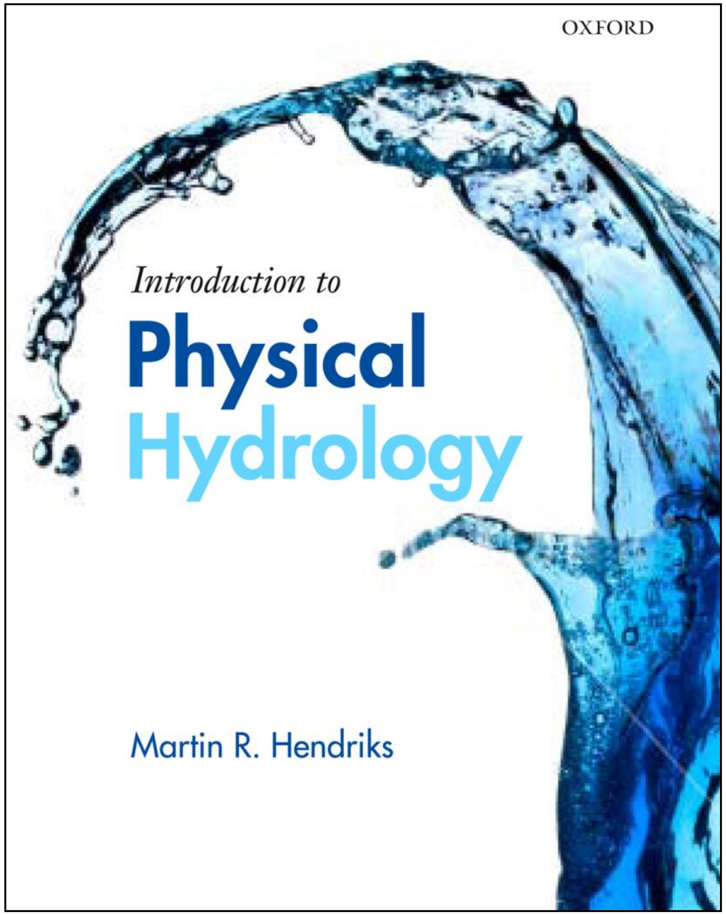
Surface water



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
4. Soil water
5. **Surface water**

Exercises

Why study surface water?

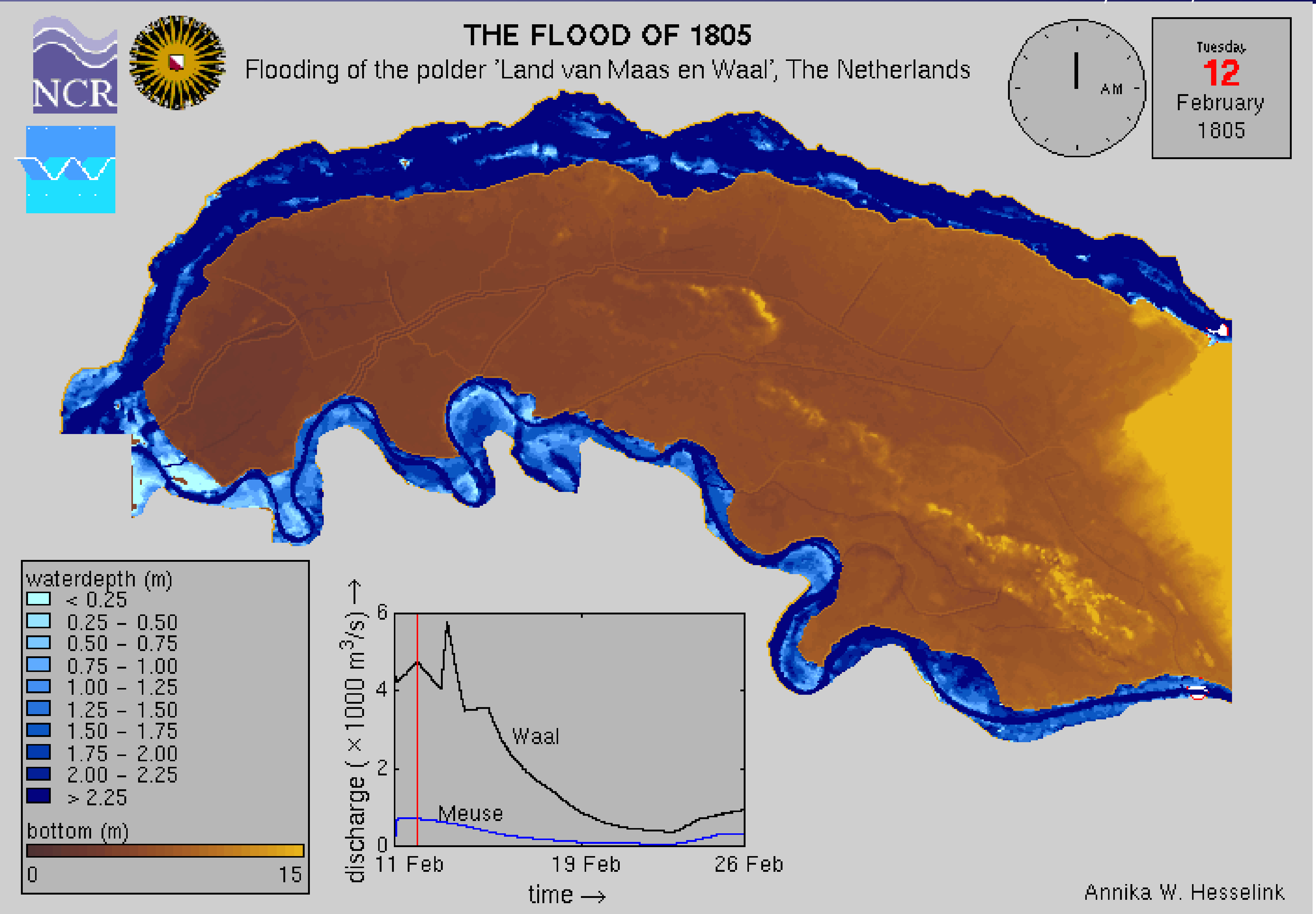
- flooding
- water shortage
- water-related diseases
- bad quality
- political conflicts

Photo taken by P.C. Beukenkamp

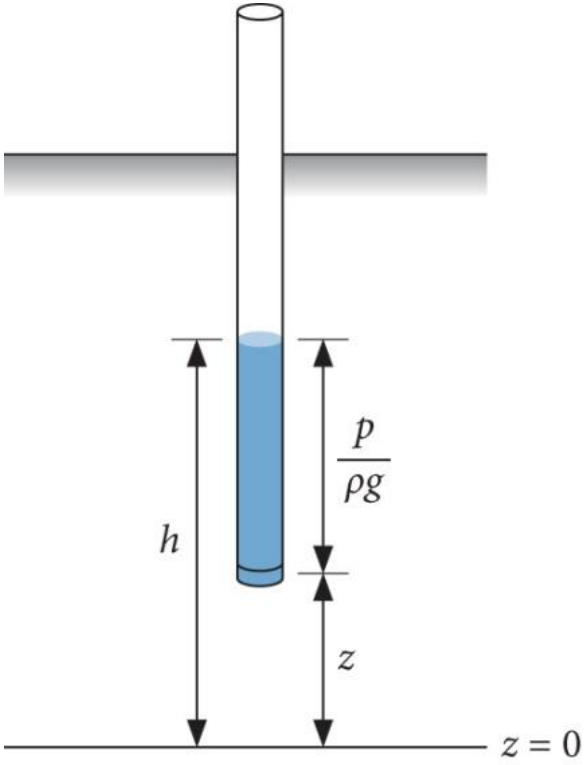
Manage our water resources in the best possible, sustainable and peaceful manner!

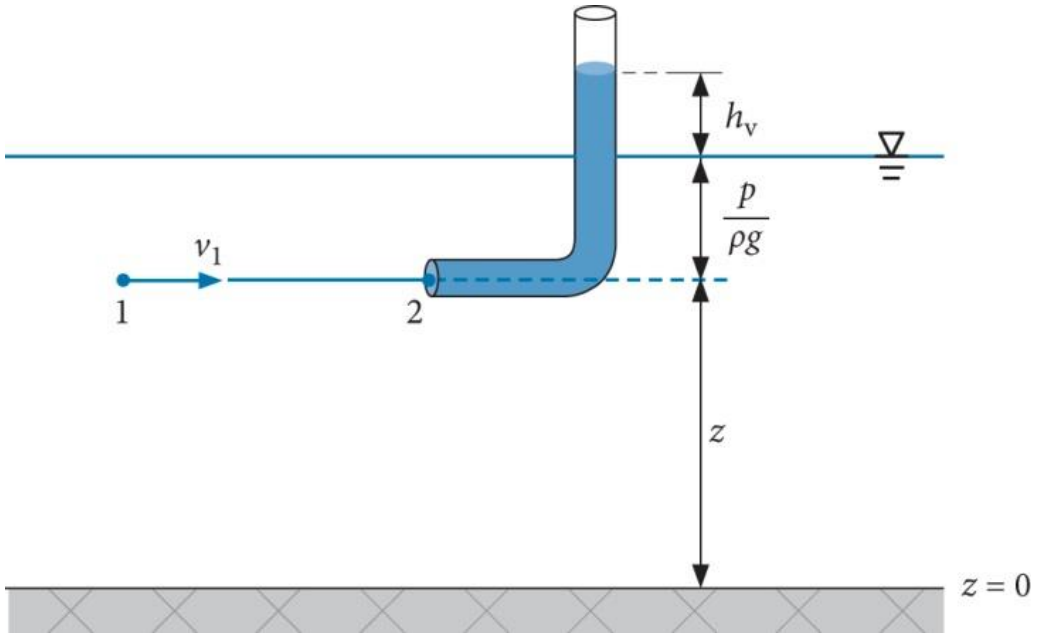
Delft-FLS Model

Delft Hydraulics / Deltares



Pitot tube



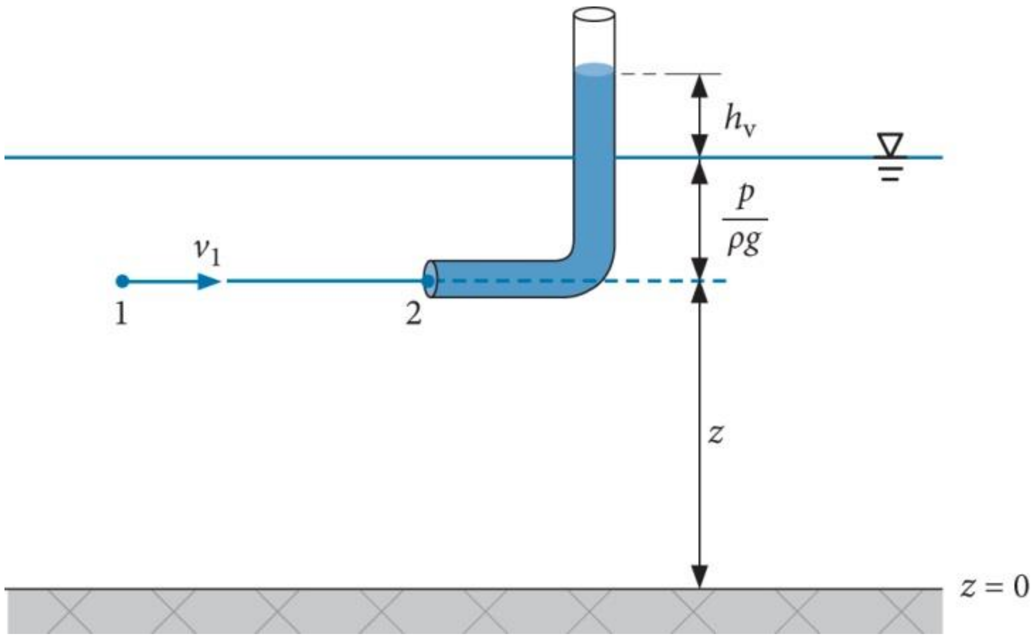


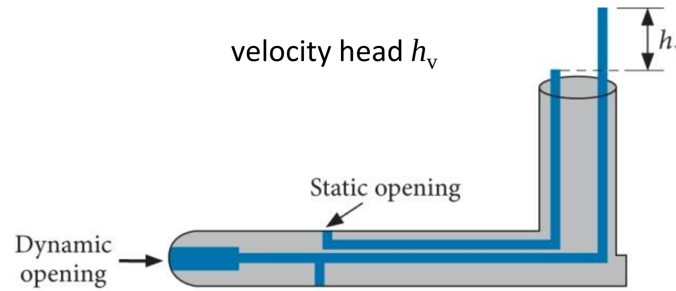
$$\tfrac{1}{2}mv^2 + mgz + pV = \text{constant}$$

$$\frac{v^2}{2g} + z + \frac{p}{\rho g} = \text{constant}$$

$$h_v = \frac{v^2}{2g} \qquad v = \sqrt{2gh_v}$$

$$\frac{v_1^2}{2g} + \frac{p_1}{\rho g} + z_1 = \frac{v_2^2}{2g} + \frac{p_2}{\rho g} + z_2$$





Combined Pitot tube

Adapted after Van Rijn (1994)

$z_1 = z_2$, $\frac{p_2}{\rho g} = \frac{p_1}{\rho g} + h_v$, and $v_2 = 0$

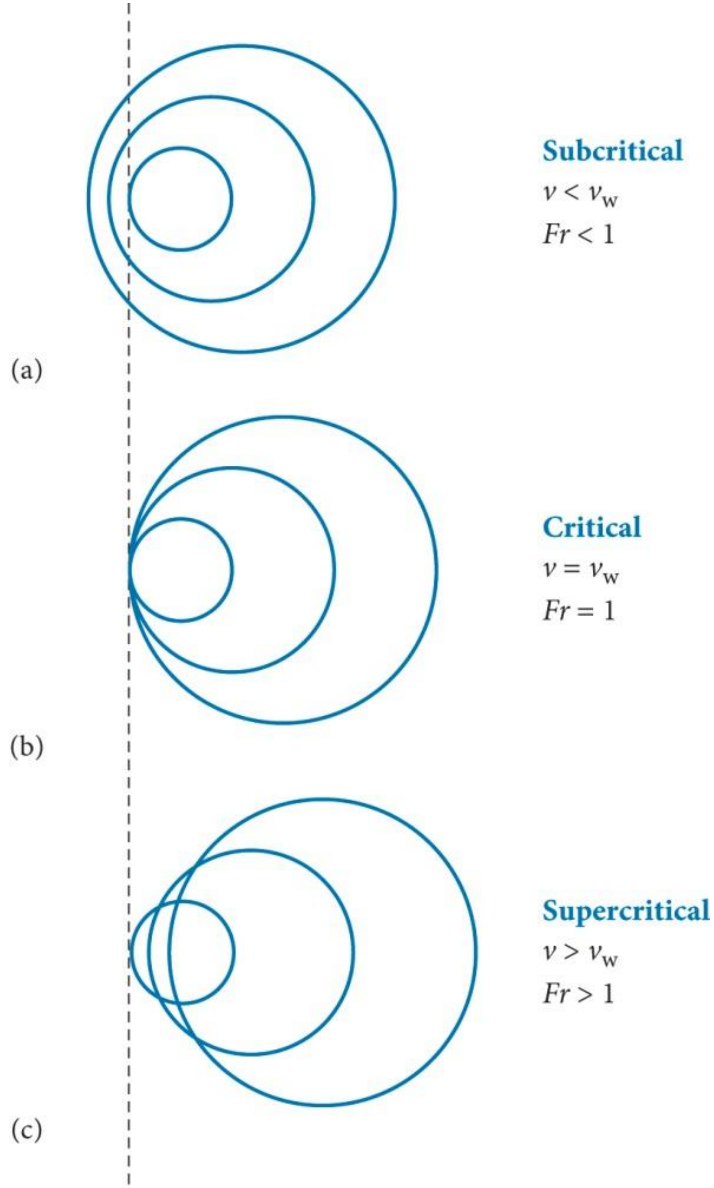
$$\frac{v_1^2}{2g} = h_v \qquad h_v = \frac{v^2}{2g}$$

Ripples in the water

$$v_w = \sqrt{gH}$$

$$Fr = \frac{v}{v_w} = \frac{v}{\sqrt{gH}}$$

v_w = propagation velocity of a surface wave



My kitchen sink

Hydraulic jump

(critical water flow)

Transition from supercritical, radial to subcritical, turbulent water flow

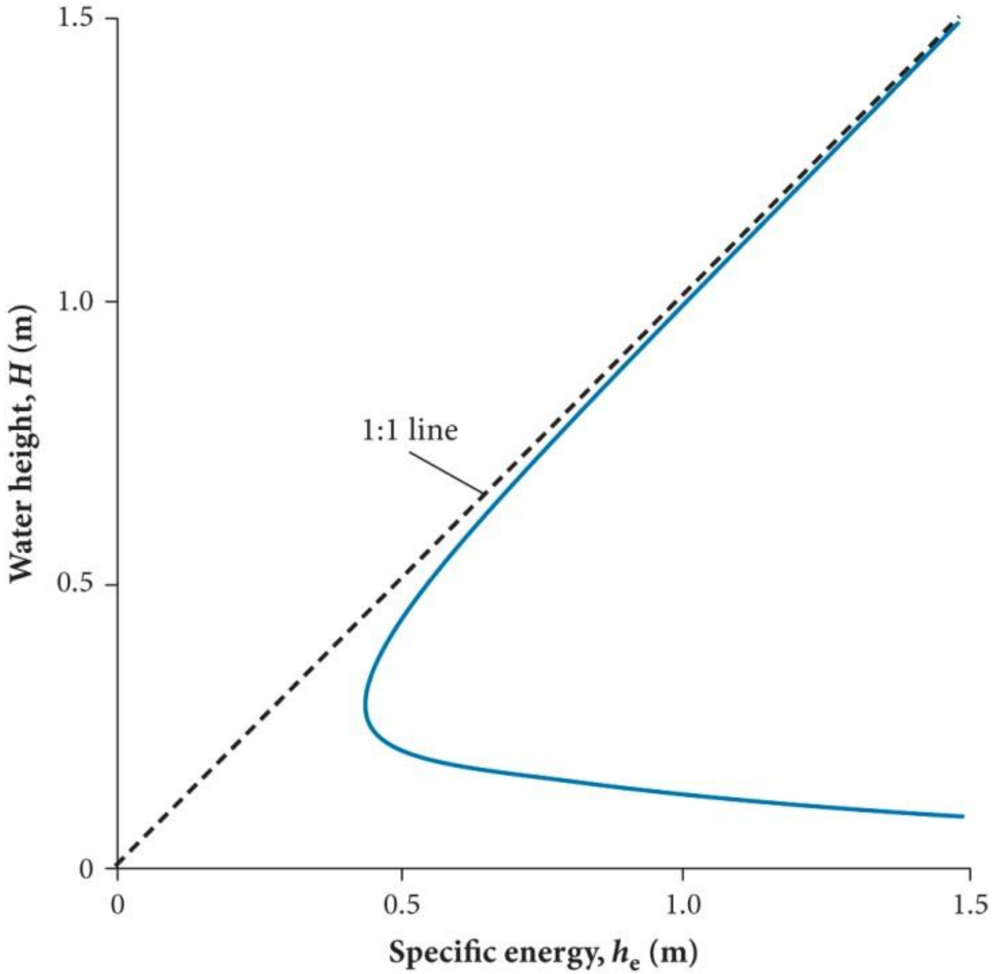
Specific energy diagram

$$h_e = \frac{q_w^2}{2gH^2} + H$$

h_e = specific energy (m)

q_w = specific discharge ($m^2\ s^{-1}$)

H = water height (m)



The specific energy diagram for $q_w = 0.5\ m^2\ s^{-1}$

Specific energy diagram

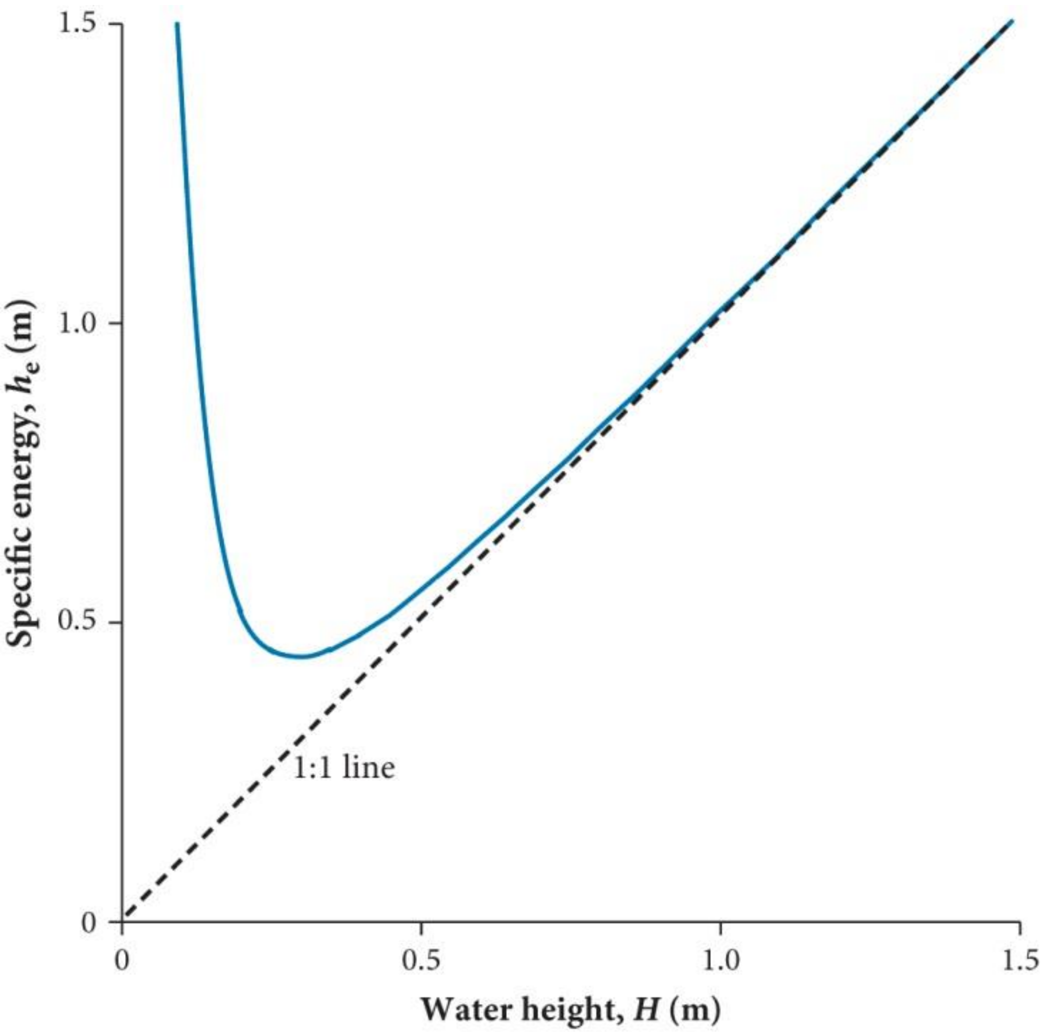
$$h_e = \frac{q_w^2}{2gH^2} + H$$

$$\frac{dh_e}{dH} = 0$$

$$q_w = H\sqrt{gH} = H^{\frac{3}{2}}\sqrt{g}$$

$$v = \frac{q_w}{H} = \sqrt{gH}$$

Only at a minimum value of h_e does h_e relate to one specific value of H, i.e. is there a specific relation between q_w and H!



The specific energy diagram for $q_w = 0.5\ m^2\ s^{-1}$

Critical flow at the dip

$$Q = w_c H_c \sqrt{g H_c}$$

Specific energy diagrams

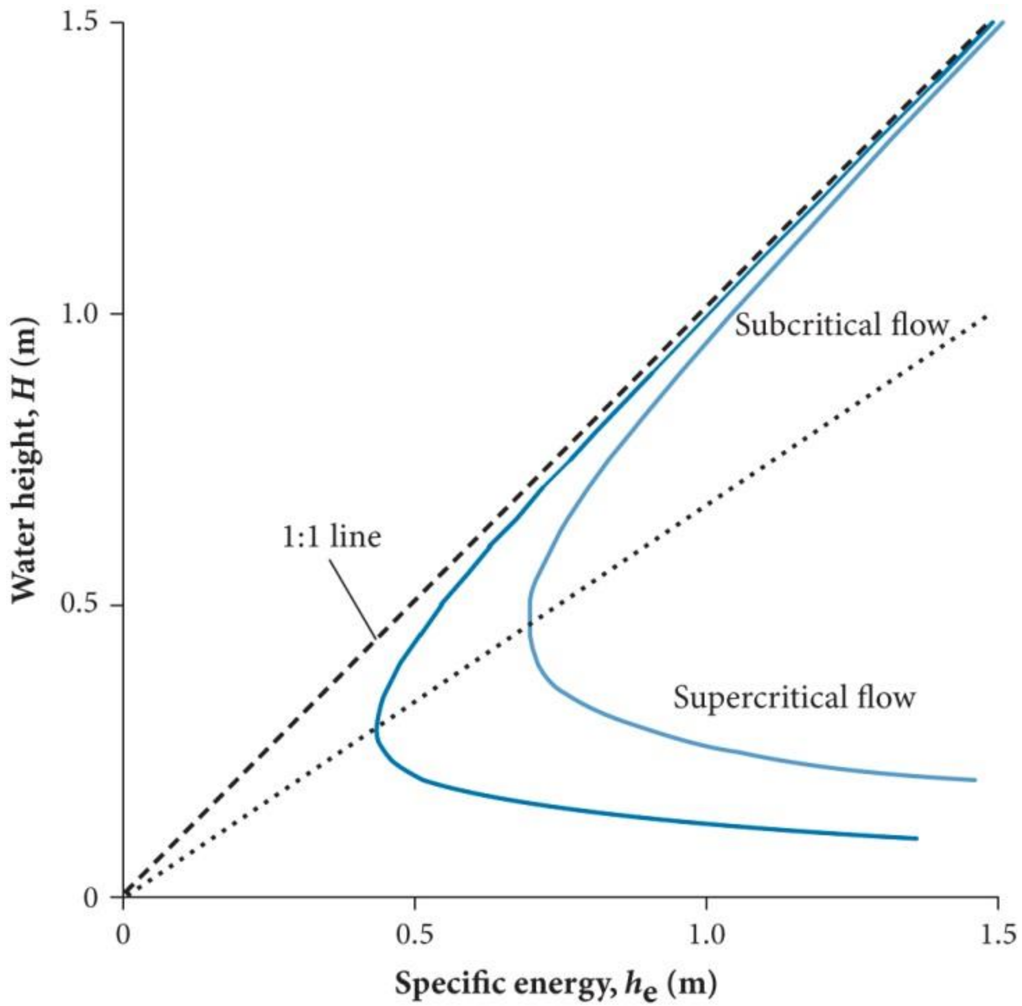
$$q_c = H_c\sqrt{gH_c} = H_c^{\frac{3}{2}}\sqrt{g}$$

in

$$h_{e,\min} = \frac{q_c^2}{2gH_c^2} + H_c$$

gives

$$h_{e,\min} = \frac{3}{2}H_c \quad \text{or} \quad H_c = \frac{2}{3}h_{e,\min}$$



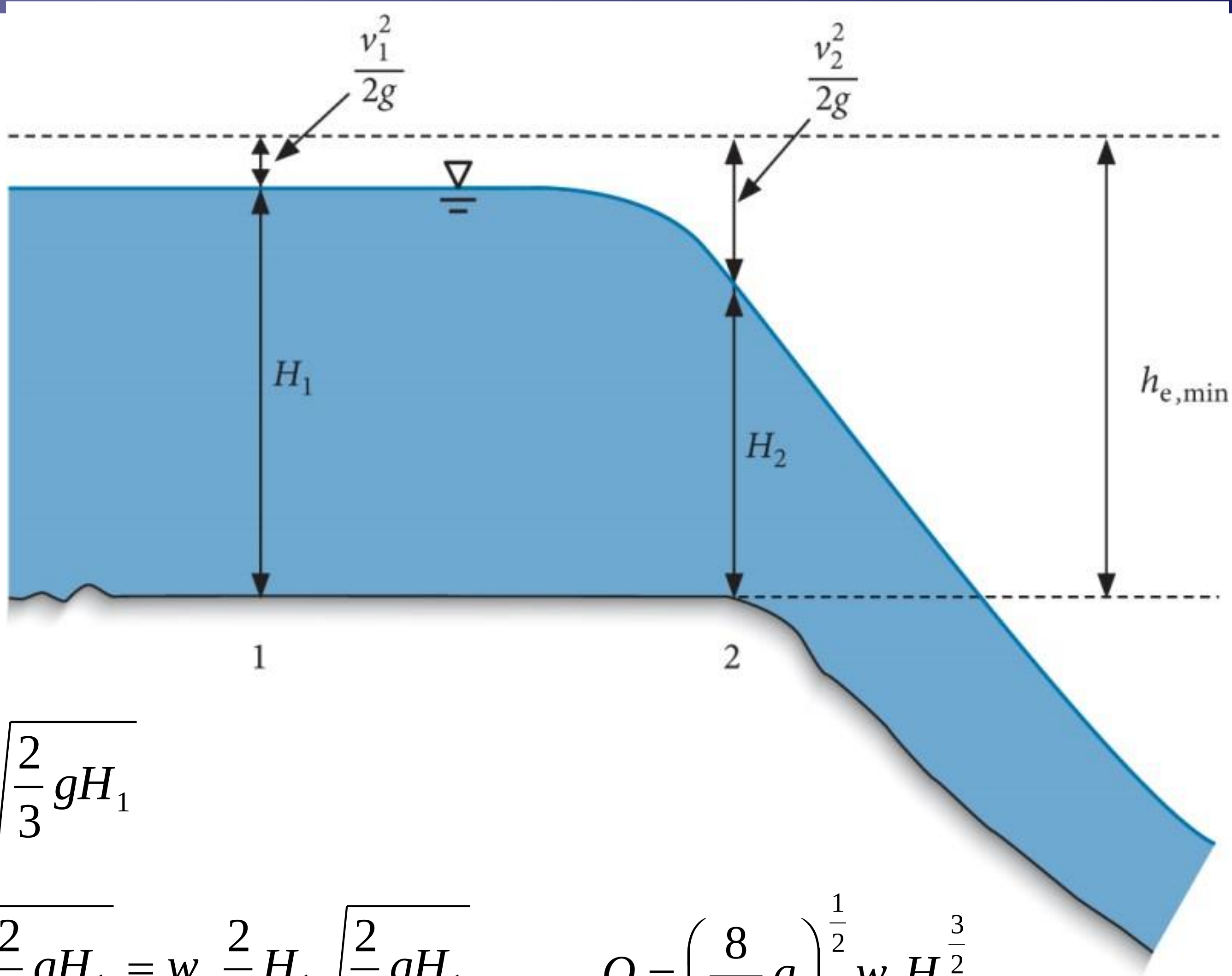
Specific energy diagrams for two specific discharges q_w of 0.5 m^2 s^{-1} (left) and 1.0 m^2 s^{-1} (right)

Q-H over a step in a river bed

$$\frac{v_1^2}{2g} = 0$$

$$H_c = \frac{2}{3} h_{e,\,min}$$

$$H_2 = \frac{2}{3} H_1$$



gives $v_2 = \sqrt{\frac{2}{3} g H_1}$

$$Q = w_c H_2 \sqrt{\frac{2}{3} g H_1} = w_c \frac{2}{3} H_1 \sqrt{\frac{2}{3} g H_1}$$

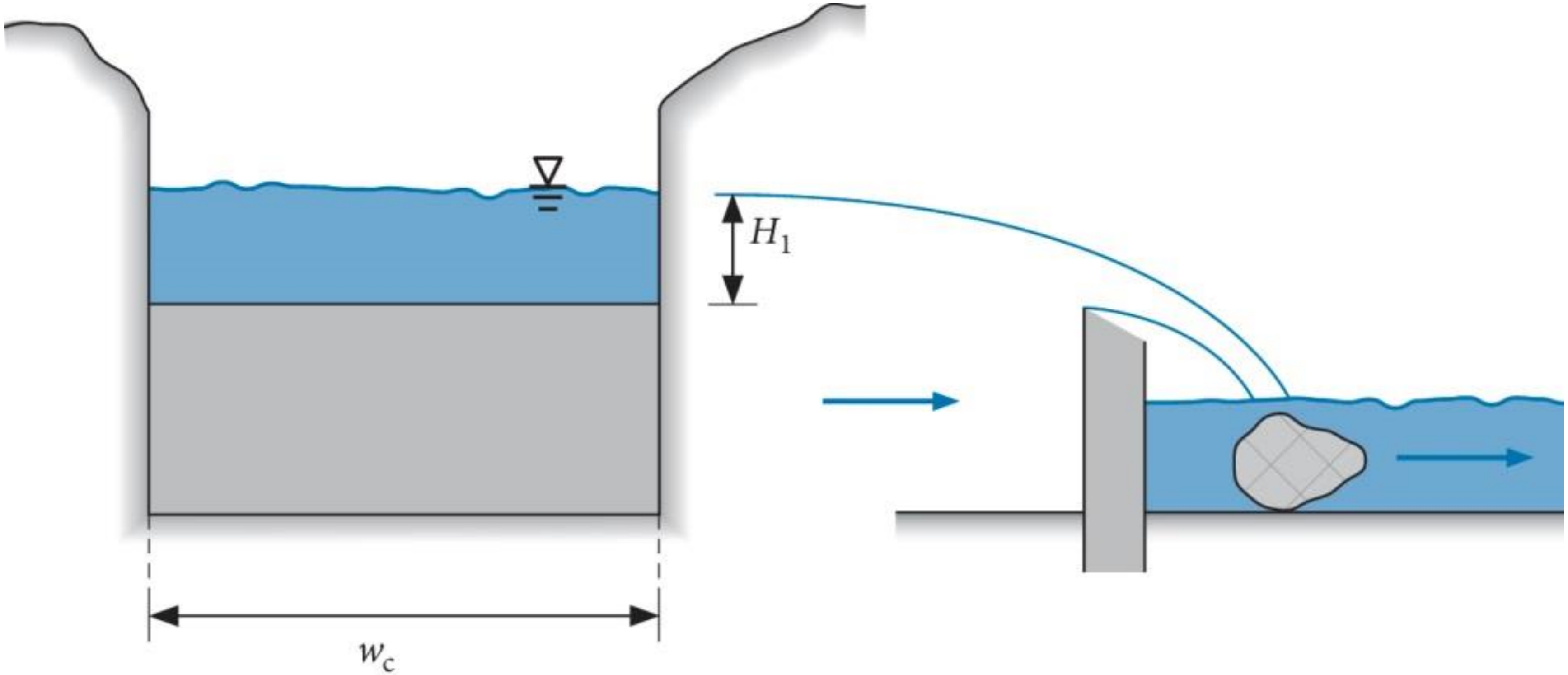
$$Q = \left(\frac{8}{27} g\right)^{\frac{1}{2}} w_c H_1^{\frac{3}{2}}$$

pages 218 and 219

Q-H over a step in a river bed

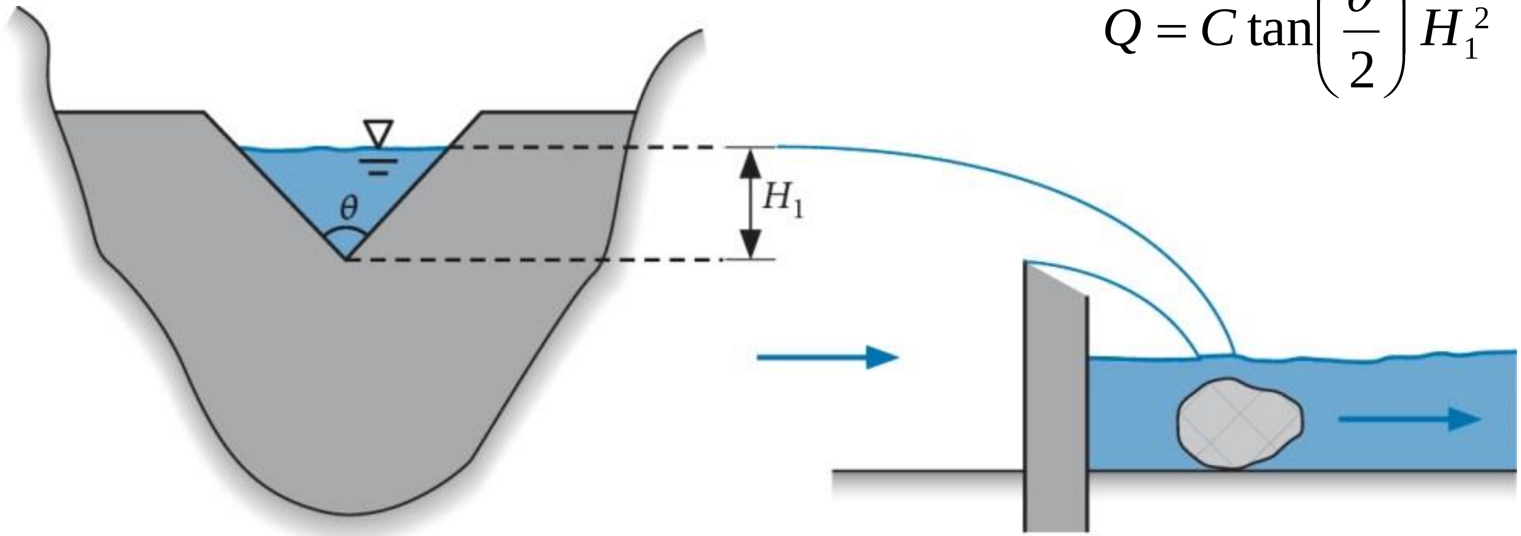
Photos taken by Dr T.A. Bogaard

Rectangular weir



$$Q = C\, w_c H_1^{\frac{3}{2}}$$

V-notch weir



$$Q = C \tan\left(\frac{\theta}{2}\right) H_1^{\frac{5}{2}}$$

V-notch weirs

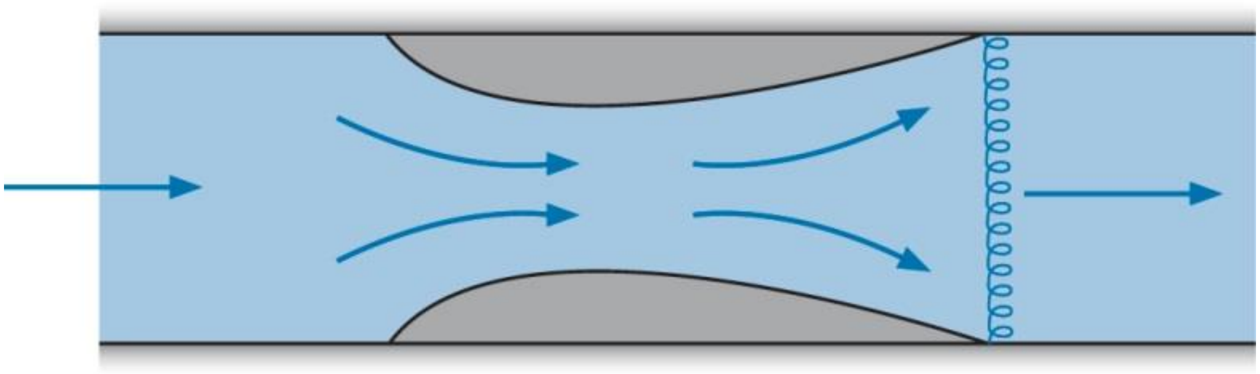
$$Q = C \tan\left(\frac{\theta}{2}\right) H_1^{\frac{5}{2}}$$

Sediment sampling

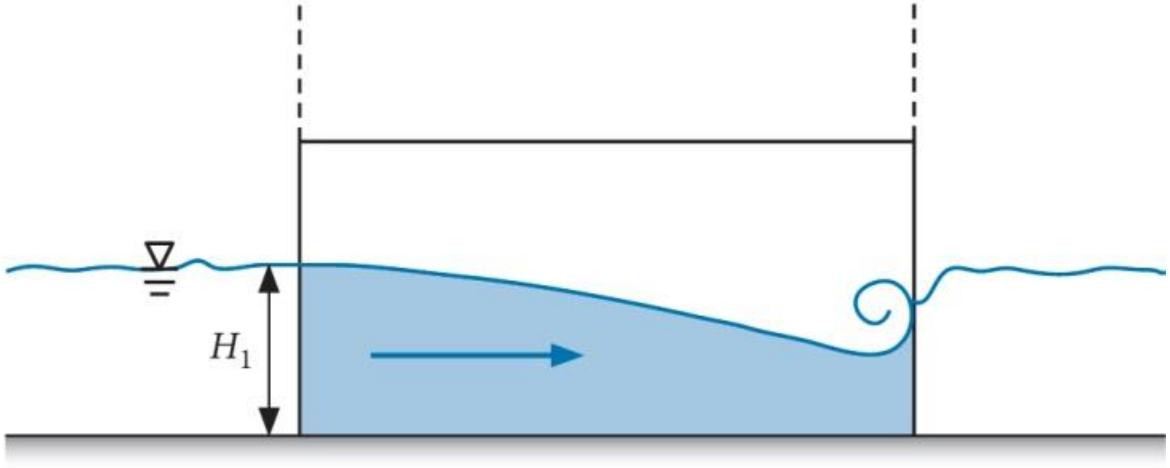
$$Q = C \tan\left(\frac{\theta}{2}\right) H_1^{\frac{5}{2}}$$

Sediment sampling in surface water at the same spot as the discharge measurements

Flume



$$Q = CH_1^{\frac{3}{2}}$$



Flume

$$Q = CH_1^{\frac{3}{2}}$$

Concluding remark

$$Q = \left(\frac{8}{27} g \right)^{\frac{1}{2}} w_c H_1^{\frac{3}{2}}$$

$$Q = C\, w_c H_1^{\frac{3}{2}}$$

$$Q = C \tan\left(\frac{\theta}{2} \right) H_1^{\frac{5}{2}}$$

$$Q = C H_1^{\frac{3}{2}}$$

References

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

Van Rijn, L.C. (1994). Principles of fluid flow and surface waves in rivers, estuaries, seas and oceans. 2nd ed. Aqua Publications, Oldemarkt, 335 pp. SISO 533.3 UDC 532 NUGI 831.