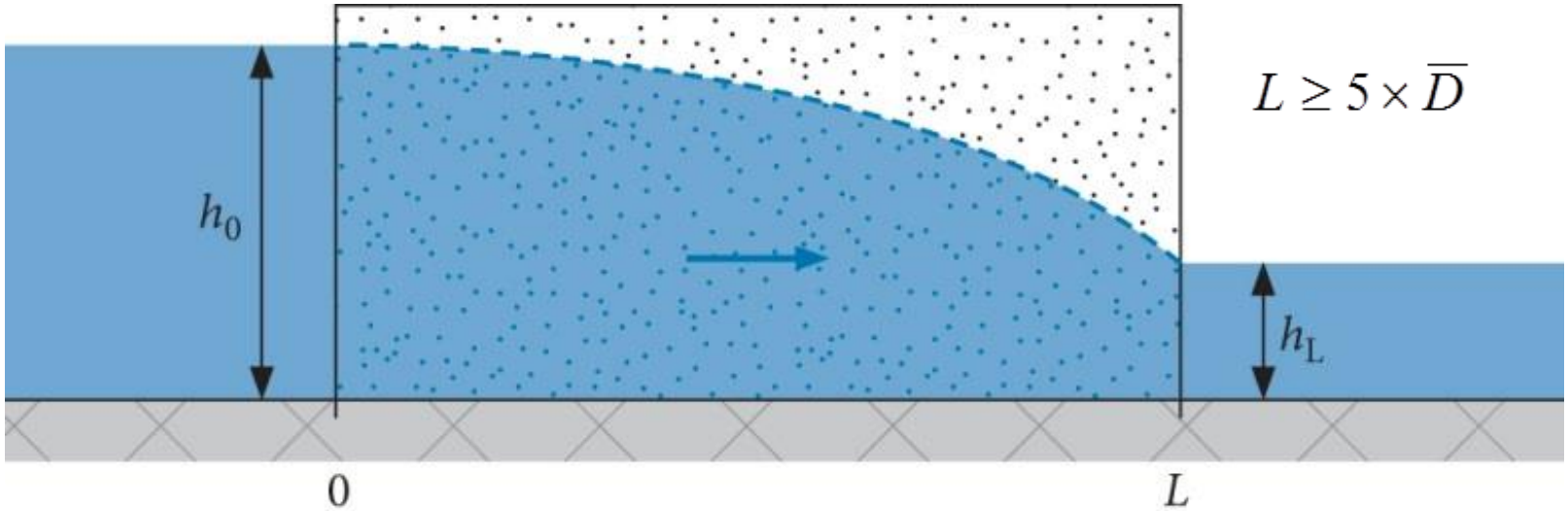


Source: Fitts (2002)

$L \geq 5 \times \overline{D}$: Dupuit-Forchheimer approximation

$$Q' = -K\overline{D}i$$

Unconfined aquifer



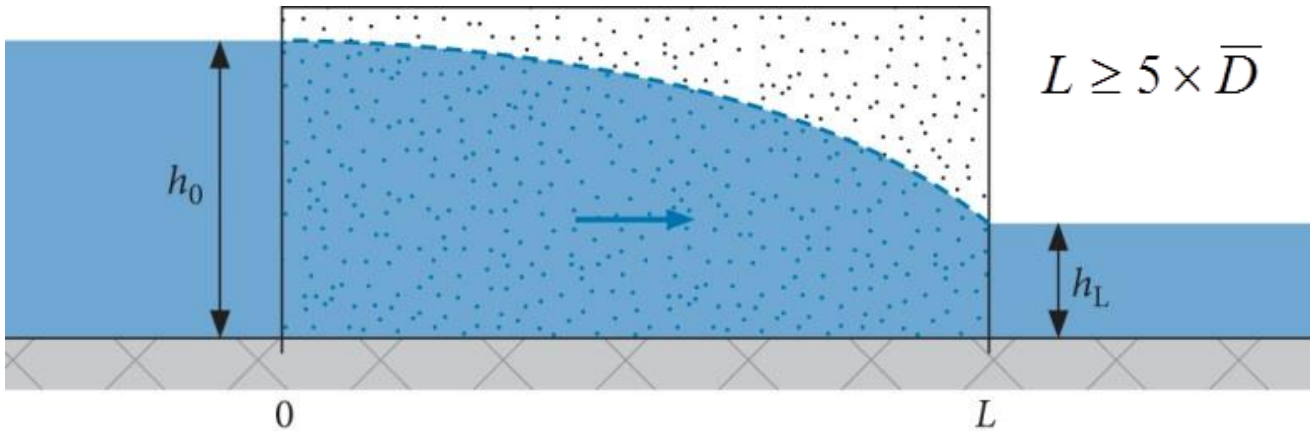
$$Q' = -K\overline{D}i \qquad \overline{D} = \frac{h_0 + h_L}{2} \qquad i = \frac{h_L - h_0}{L}$$

$$Q' = -K\frac{h_L + h_0}{2}\frac{h_L - h_0}{L} = -K\frac{h_L^2 - h_0^2}{2L}$$

Dupuit-Forchheimer equation

Unconfined aquifer

$$Q' = -Kh\frac{dh}{dx}$$

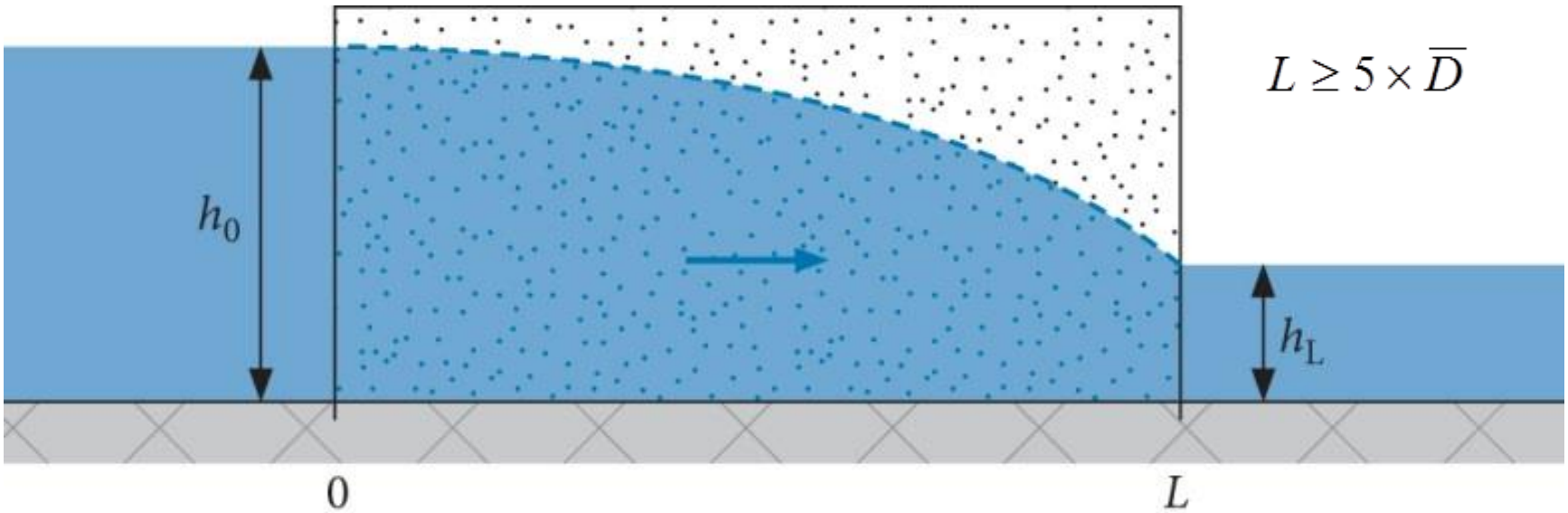


$$Q' = \text{constant} \Rightarrow -Kh\frac{dh}{dx} = \text{constant}$$

chain rule $\frac{dy}{dx} = \frac{dy}{dh}\frac{dh}{dx}$ with $y = h^2$ gives $\frac{dh^2}{dx} = \frac{dh^2}{dh}\frac{dh}{dx} = 2h\frac{dh}{dx}$

$$h\frac{dh}{dx} = \text{constant} \Rightarrow \tfrac{1}{2}\frac{dh^2}{dx} = \text{constant} \Rightarrow \frac{dh^2}{dx} = \mathrm{C}_1 \Rightarrow h^2 = C_1 x + C_2$$

Unconfined aquifer



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

$$h^2 = \frac{h_L^2 - h_0^2}{L} x + h_0^2$$

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

Recharge; equal water levels $$h^2 = -\frac{N}{K} x^2 + C$$

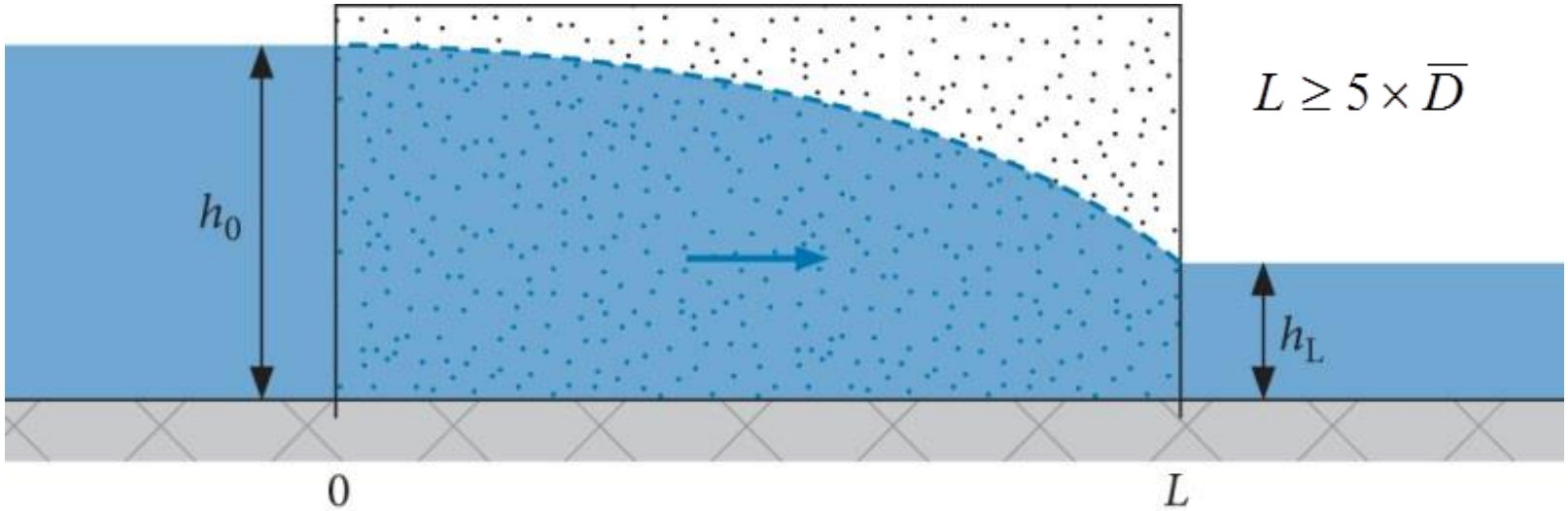
Recharge; different water levels $$h^2 = -\frac{N}{K} x^2 + C_1 x + C_2$$

Radial-symmetric steady groundwater flow

Confined $$h = h_R + \frac{Q_0}{2\pi KD} \ln \frac{r}{R} \quad \text{for} \quad r_w \le r \le R$$

Unconfined $$h^2 = h_R^2 + \frac{Q_0}{\pi K} \ln \frac{r}{R} \quad \text{for} \quad r_w \le r \le R$$

Unconfined aquifer



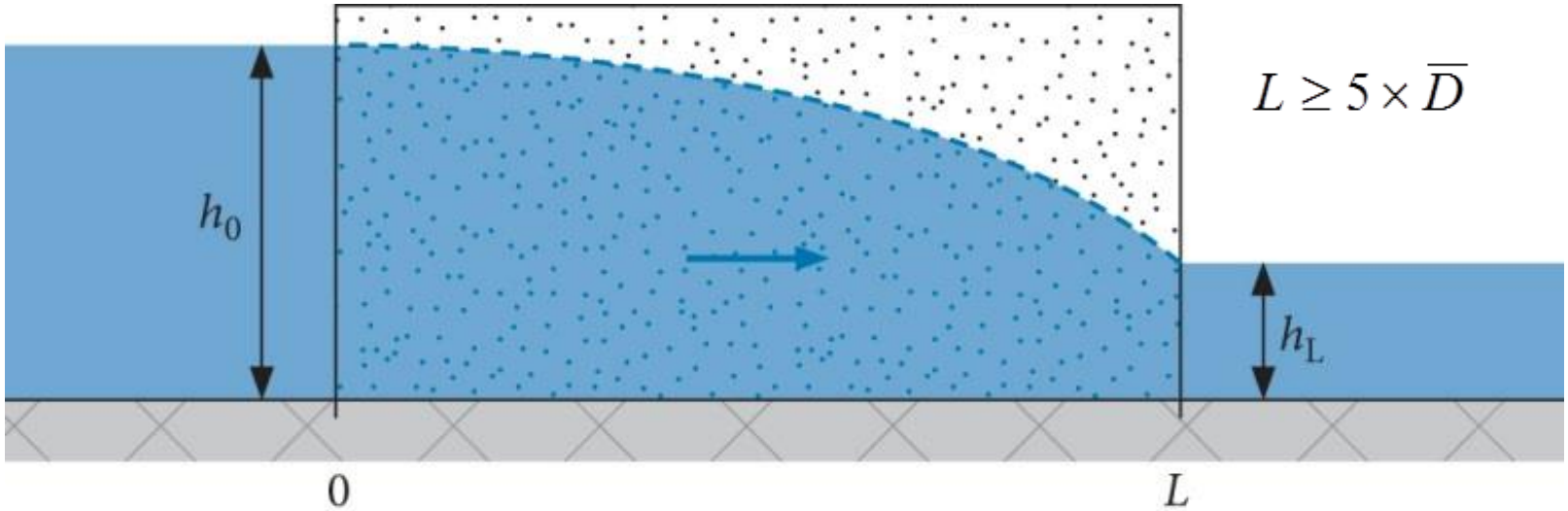
$$h^2 = C_1 x + C_2 \quad \Rightarrow \quad h = \left(C_1 x + C_2\right)^{\frac{1}{2}} \quad \Rightarrow \quad \frac{dh}{dx} = \tfrac{1}{2}\left(C_1 x + C_2\right)^{-\frac{1}{2}} C_1$$

$$h\frac{dh}{dx} = (C_1 x + C_2)^{\frac{1}{2}} \tfrac{1}{2}\left(C_1 x + C_2\right)^{-\frac{1}{2}} C_1 = \frac{1}{2} C_1 \quad \Rightarrow \quad Q' = -Kh\frac{dh}{dx} = -K\frac{1}{2}C_1$$

$$C_1 = \frac{h_L^2 - h_0^2}{L} \qquad Q' = -\tfrac{1}{2}K\frac{h_L^2 - h_0^2}{L}$$

Dupuit-Forchheimer equation

Unconfined aquifer



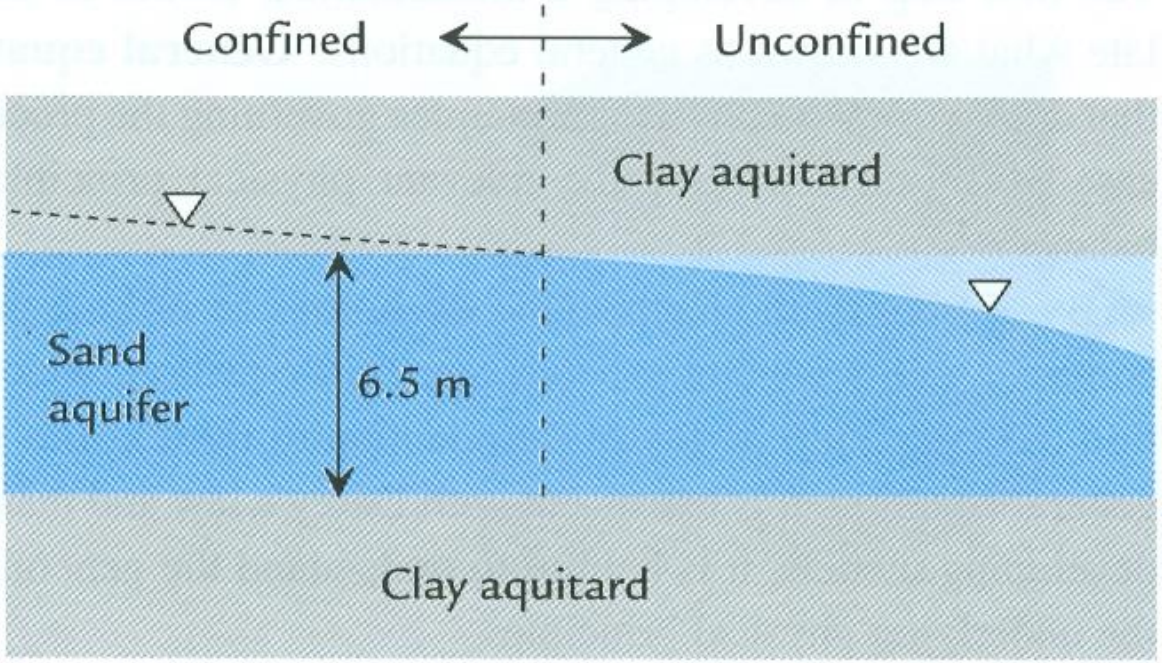
$$h^2 = C_1 x + C_2 \quad \Rightarrow \quad \frac{dh^2}{dx} = C_1 \qquad \frac{dh^2}{dx} = 2h\frac{dh}{dx} \quad \Rightarrow \quad h\frac{dh}{dx} = \tfrac{1}{2}C_1$$

$$Q' = -Kh\frac{dh}{dx} \quad \Rightarrow \quad Q' = -\tfrac{1}{2}C_1 K \qquad C_1 = \frac{h_L^2 - h_0^2}{L}$$

$$Q' = -\tfrac{1}{2}K\frac{h_L^2 - h_0^2}{L}$$

Dupuit-Forchheimer equation

Exercise 3.15.1.4



Source: Fitts (2002)

Figure 5.23 Sand aquifer that is confined where the head is above the aquifer top and unconfined elsewhere (Example 5.4).

Two layer/aquifer problem in hydrology: always use continuity: $Q_1=Q_2$

References

Fitts, C.R. (2002). Groundwater Science. Academic Press, Elsevier Science.

Hendriks, M.R. (2010). Introduction to Physical Hydrology. Oxford University Press.

National Geographic Channel (2012). Seconds from Disaster - Mountain Tsunami.