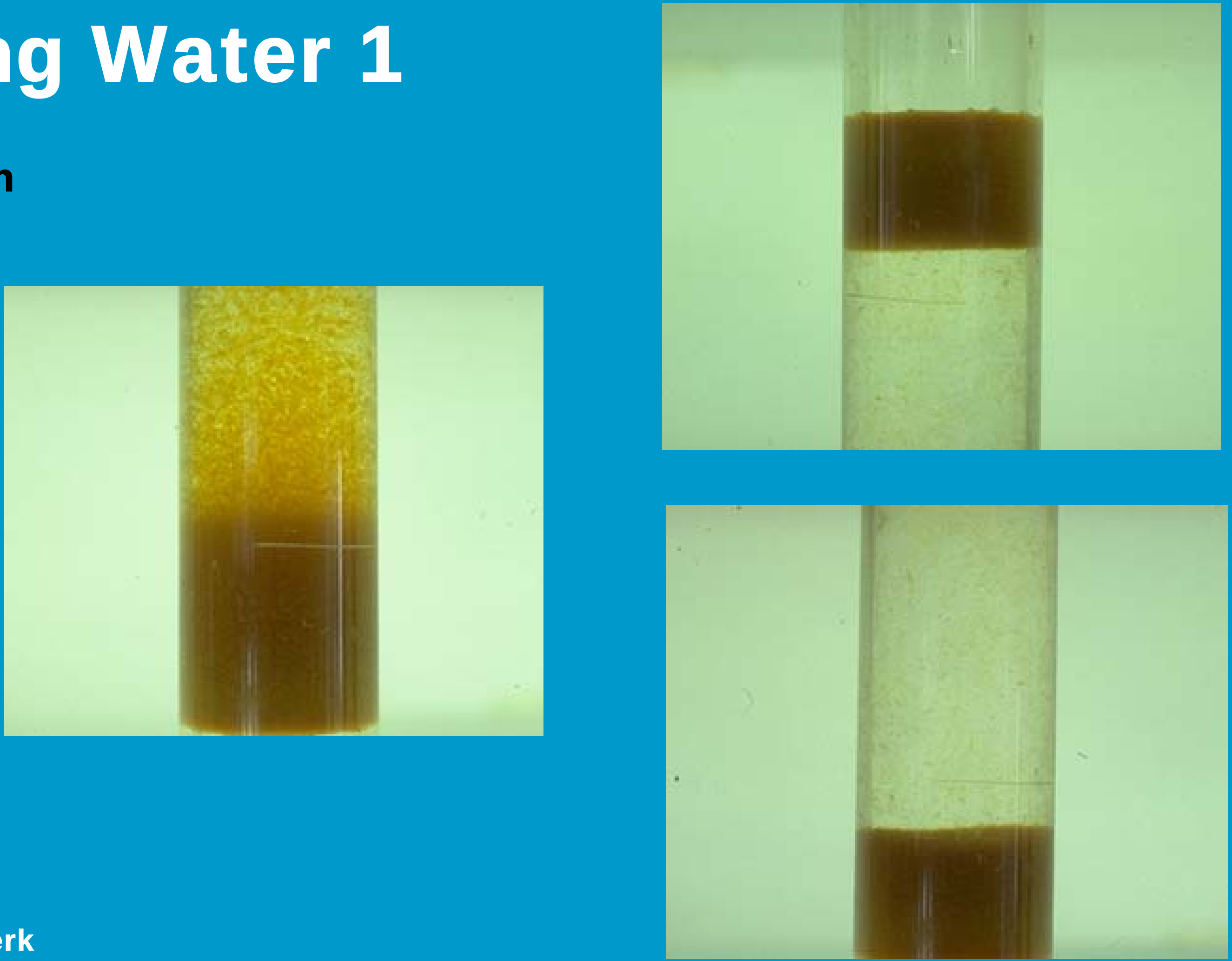
Drinking Water 1

Sedimentation

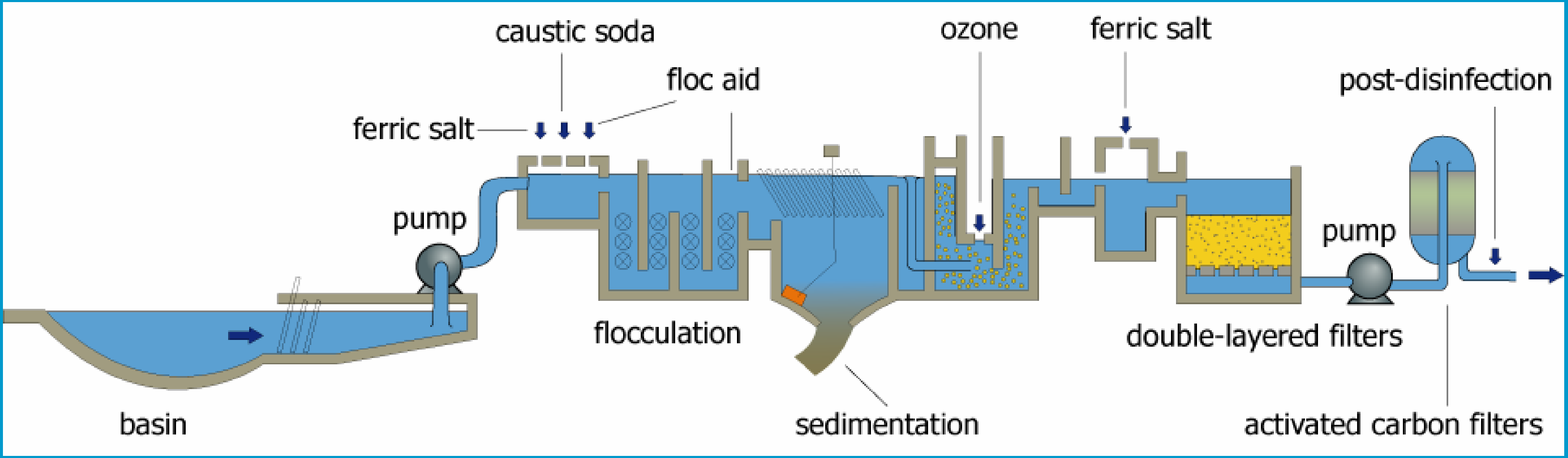


Dr.ir. Jasper Verberk

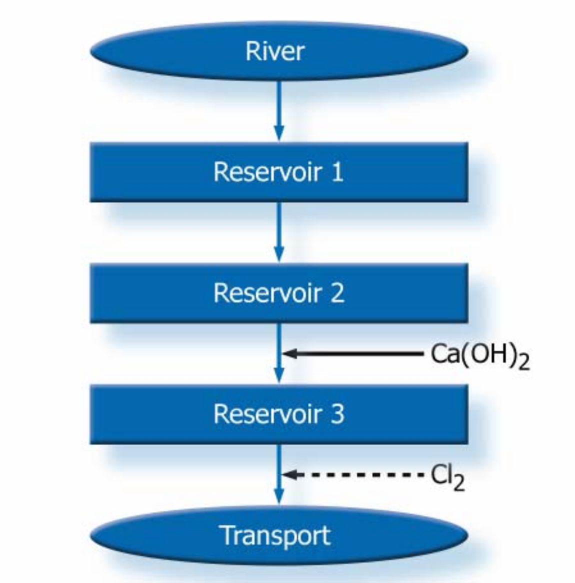
Room 2.98

Contents

Introduction



Natural settling



River

Reservoir 1

Reservoir 2

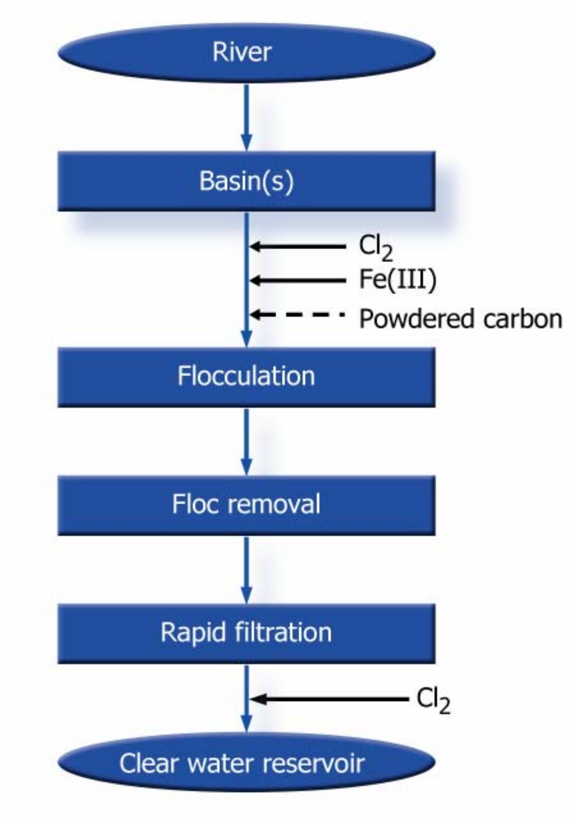
$Ca(OH)_2$

Reservoir 3

Cl_2

Transport

Settling after coagulation & flocculation


River

Basin(s)

Cl_2

Fe(III)

Powdered carbon

Flocculation

Floc removal

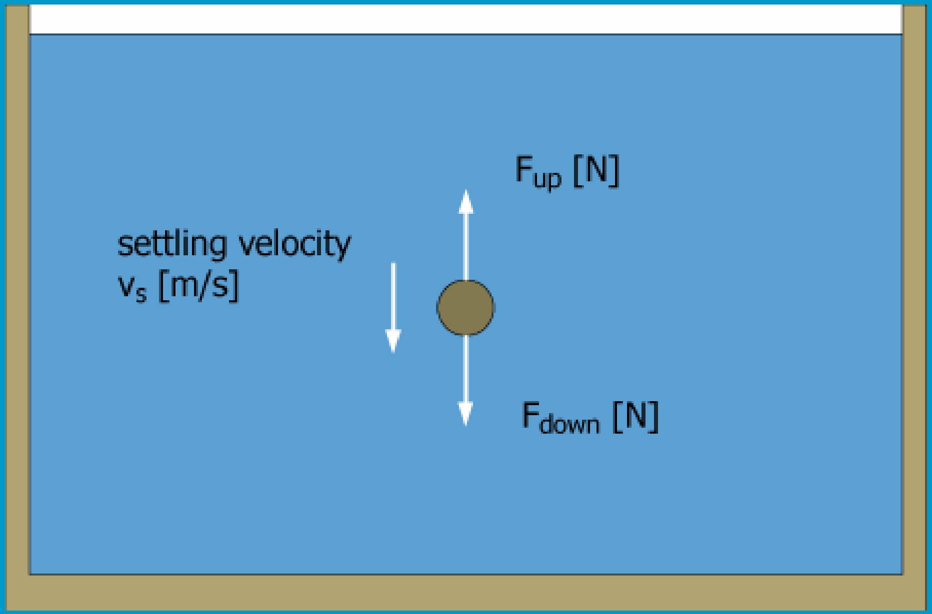
Rapid filtration

Cl_2

Clear water reservoir

Theory of settling

Settling velocity of discrete particles



Flow resistance

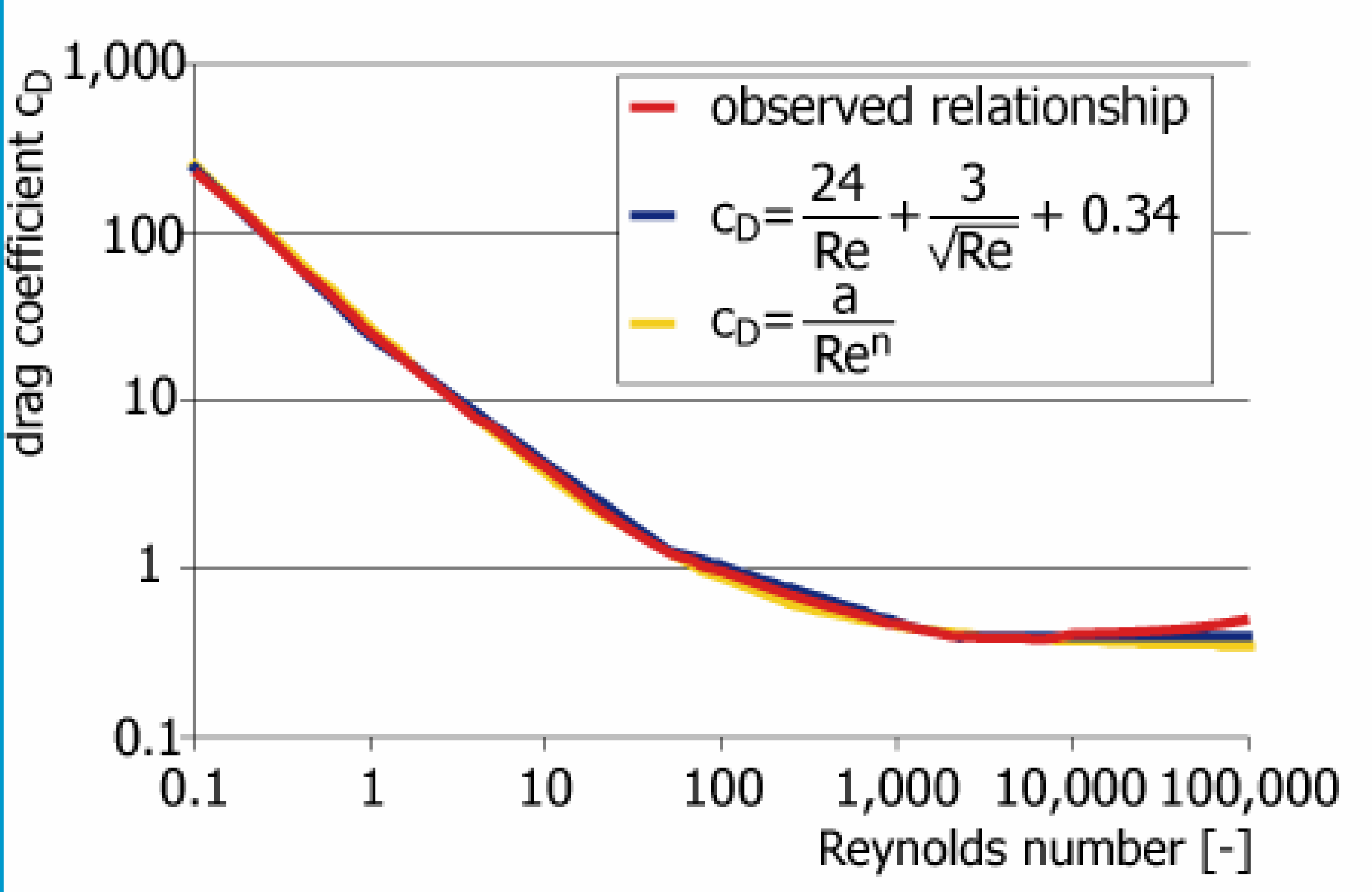
$$F_d = c_D \cdot \frac{\rho_w}{2} \cdot v_s^2 \cdot A$$

Submerged weight

$$F_i = (\rho_s - \rho_w) \cdot g \cdot V$$

$$A = \frac{\pi}{4} \cdot d^2; \quad V = \frac{\pi}{6} \cdot d^3 \quad \Rightarrow \quad v_s = \sqrt{\frac{4}{3 \cdot c_D} \cdot \frac{\rho_s - \rho_w}{\rho_w} \cdot g \cdot d}$$

Drag coefficient



Laminar settling

Re < 1 $$c_D = \frac{24}{Re}$$ $$v_s = \frac{1}{18} \cdot \frac{g}{\nu} \cdot \frac{\rho_s - \rho_w}{\rho_w} \cdot d^2$$ Stokes equation

Example

ρ_s = 2,650 kg/m^3, ρ_w = 1,000 kg/m^3, d = 1·10^{-4} m

T = 10 °C -> ν = 1.31·10^{-6} m^2/s

Calculate the settling velocity of this particle

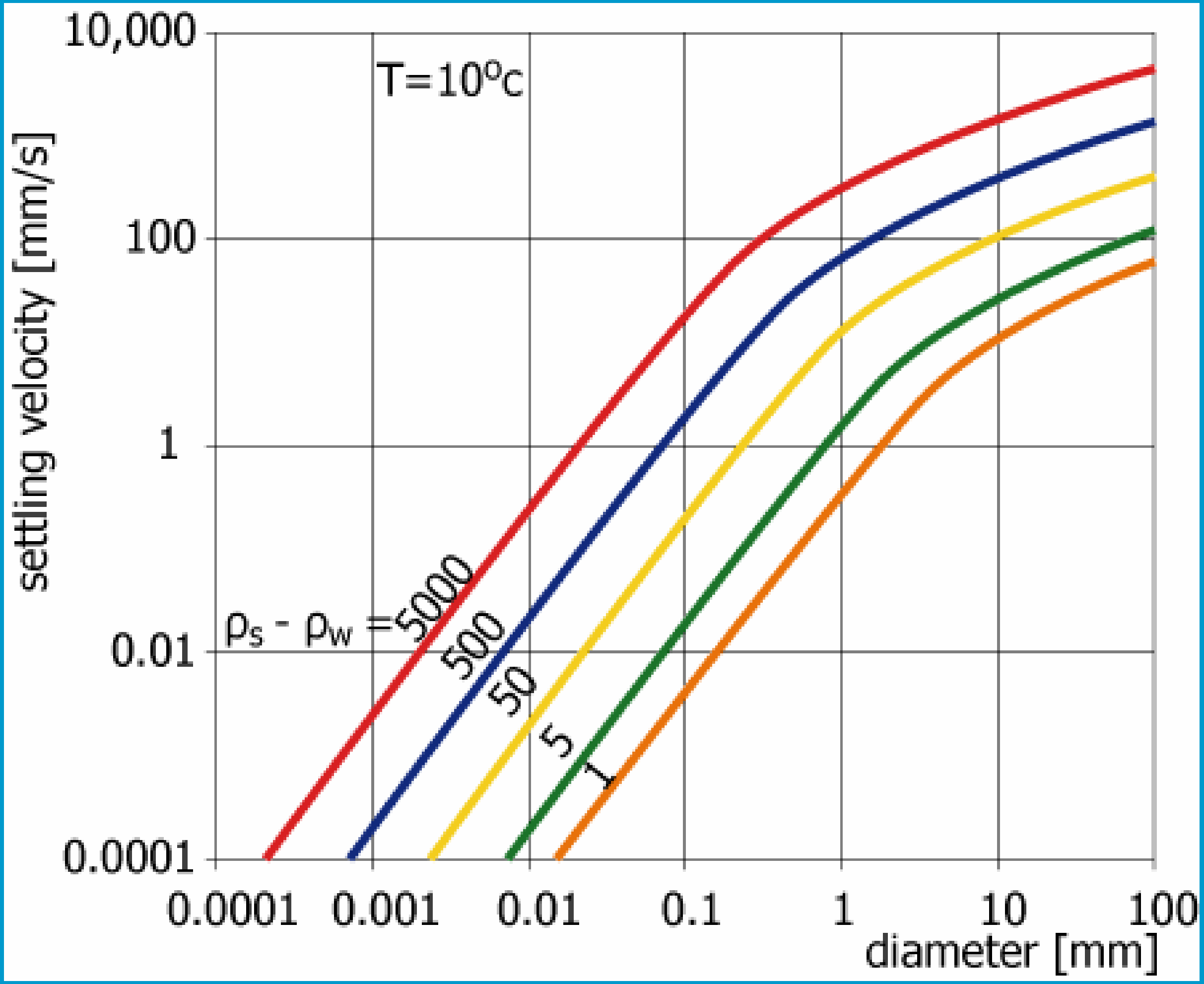
$$s = \frac{1}{18} \cdot \frac{9.81}{1.31 \cdot 10^{-6}} \cdot \left(\frac{2650 - 1000}{1000}\right) \cdot \left(1 \cdot 10^{-3}\right)^2$$

$$= 0.0069 \text{ m/s} = 24.8 \text{ m/h}$$

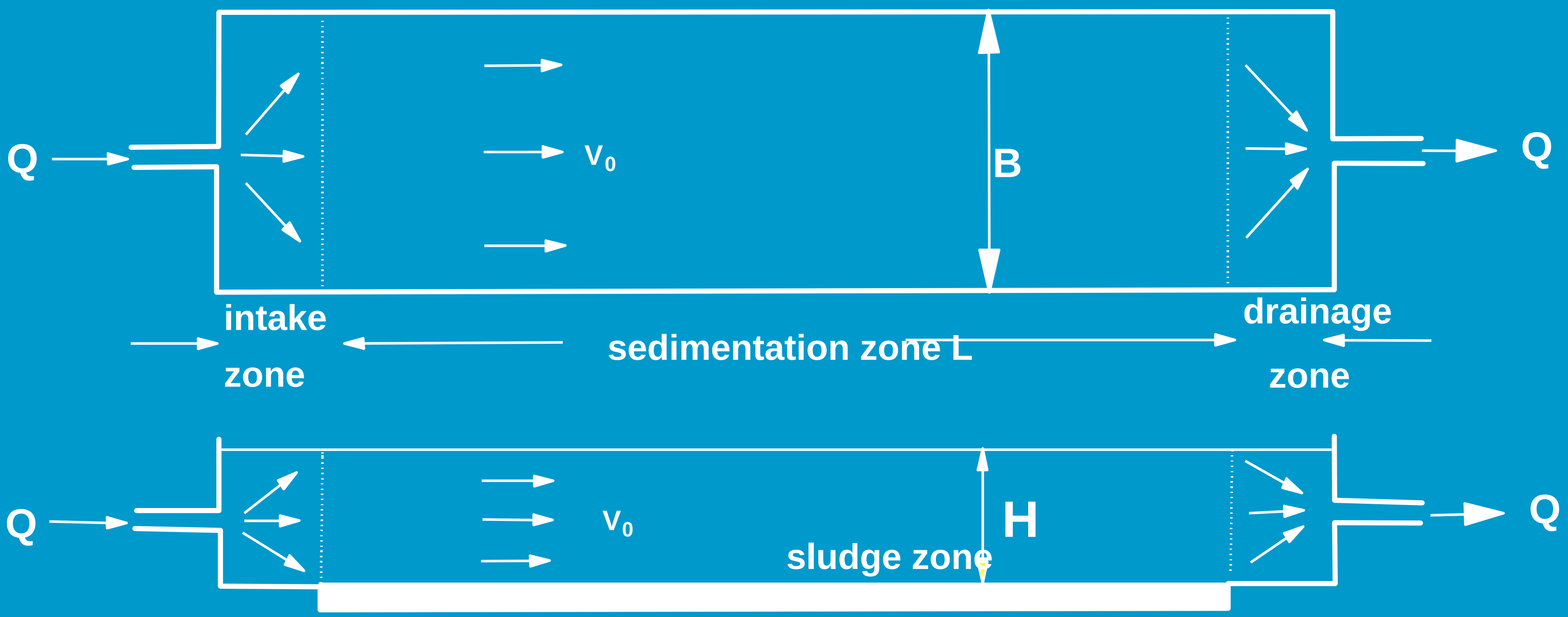
check Re:

$$Re = \frac{v_s \cdot d}{\nu} = \frac{0.0069 \cdot 1 \cdot 10^{-4}}{1.31 \cdot 10^{-6}} = 0.53 < 1$$

Settling velocities



Horizontal sedimentation



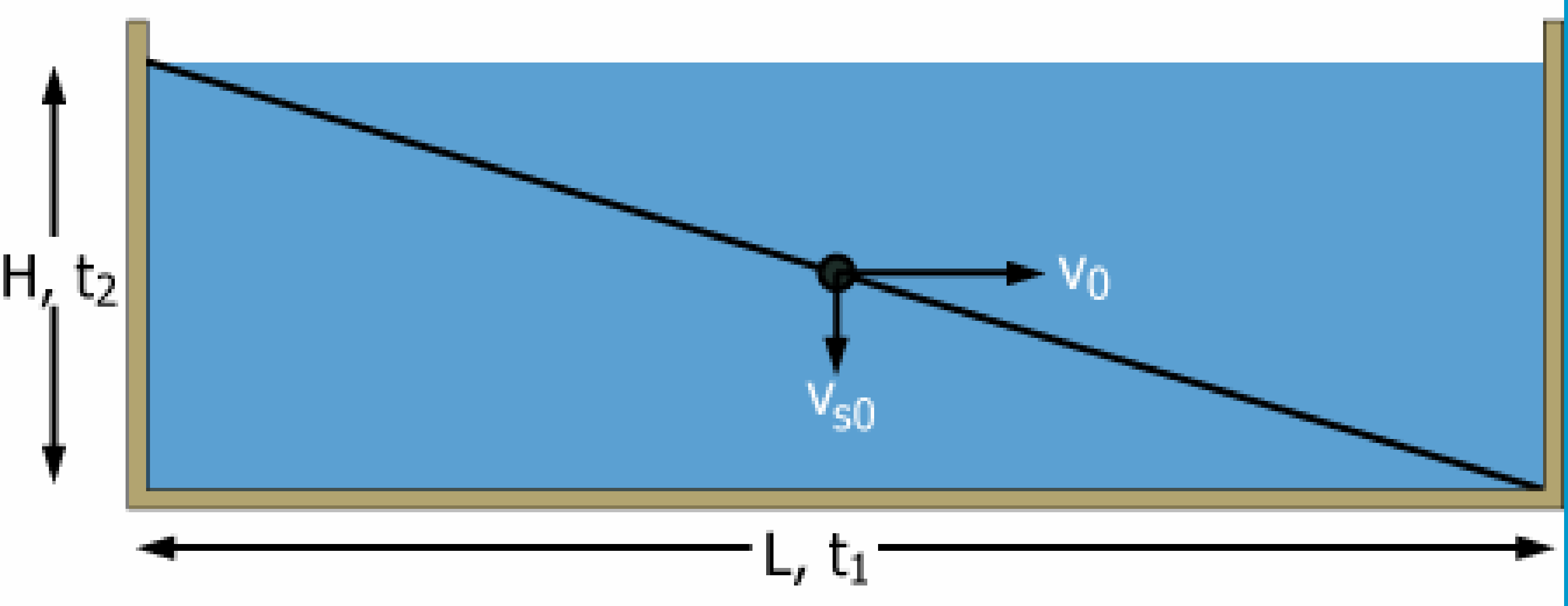
$$v_0 = \frac{Q}{B \cdot H}$$

v_0 = velocity [m/h]

$$v_{s0} = \frac{Q}{B \cdot L}$$

v_{s0} = surface loading [m/h]

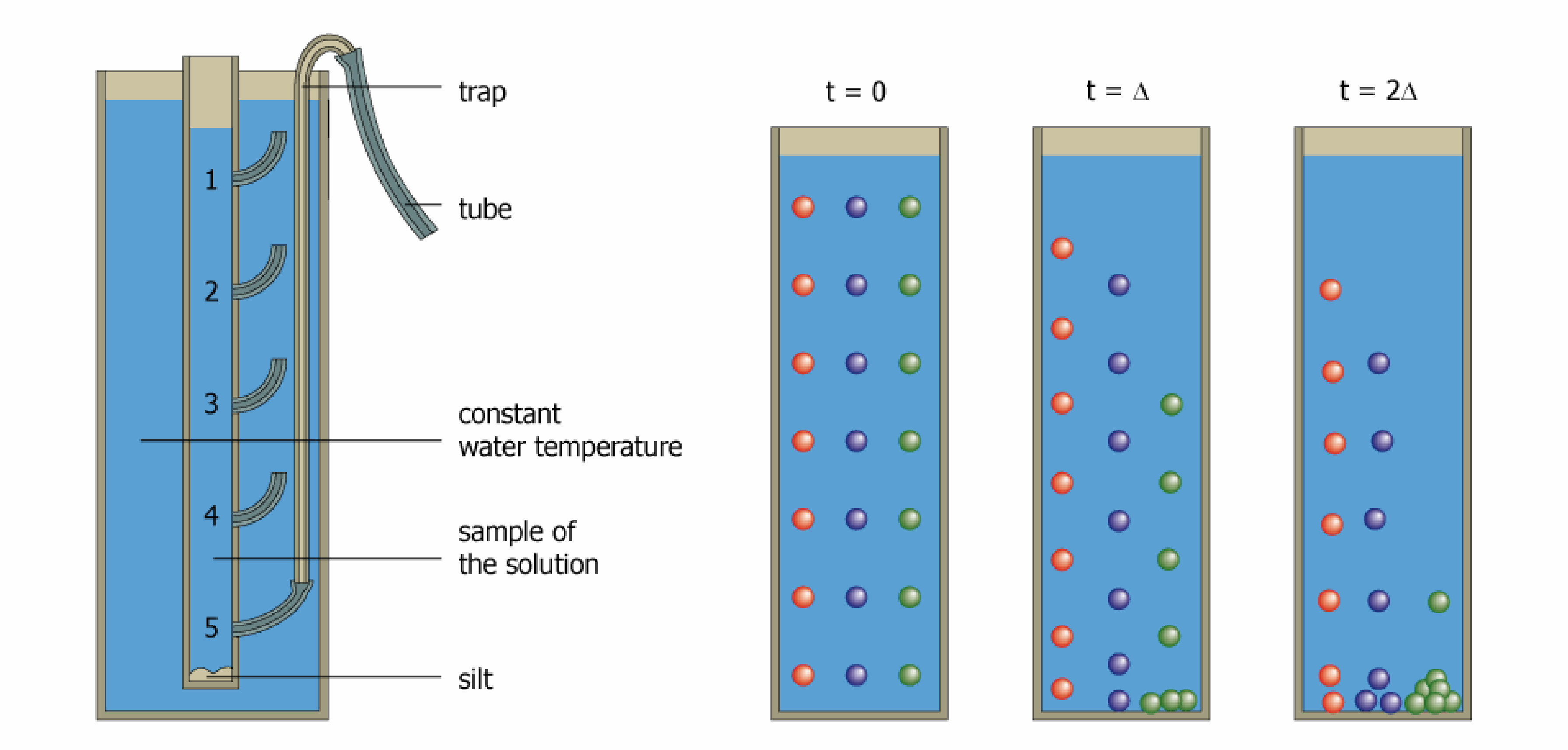
Horizontal sedimentation



$$\frac{v_0}{L} \le \frac{v_{s0}}{H} \Rightarrow \frac{Q}{B \cdot H \cdot L} \le \frac{v_{s0}}{H} \Rightarrow \frac{Q}{B \cdot L} = v_{s0} \le v_s$$

Settling only depends on the surface loading v_{s0}, depth H has no influence

Quiescent settling test



Discrete settling

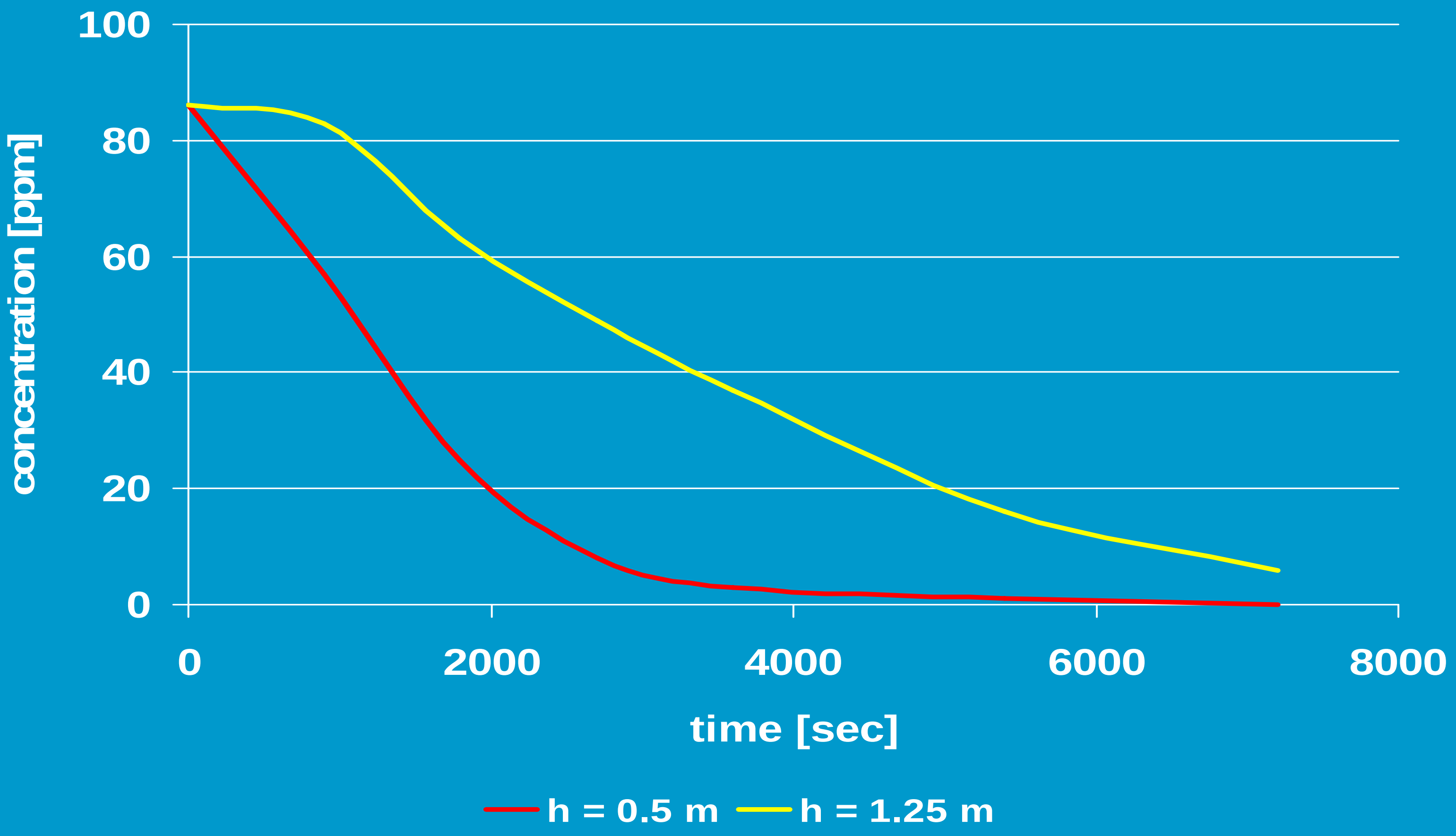
h = 0.5 m

t [sec]	0	900	1800	2700	3600	5400	7200
C [ppm]	86	57	25	8	3	1	0
C/C_o[%]	100	66	29	9	4	1	0

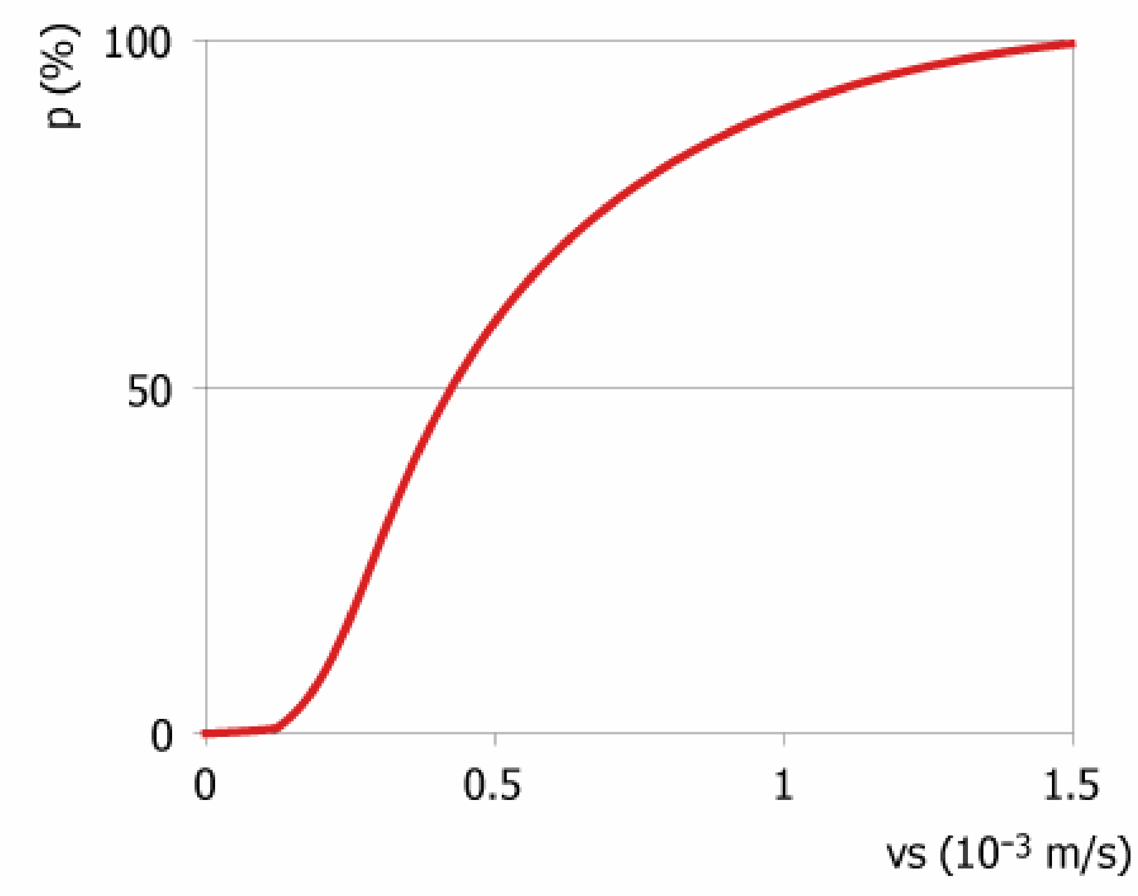
h = 1.25 m

t [sec]	0	900	1800	2700	3600	5400	7200
C [ppm]	86	83	63	49	37	16	6
C/C_o[%]	100	96	73	57	42	19	7

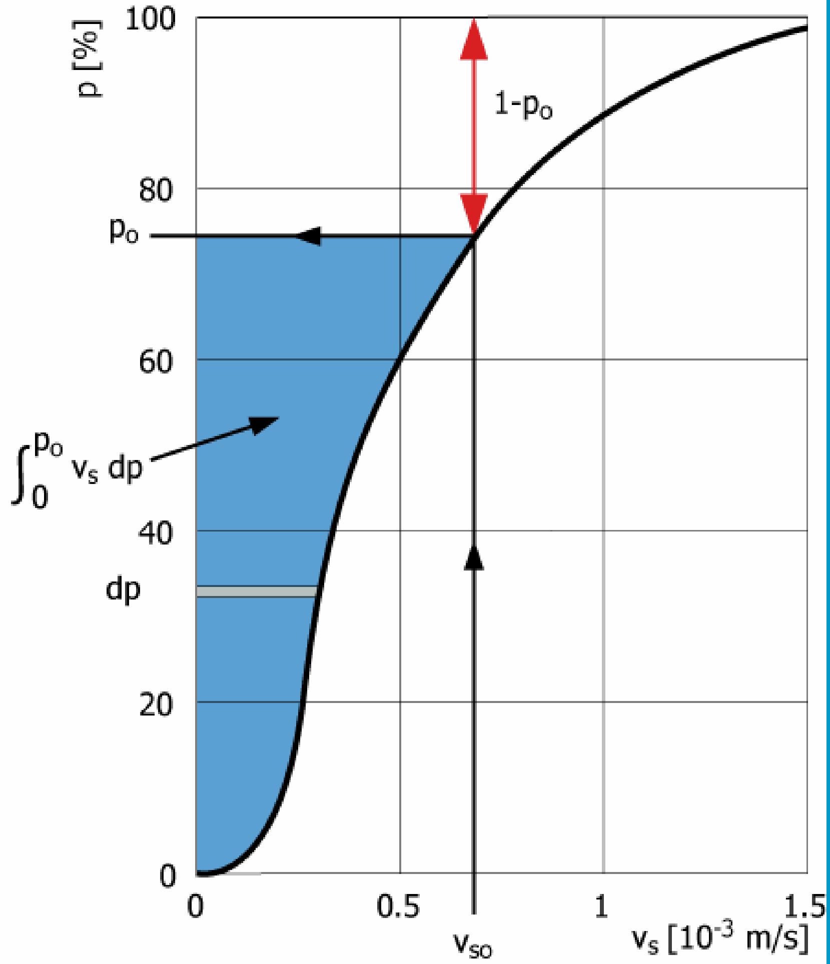
Discrete settling



Cumulative frequency distribution settling velocity



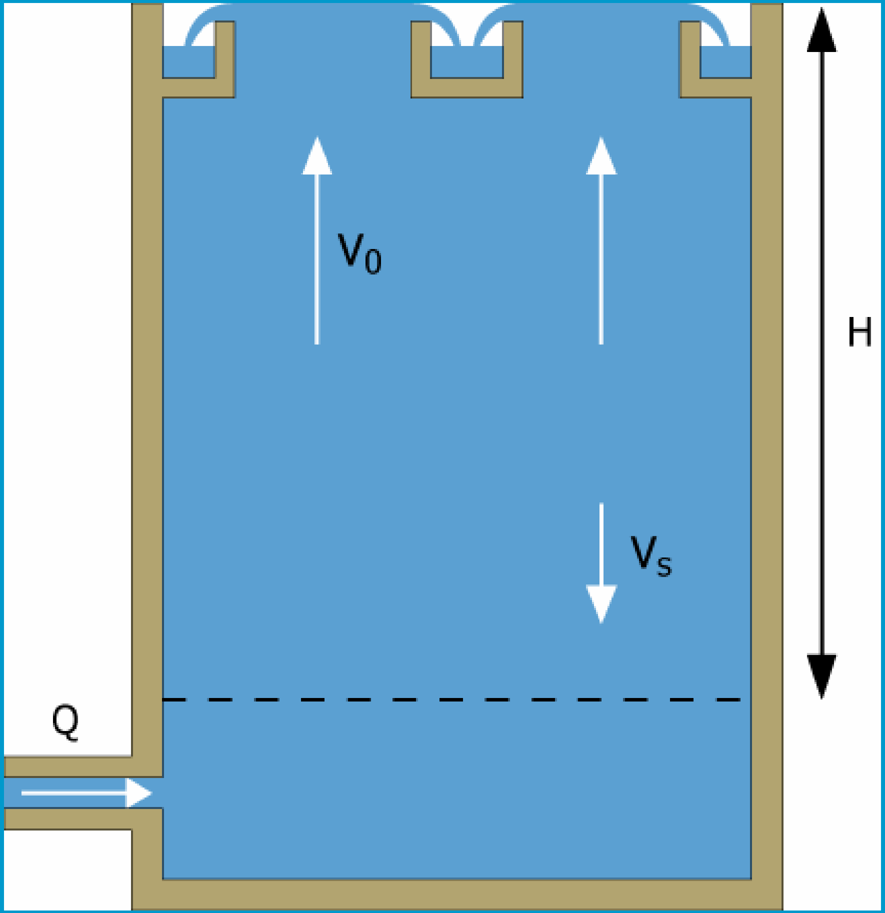
Efficiency sedimentation



v_s>=v_{s0} settles completely

r = 1-p_0

Vertical sedimentation

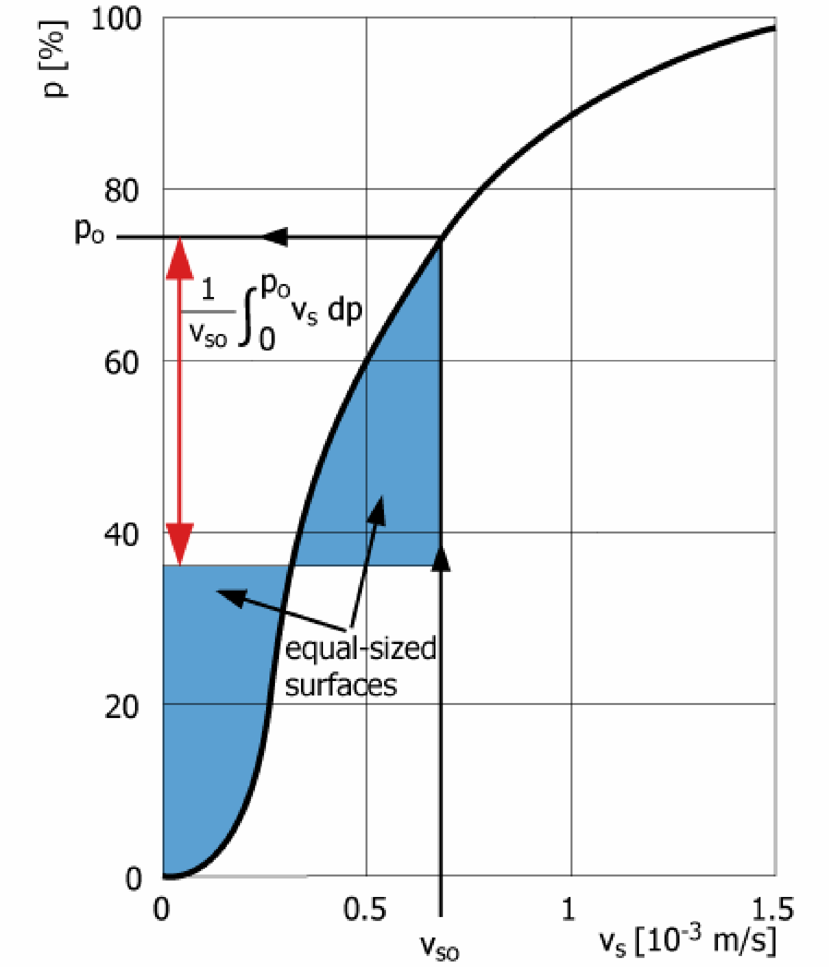


$v_s >= v_{s0}$ settles completely
$v_s < v_{s0}$ does not settle

$r = 1 - p_0$

$$v_0 = \frac{Q}{B \cdot L} = v_{s0}$$

Efficiency horizontal sedimentation

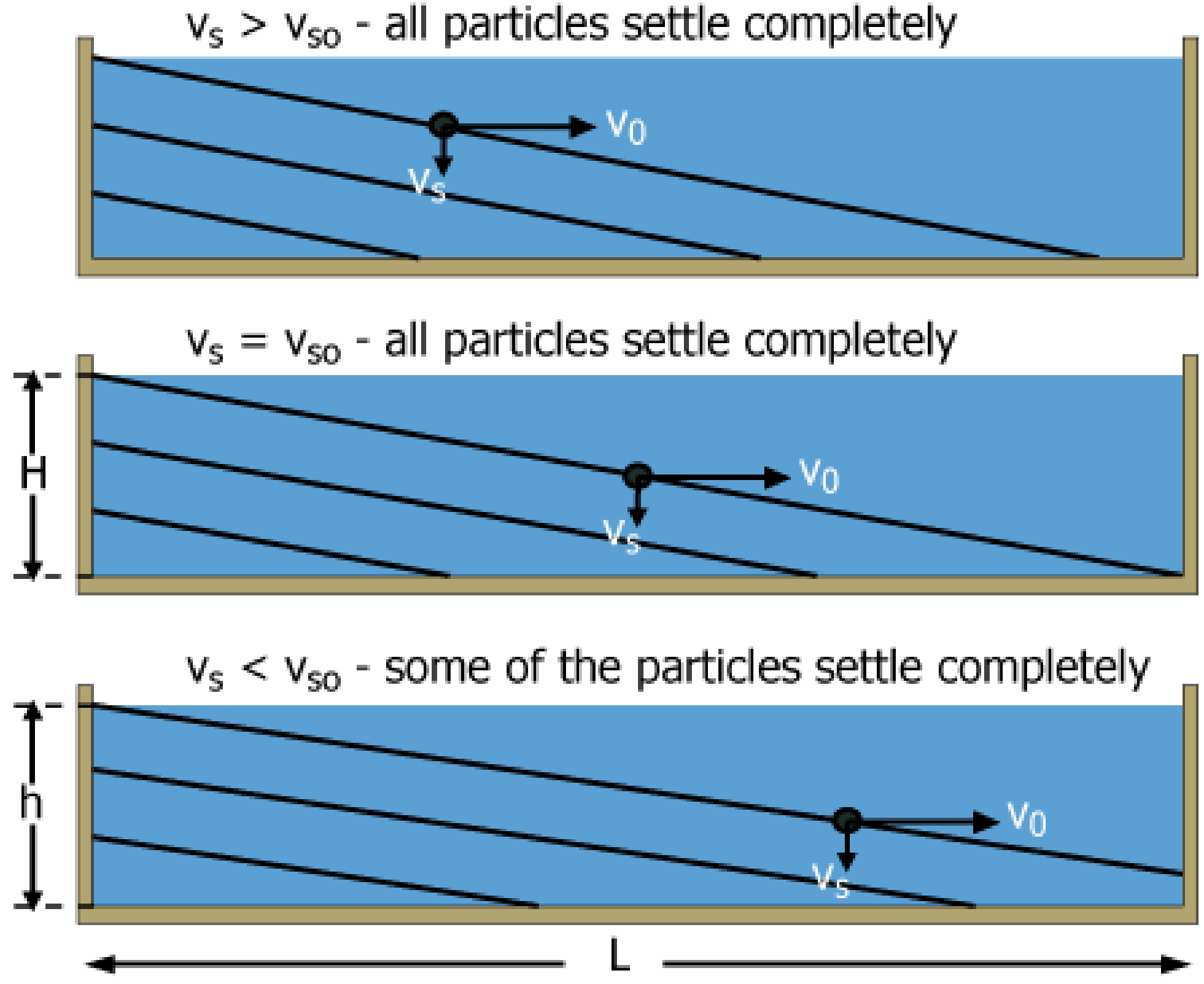


v_s>=v_{s0} settles completely

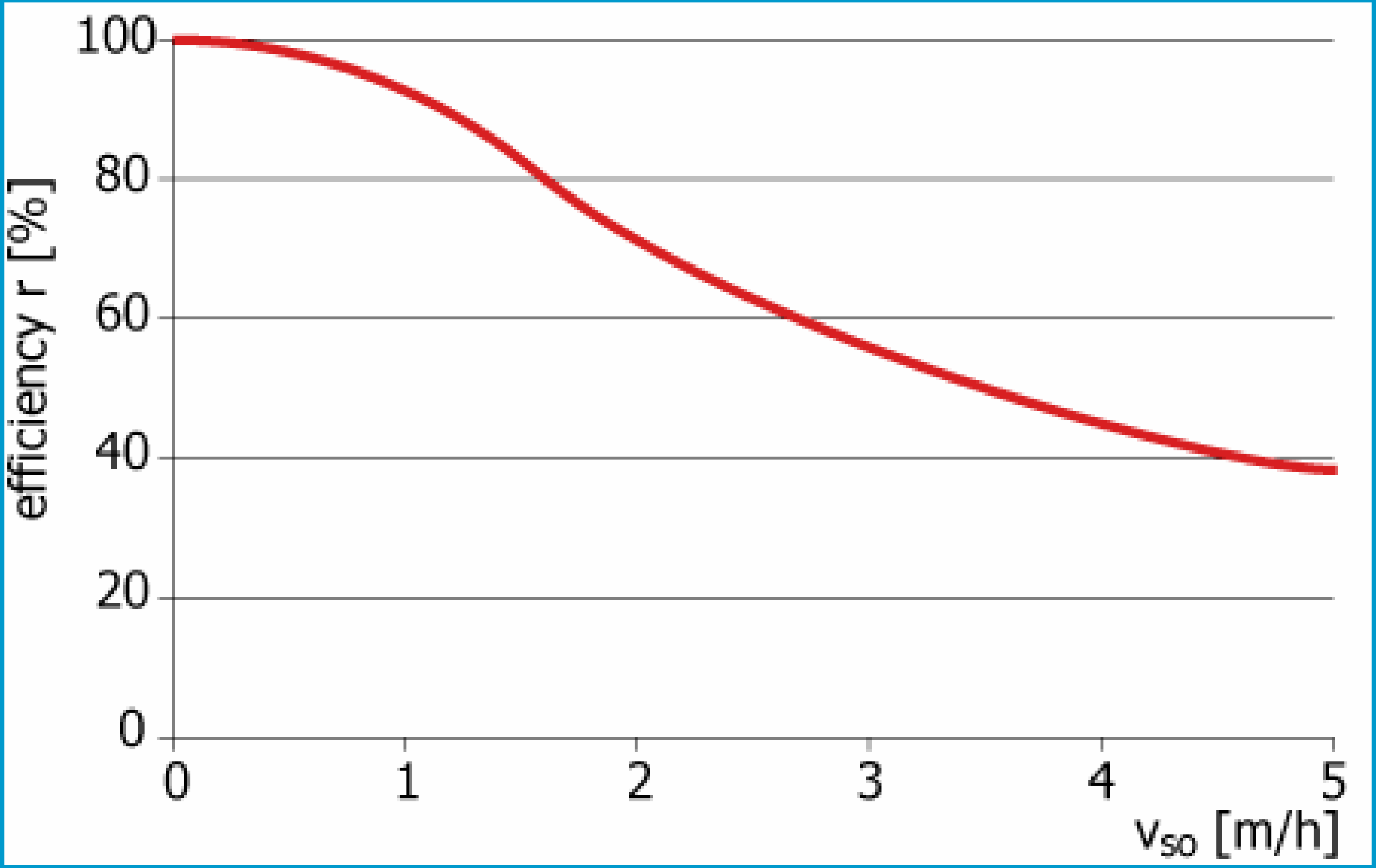
v_s <= v_{s0} settles partially, depends on h/H

$$r = (1 - p_0) + \frac{1}{v_{s0}} \int_0^{p_0} v_s\,dp$$

Efficiency horizontal sedimentation



Removal efficiency horizontal sedimentation



Example horizontal sedimentation

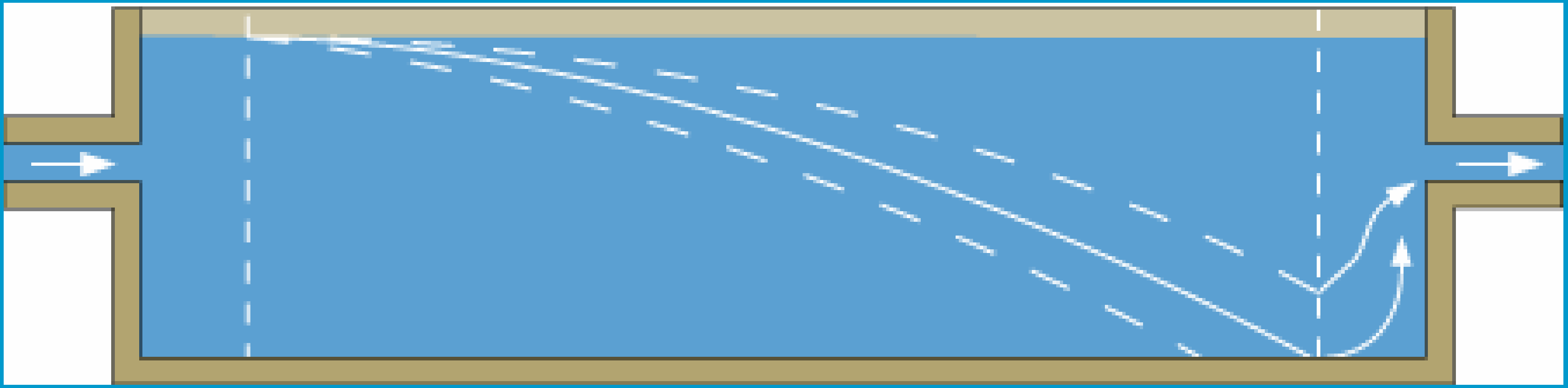
Calculate the efficiency of a sedimentation tank as function of the surface. The flow through the sedimentation tank is 0.5 m^3/s

A [m^2]	s_0 [m/h]	p [%]
500	3.60	47
1000	1.80	74
1500	1.19	89
2000	0.90	94
2500	0.72	97
3000	0.61	98

Reduction in efficiency

- Turbulence → Reynolds number
- Stability → Camp or Froude number
- Scouring → Scouring velocity

Influence of turbulence



$$v_0 = \frac{Q}{B \cdot H}$$

$$Re = \frac{v_0 \cdot R}{\nu}$$

$$R = \frac{B \cdot H}{B + 2 \cdot H}$$

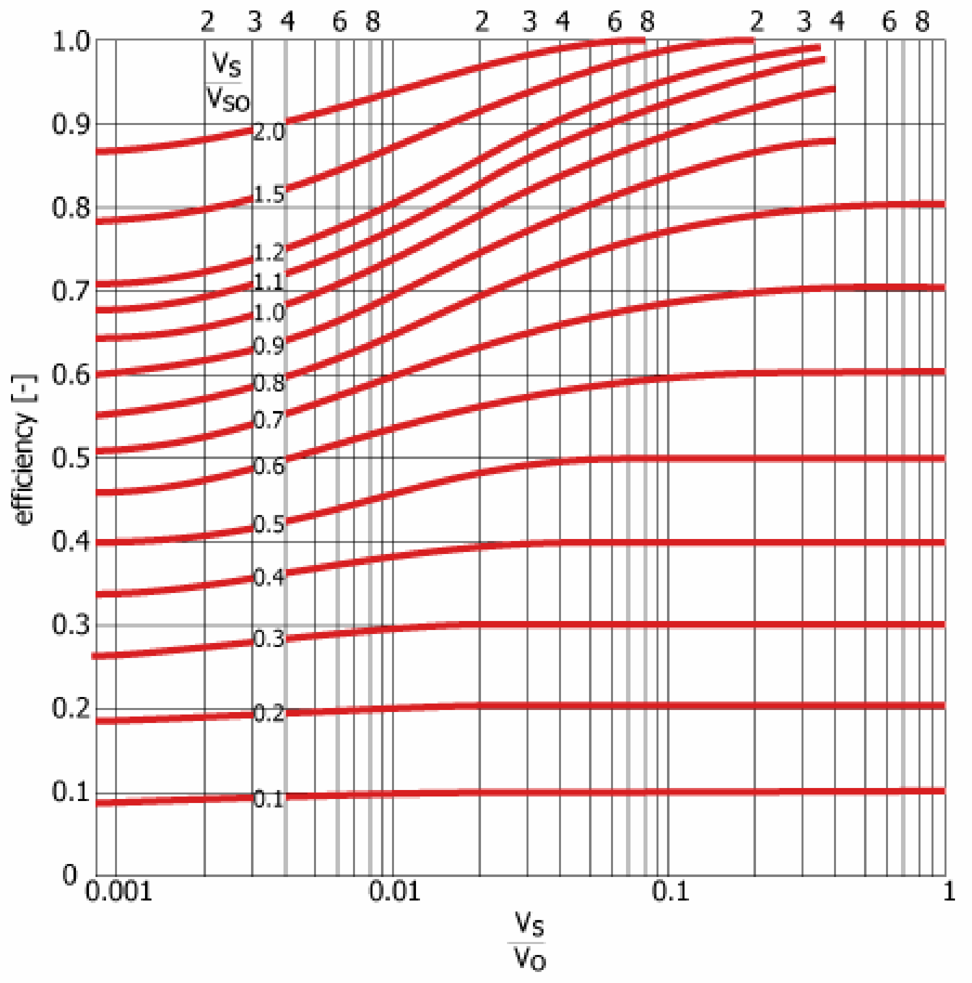
$$Re = \frac{Q}{\nu} \cdot \frac{1}{B + 2 \cdot H}$$

$Re > 2{,}000$ turbulent flow

$Re < 2{,}000$ laminar flow

Short, wide and deep basin

Theory turbulence



$r = v_s/v_{s0} = 0.8$

$\Rightarrow \quad v_s/v_0 > 0.5$

$$\frac{L}{H} = \frac{v_0}{v_{s0}} = \frac{v_s/v_{s0}}{v_s/v_0} = \frac{0.8}{0.5} = 1.6$$

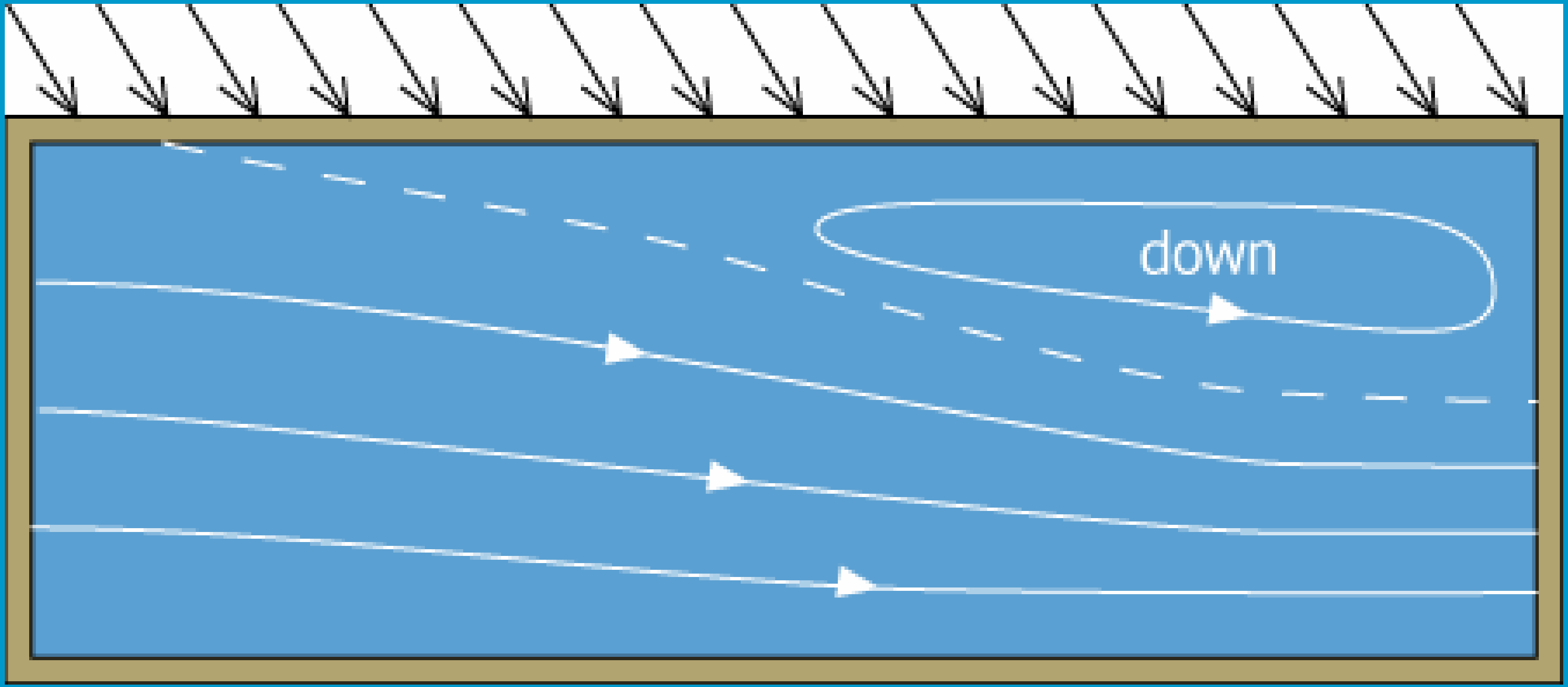
Short, wide and deep basin

$L/H = 20, \quad v_s/v_{s0} = 0.8$

$$\Rightarrow \quad \frac{v_s}{v_0} = \frac{0.8}{20} = 0.04$$

$r = 0.73$

Short circuit flow



Short circuit flow

$$C_p = \frac{v_0^{\,2}}{g \cdot R}$$

$$v_0 = \frac{Q}{B \cdot H}$$

$$R = \frac{B \cdot H}{B + 2 \cdot H}$$

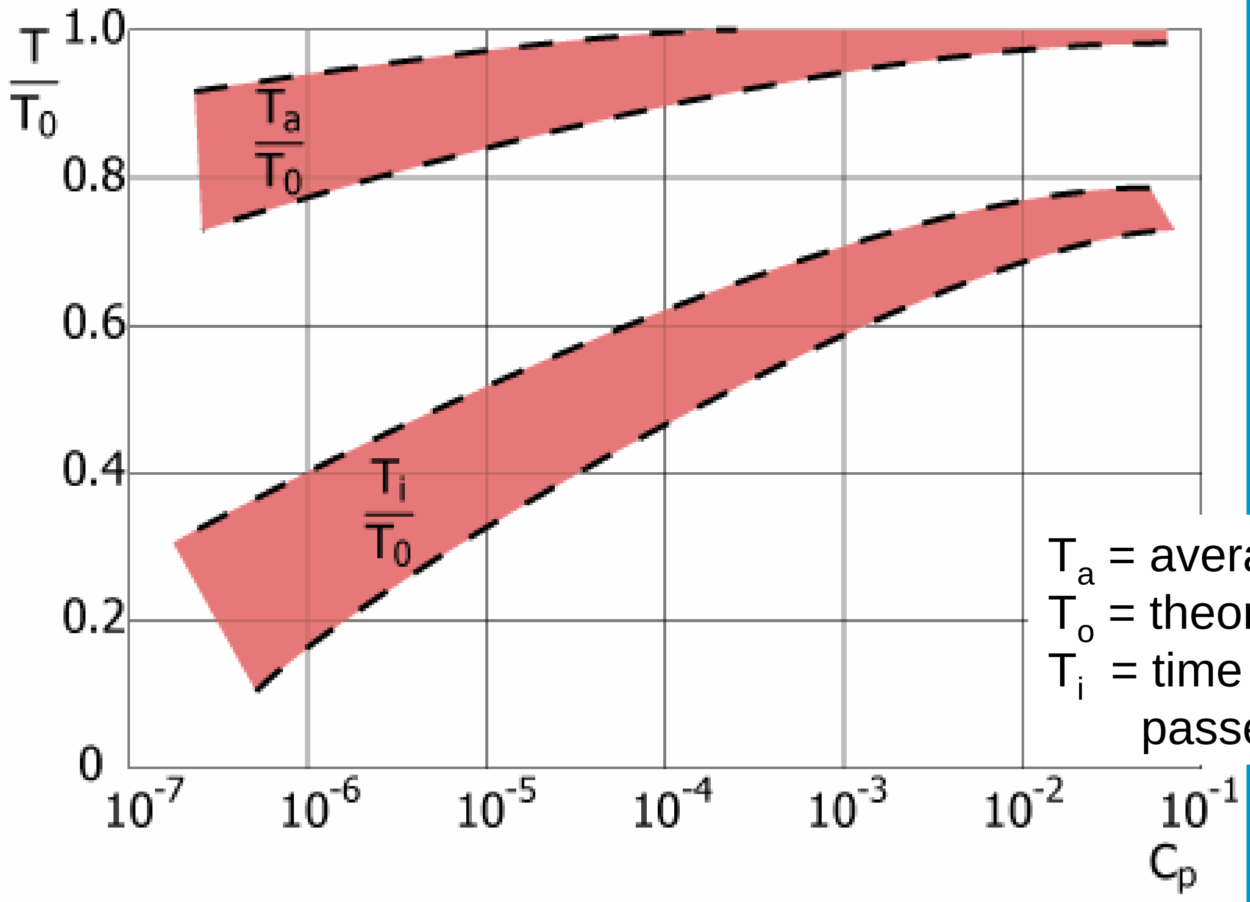
$$C_p = \frac{Q^2}{g} \cdot \frac{B + 2 \cdot H}{B^3 \cdot H^3}$$

$C_p > 1{\cdot}10^{-5}$ stable

$C_p < 1{\cdot}10^{-5}$ non stable

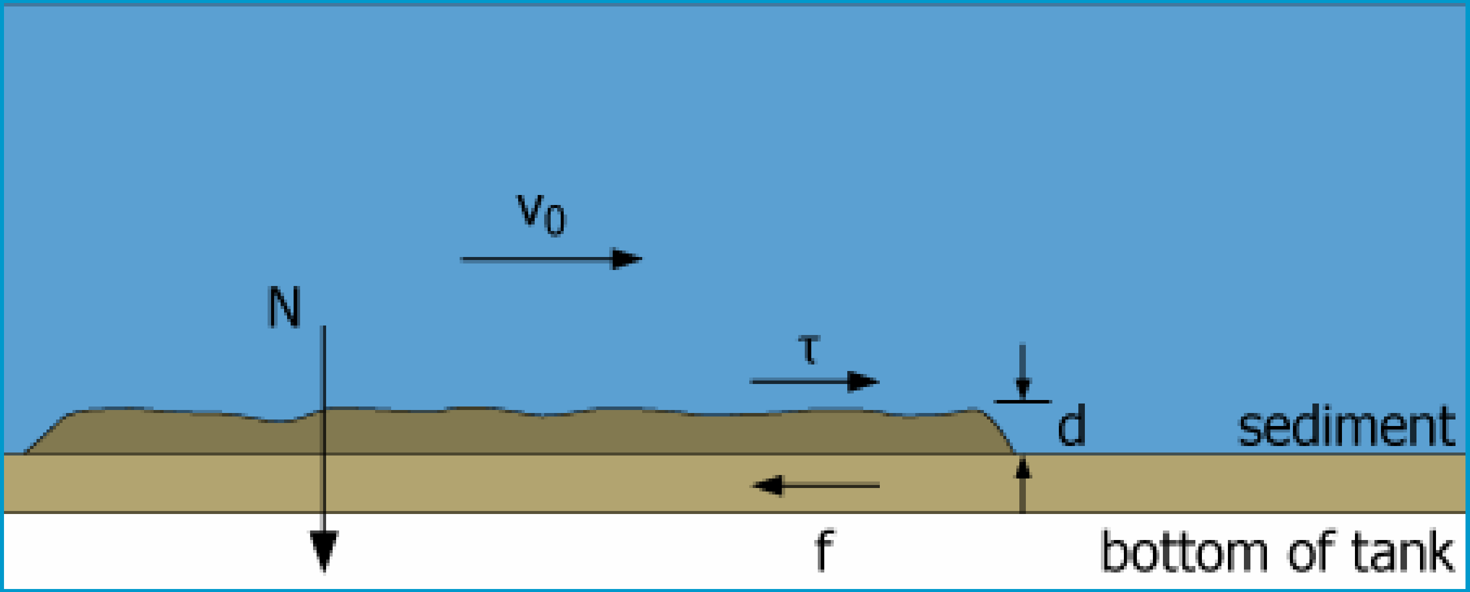
Long, narrow and shallow

Short circuit flow



T_a = average residence time
T_o = theoretical residence time
T_i = time until first water particle passes

Shear stress



$$\tau = \frac{\lambda}{8} \cdot \rho_w \cdot v_s^2$$

$$v_{sc} = \sqrt{\frac{40}{3} \cdot \frac{\rho_s - \rho_w}{\rho_w} \cdot g \cdot d}$$

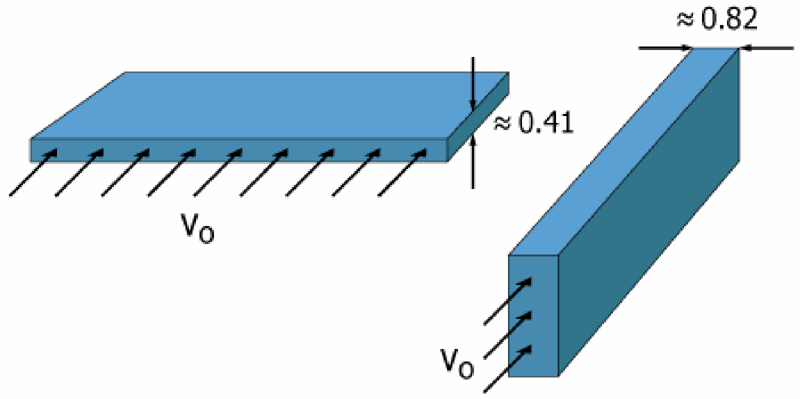
$$f = \beta \cdot (\rho_w - \rho_s) \cdot g \cdot d$$

$v_0 < v_{sc}$ no bottom scour

Short, wide and deep basin

Design settling zone

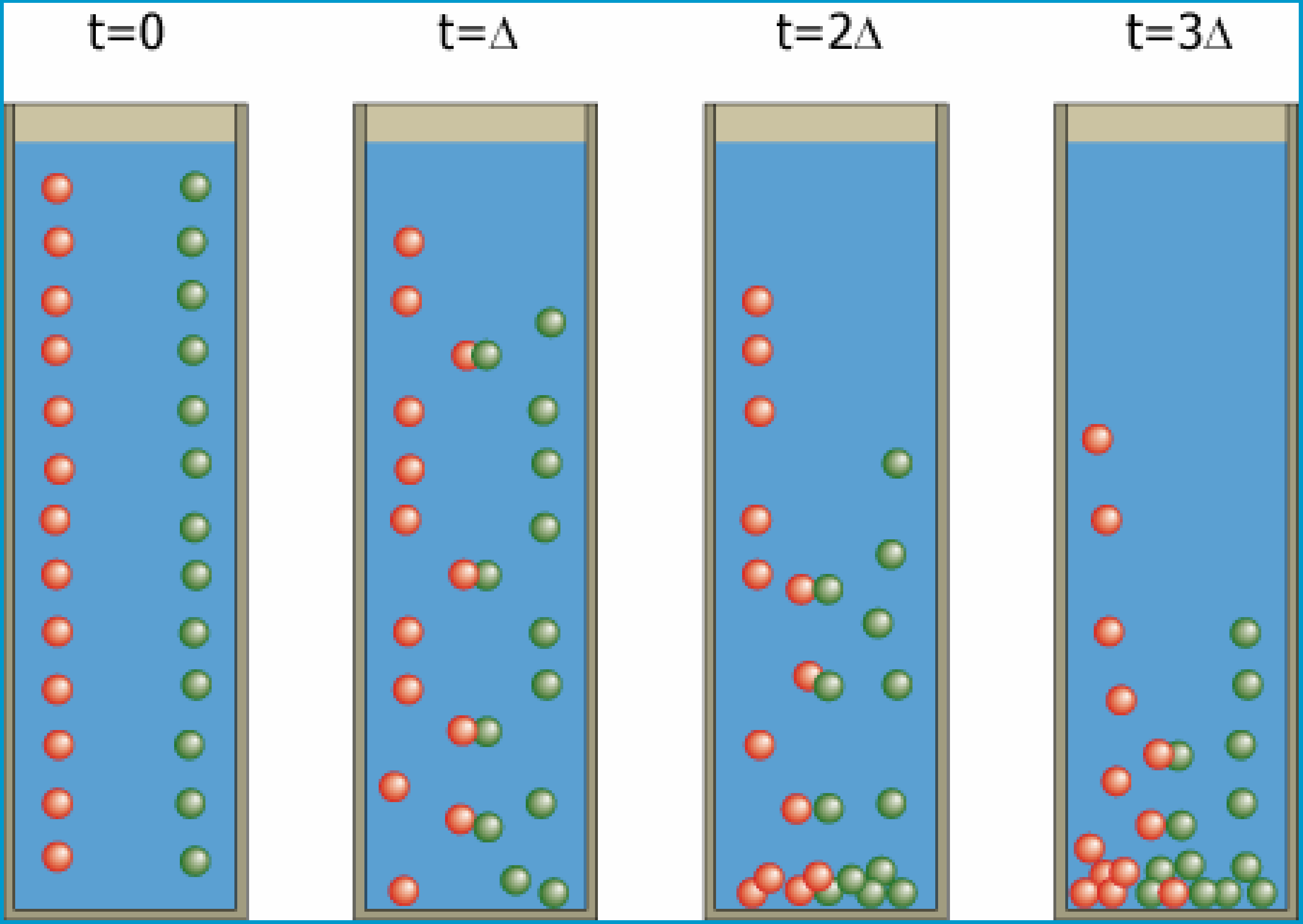
- Turbulence → Reynolds number < 2,000
- Stability → Camp or Froude number > $1 \cdot 10^{-5}$
- Scouring → Scouring velocity $v_0 < v_{sc}$



Practical solution → L/H = 6 - 10

Short, wide and deep basin Long, narrow and shallow

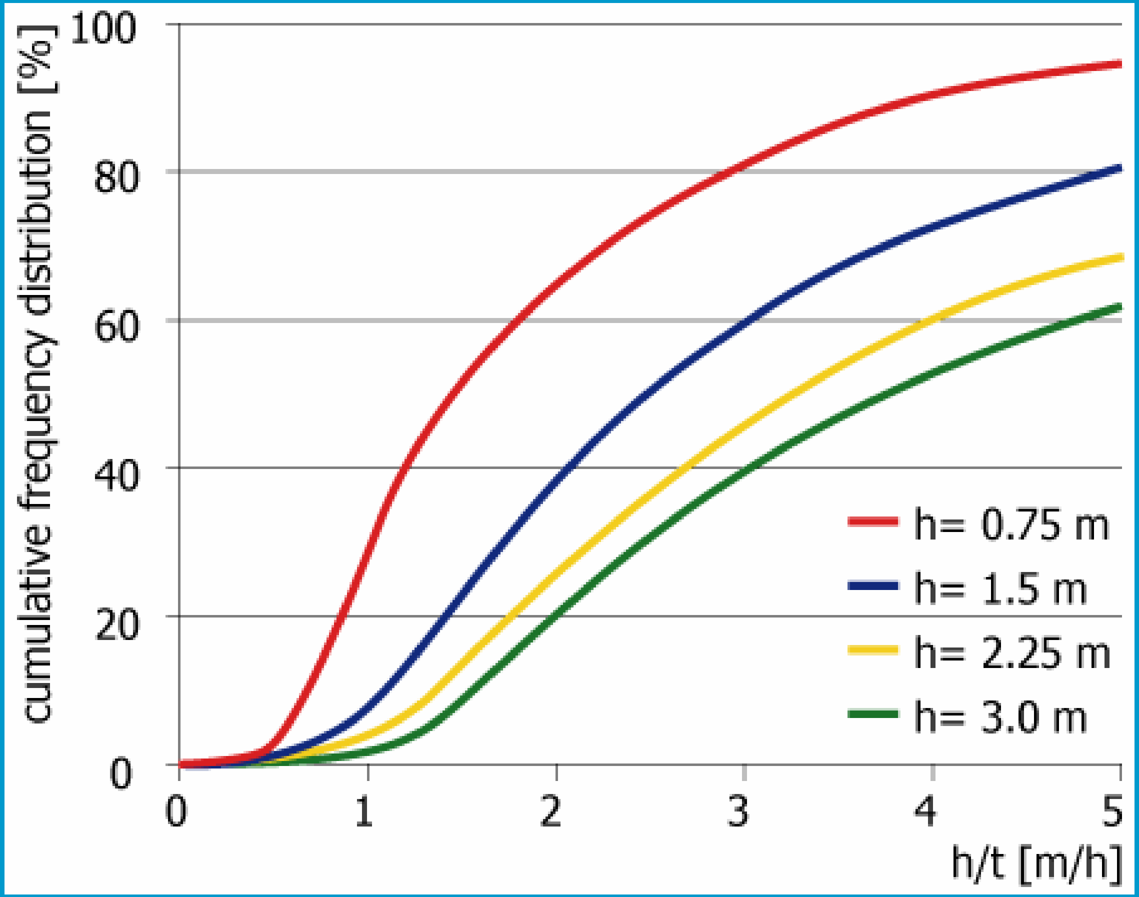
Flocculent settling



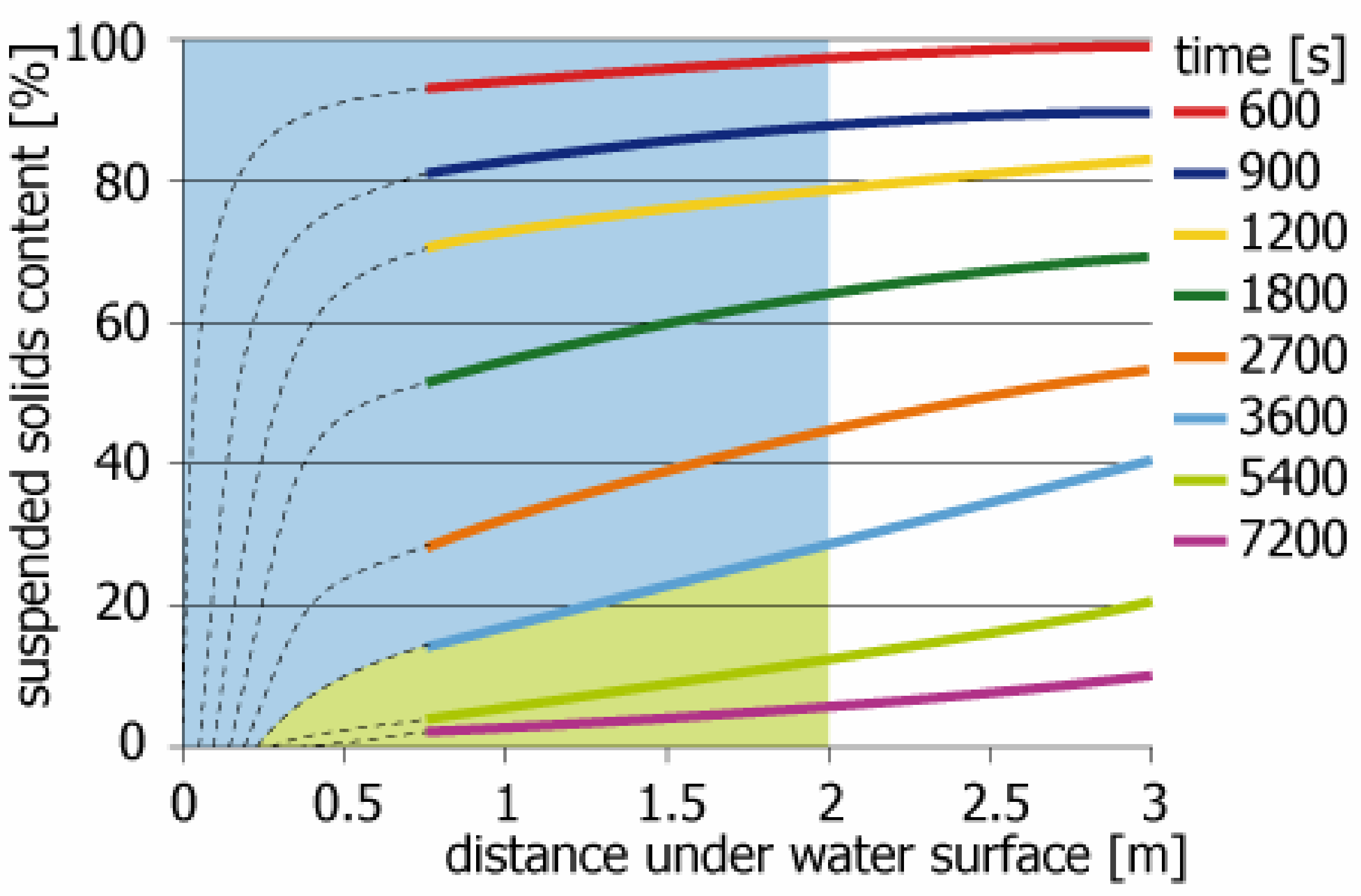
Flocculent settling

t	h = 0.75m	1.50 m	2.25 m	3.0 m
0	100	100	100	100
600	93	96	98	99
1200	81	86	88.5	89.5
1800	70.5	77.5	81	83
2700	28	38	46.5	53
3600	13.5	22	31	40
5400	3	8	13.5	20
7200	1.5	3	6	9.5

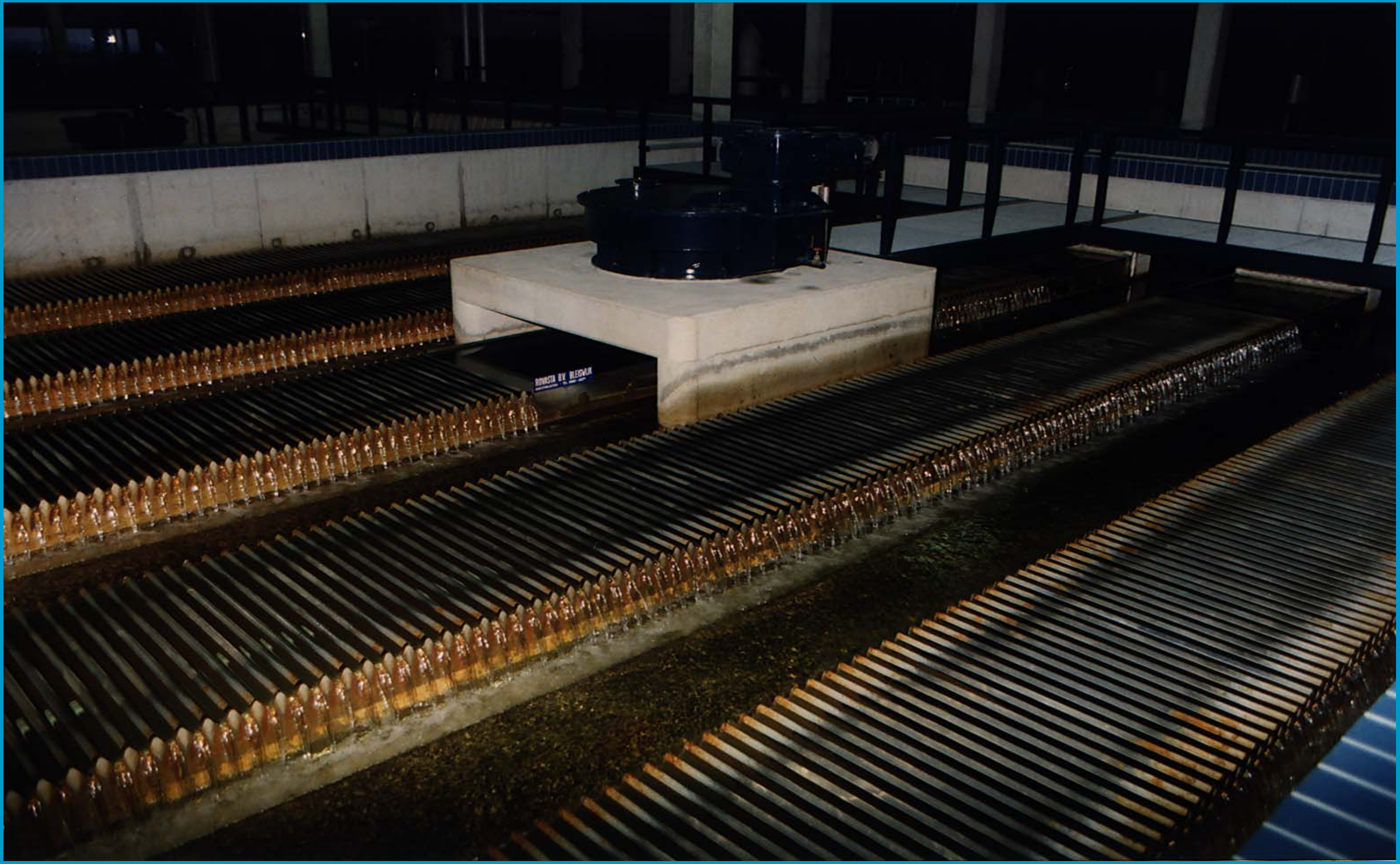
Cumulative frequency distribution flocculent settling



Flocculent settling

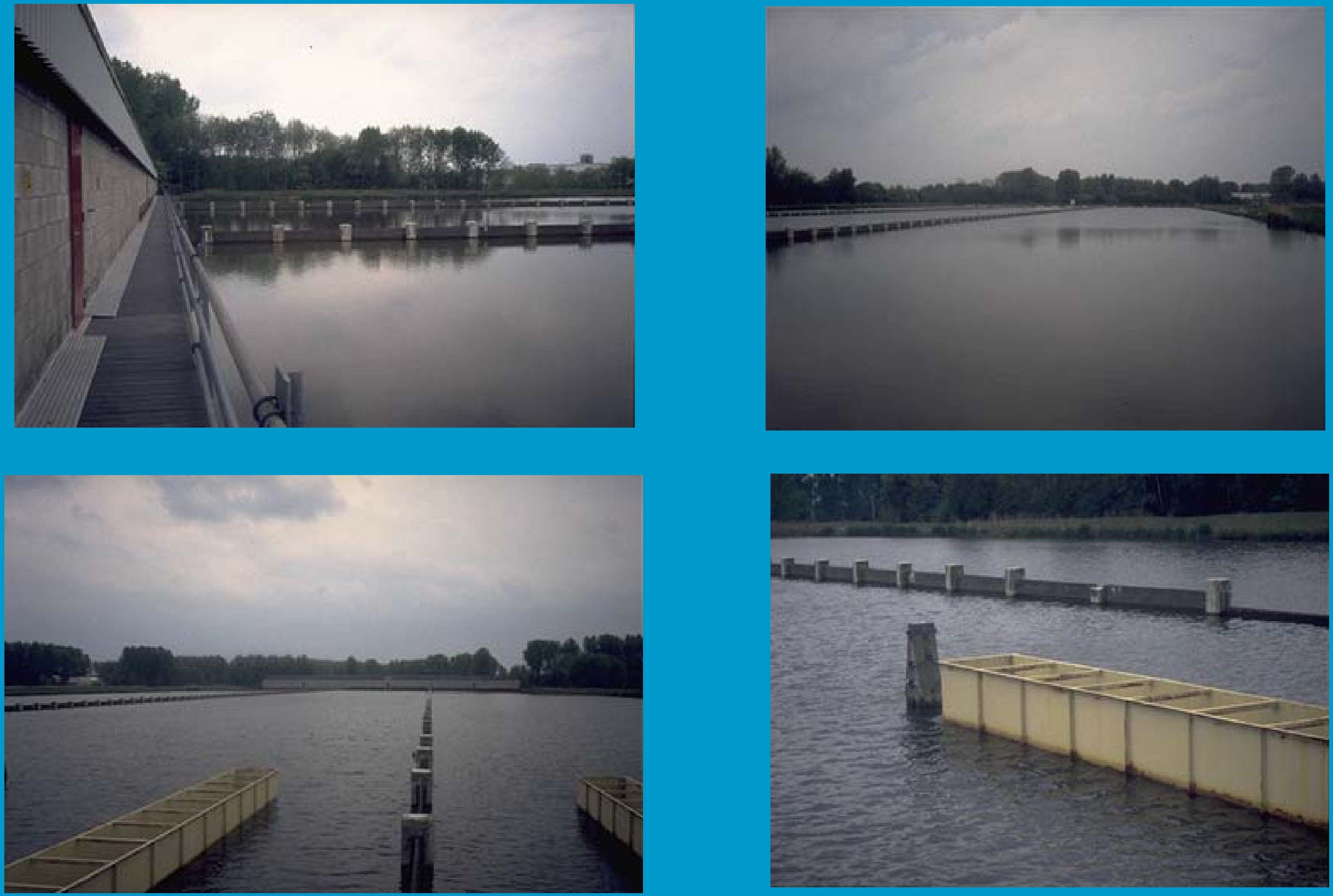


Construction alternatives

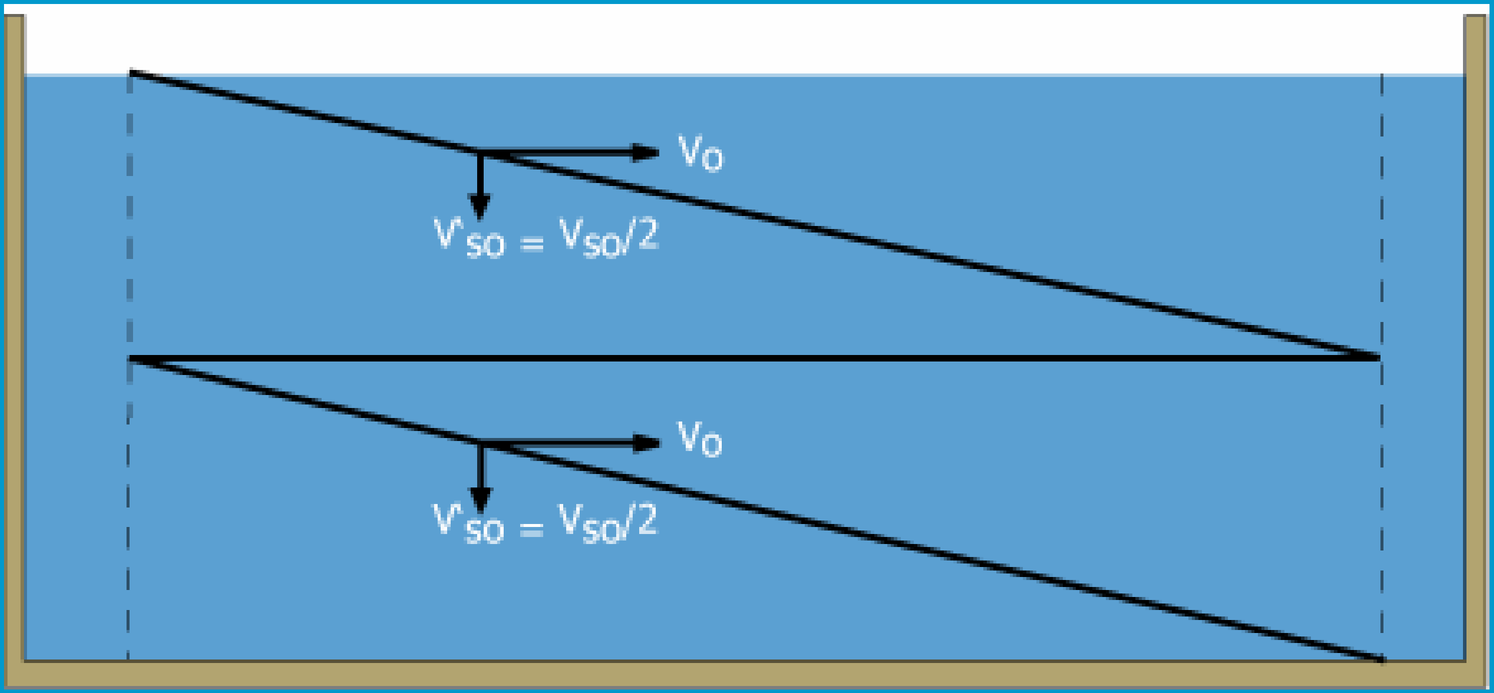


Sedimentation tanks WRK I-II

Sedimentation tanks WRK I-II

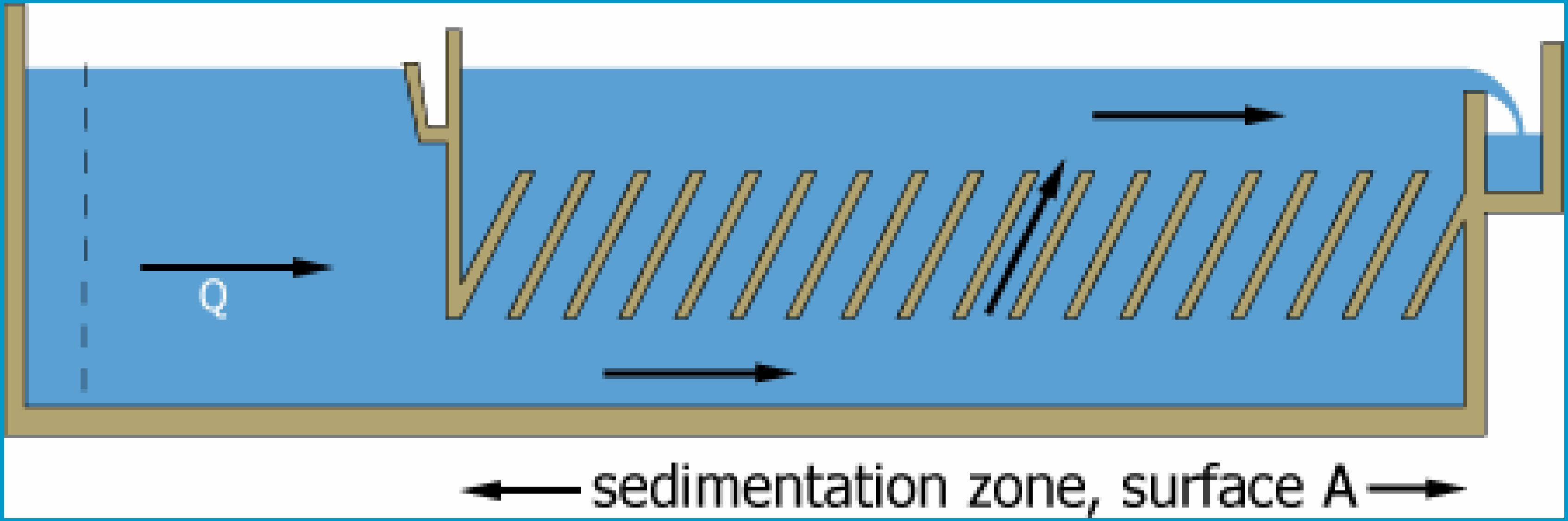


Tray settling tanks

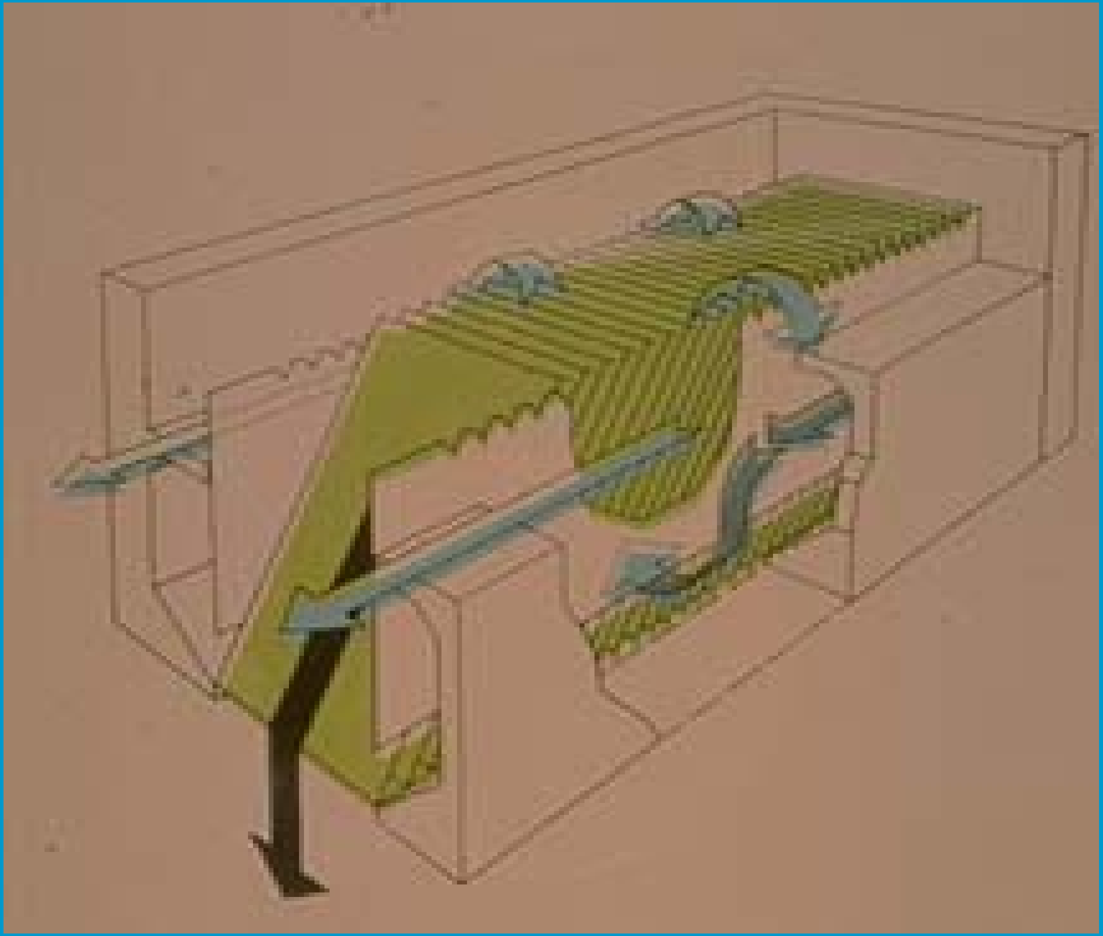


Tray settling tanks

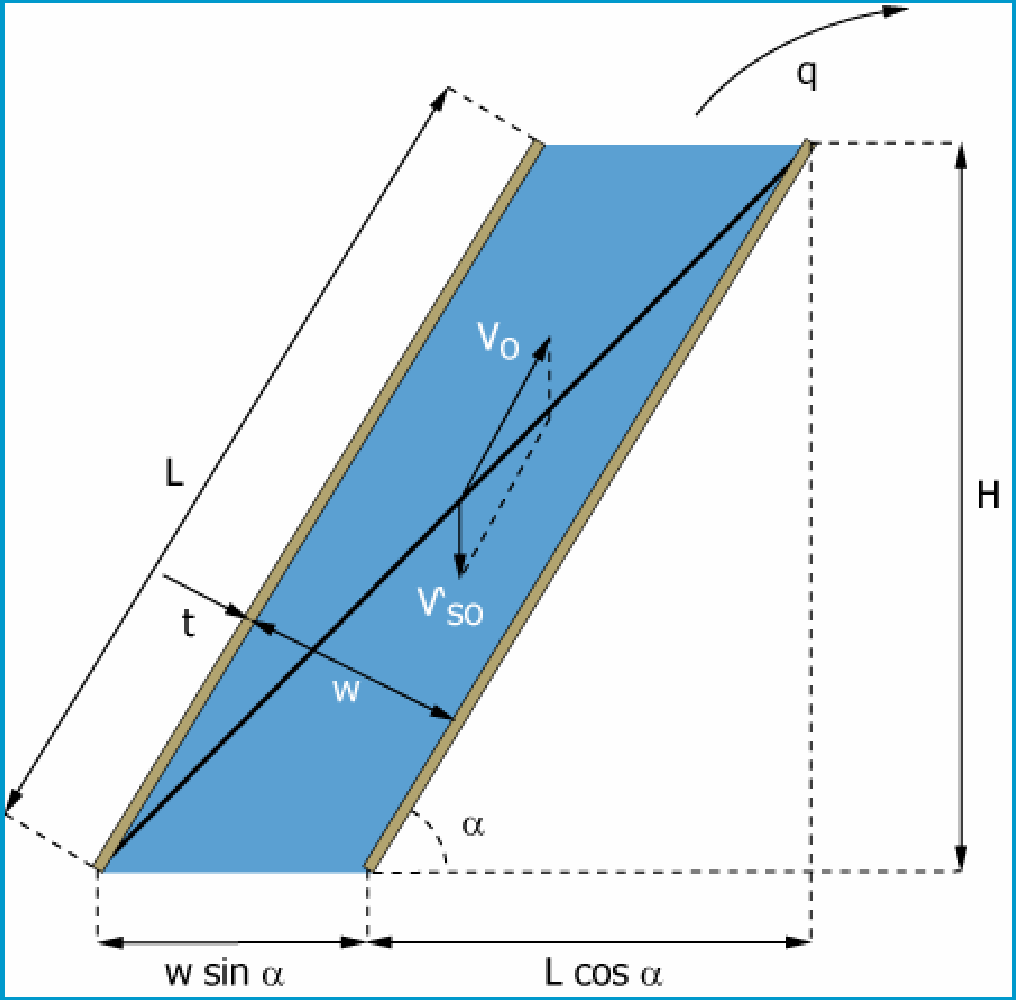
Tilted plate separators



Tilted plate separators



Tilted plate separators



Tilted plate separators

Counter current tilted plate separator

$$v_{s0}' = v_{s0} \cdot \frac{w + t}{H \cdot \cos\alpha + w}$$

Co-current tilted plate separator

$$v_{s0}' = v_{s0} \cdot \frac{w + t}{H \cdot \cos\alpha - w}$$

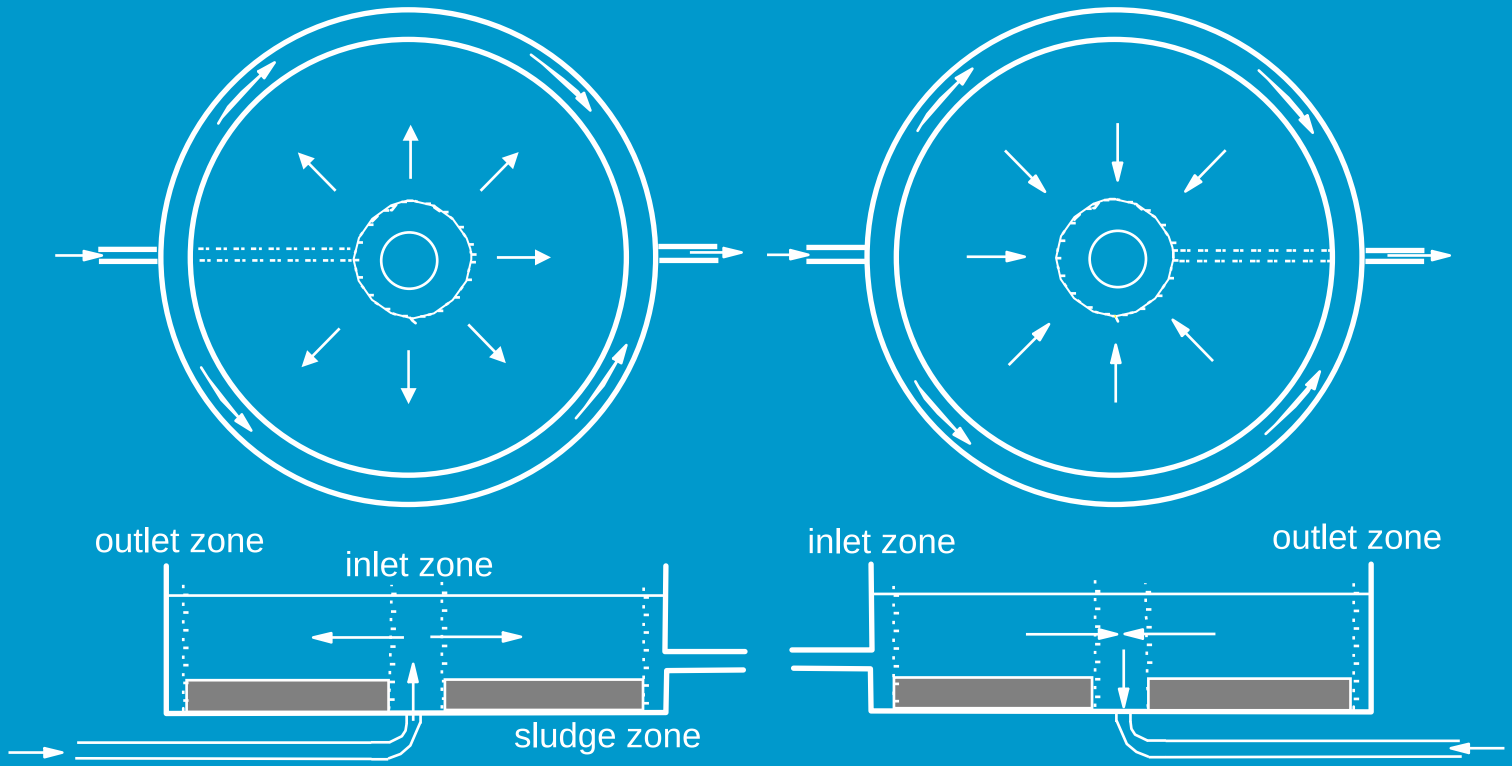
α	counter current:	55 - 60°
	co-current:	30 - 40°
H:	1 - 3 m	
w:	3.5 - 8 cm	
t:	5 mm	

$$\Rightarrow v_{s0}' \text{ » } \frac{v_{s0}}{20}$$

Details tilted plate separators

Details tilted plate separator

Circular sedimentation tanks



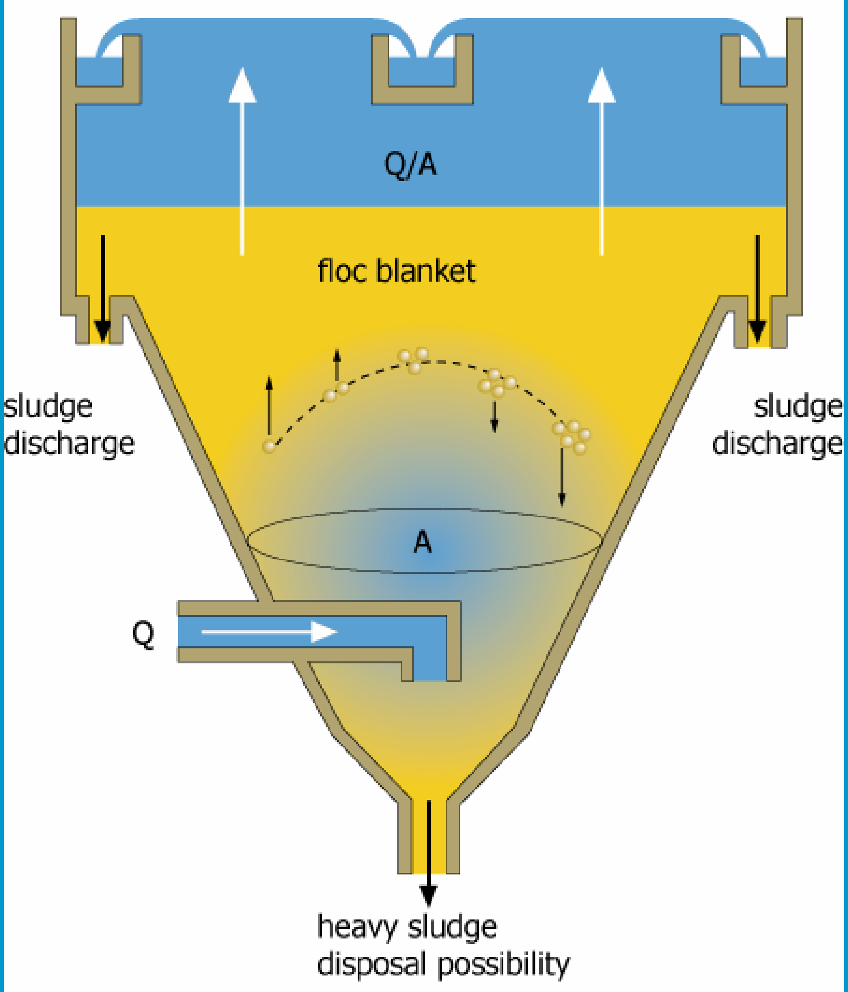
centre feed

peripheral feed

Circular sedimentation tanks

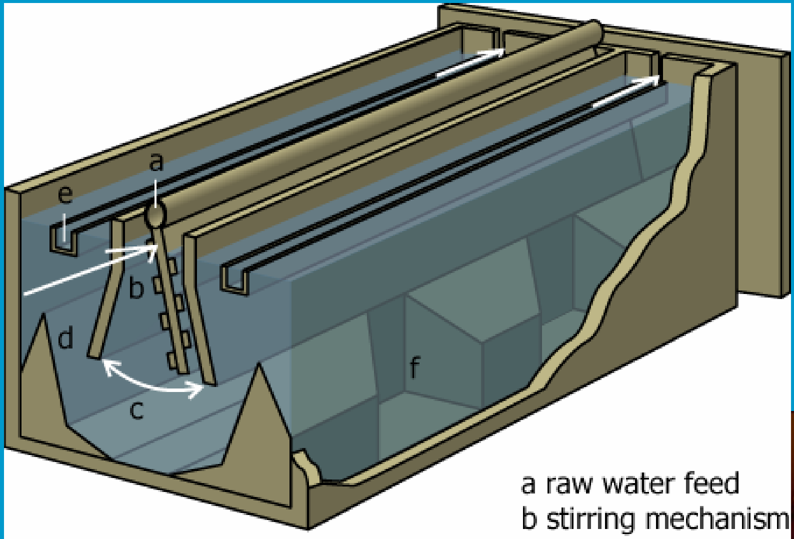
Circular sedimentation tanks

Sludge blanket installation



Special constructions

Sludge blanket installation Berenplaat



a raw water feed
b stirring mechanism
c blending space
d floc blanket
e clear water exit
f floc exit

Sludge blanket installation Bombay

Sludge blanket installation Bombay

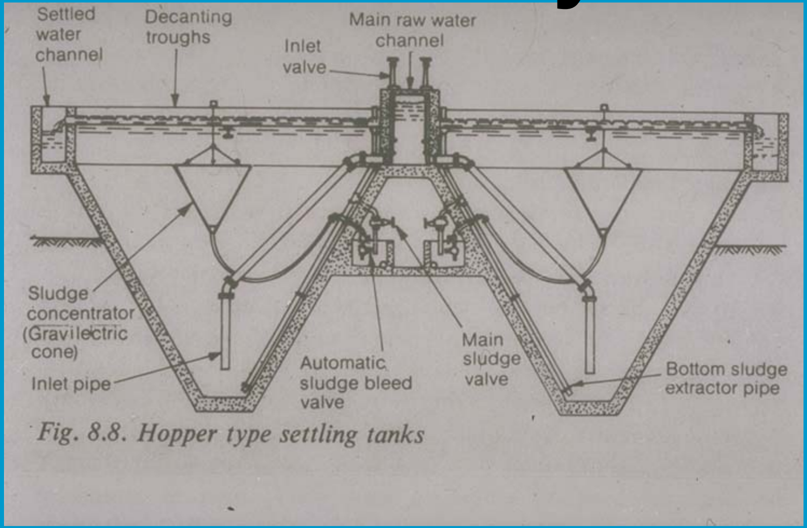
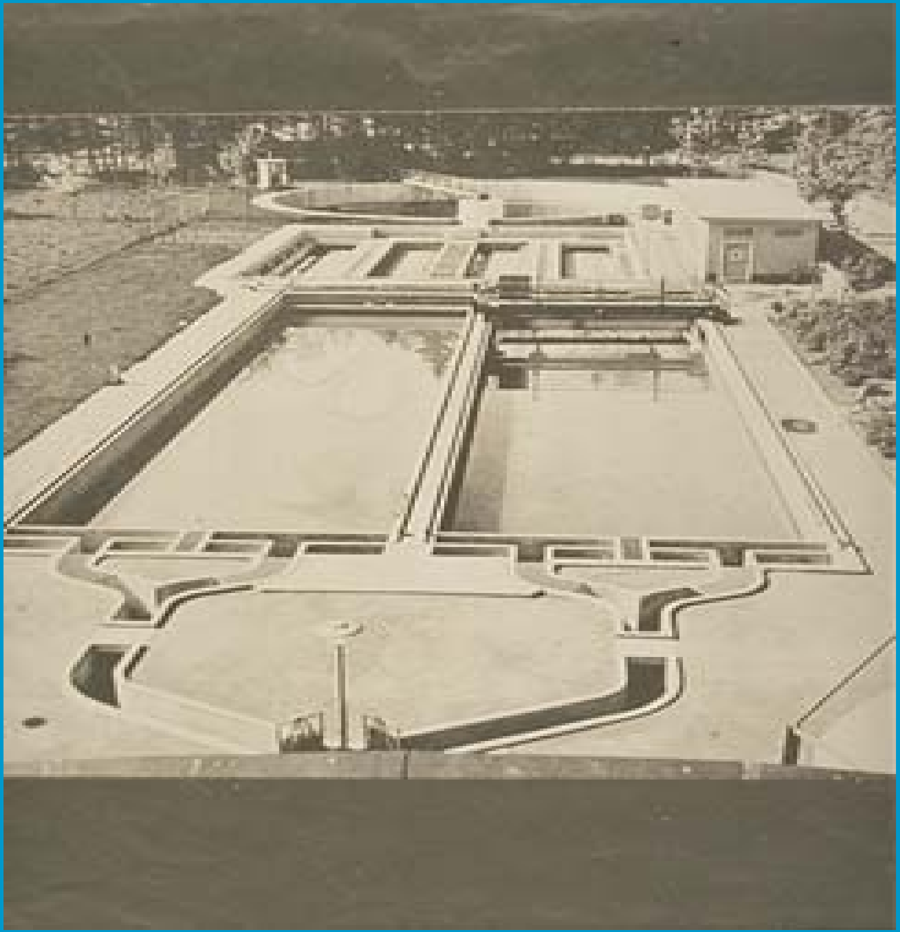
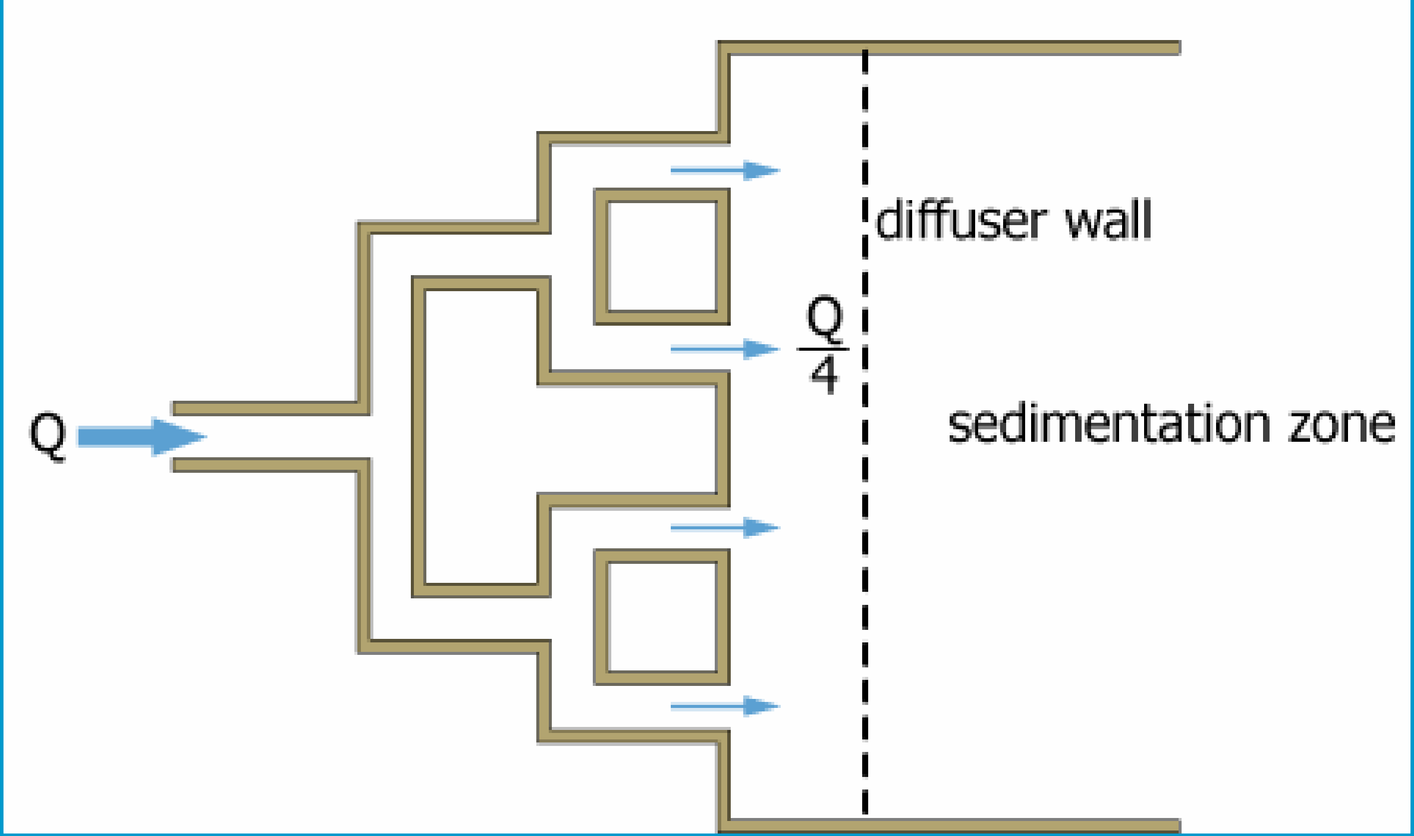


Fig. 8.8. Hopper type settling tanks

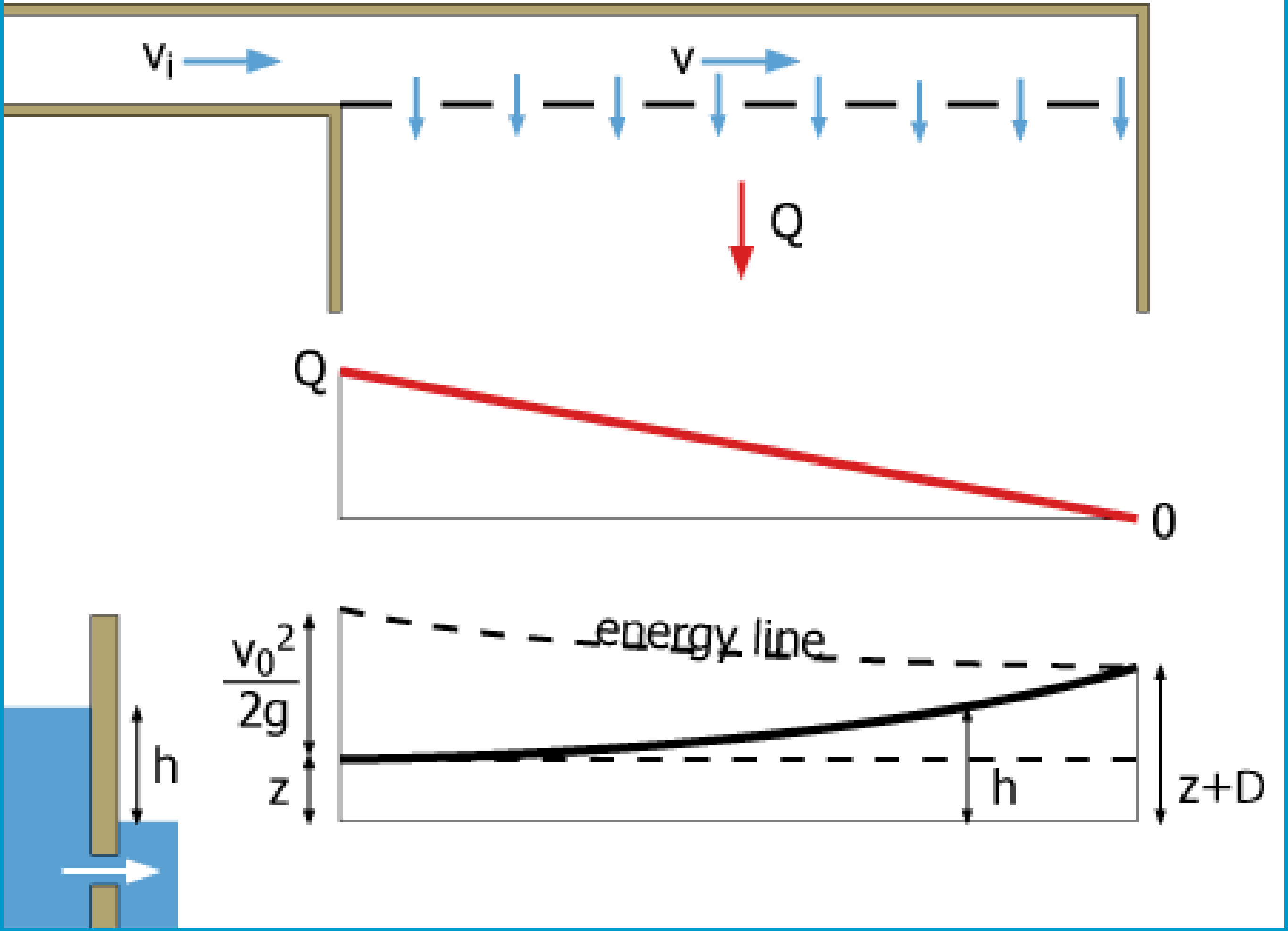
Inlet and outlet constructions



Inlet constructions

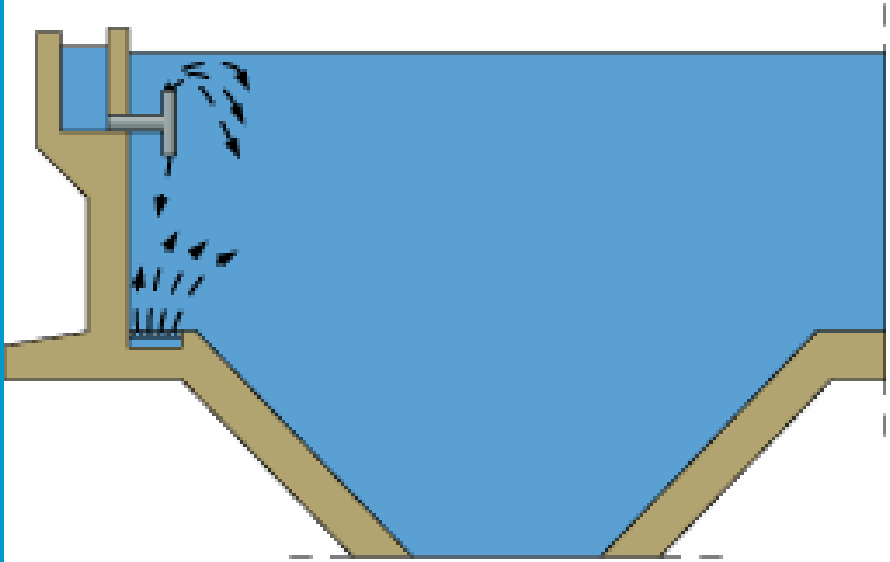


Diffusor wall

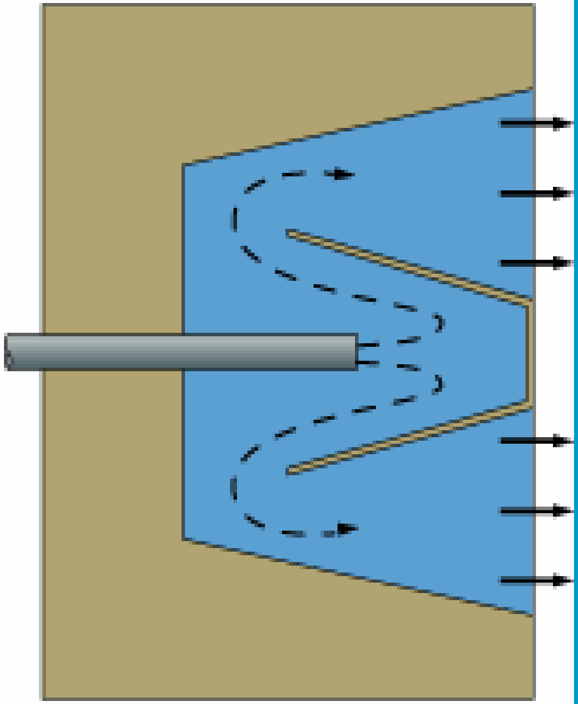


Diffusor wall

Inlet constructions



Clifford inlet



Stuttgarter inlet

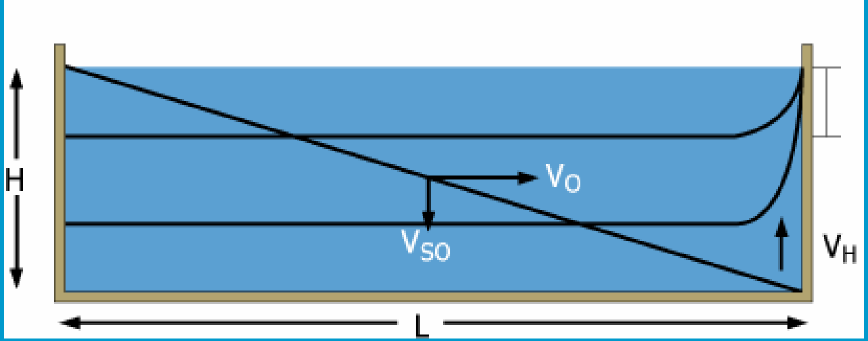
Outlet constructions

Outlet constructions

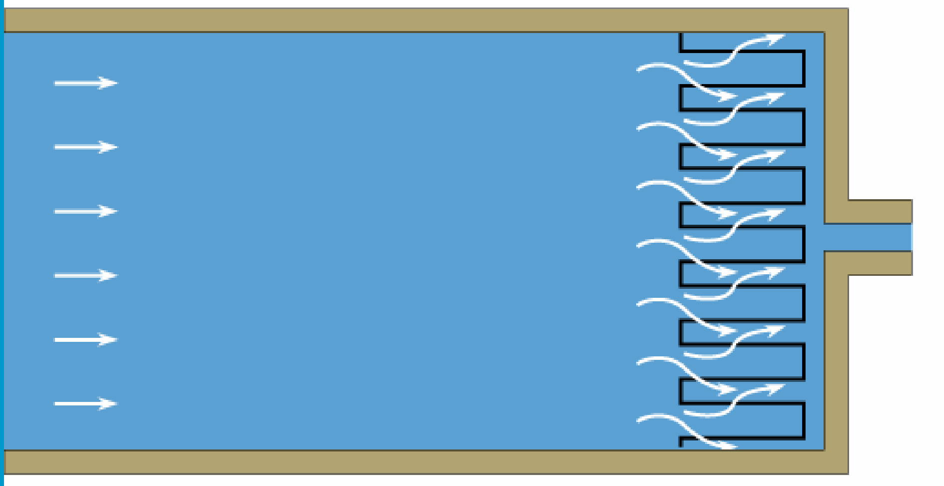
$$v_H = \frac{1}{5} \cdot \frac{Q}{B \cdot H} \leq v_{s0}$$

$$\frac{Q}{B} = q < 5 \cdot H \cdot v_{s0}$$

$$L/H < 5$$



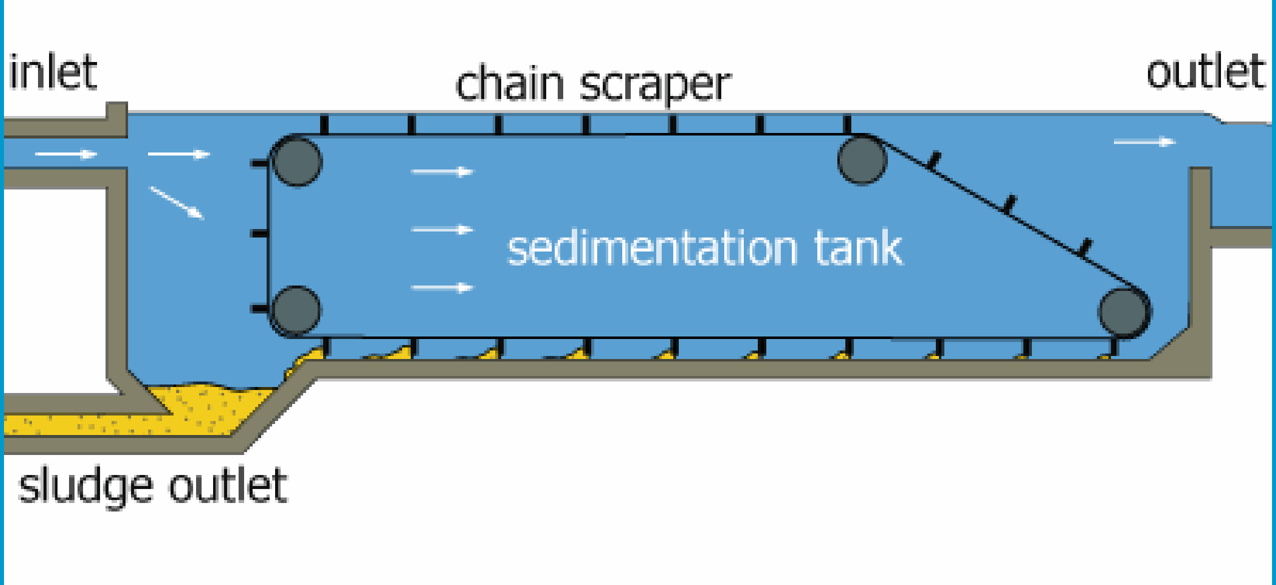
$$\frac{Q}{n \cdot B} \leq 5 \cdot H \cdot v_{s0}$$



Sludge removal

Sludge zone and sludge removal

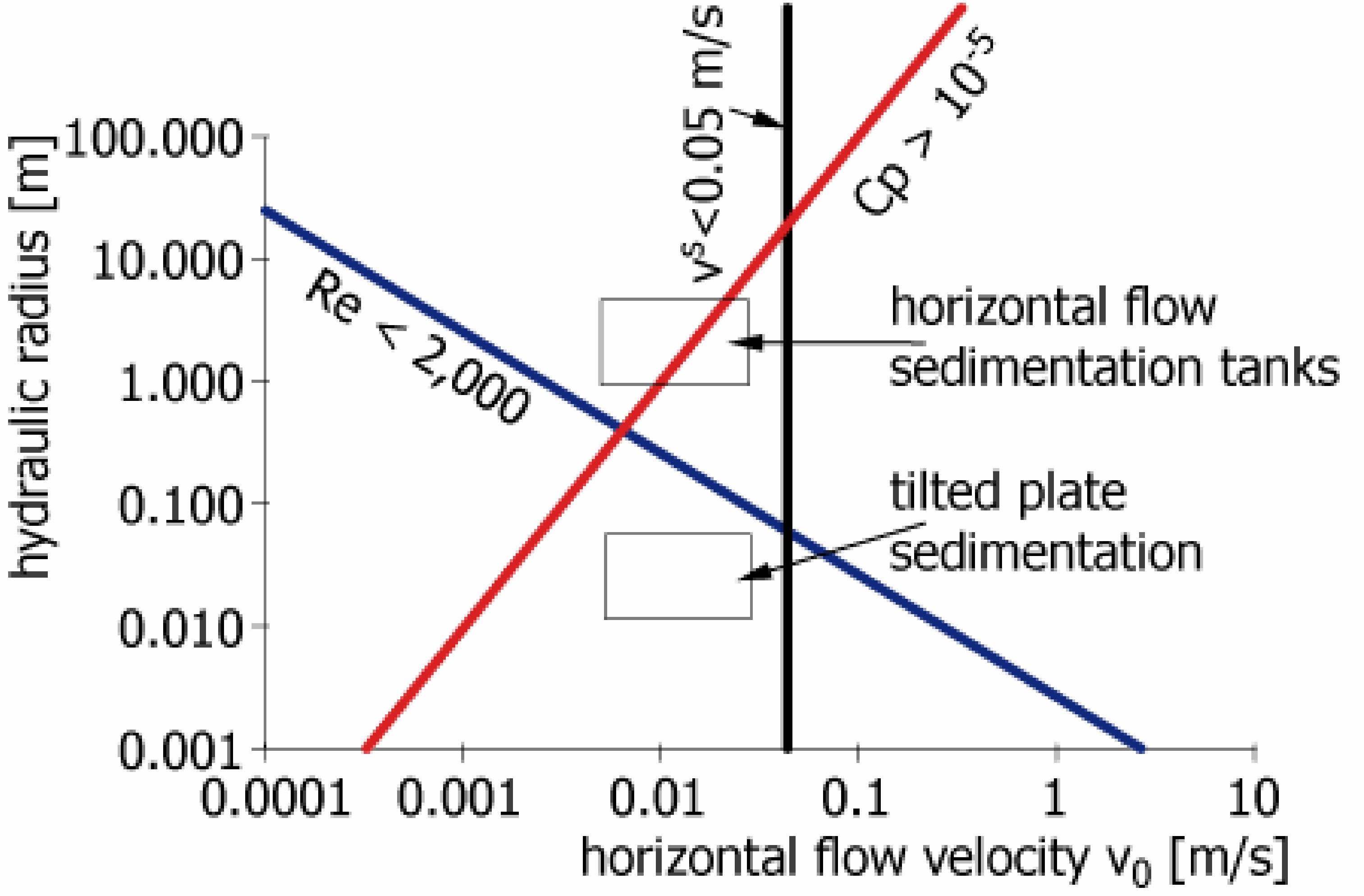
Sludge removal device



Summary

- discrete settling	$s = f(\rho, d, \nu)$
- vertical sedimentation	$r = 1 - p_0$
- horizontal sedimentation	$r = (1 - p_0) + \frac{1}{v_{s0}} \int_0^{p_0} v_s dp$
- influence turbulence	$Re = \frac{v_0 \cdot R}{\nu}$
- influence stability	$C_p = \frac{v_0^2}{g \cdot R}$
- influence shear stress	$v_s = f(\rho, d)$
- flocculent settling	influence t (detention time)

Summary



hydraulic radius [m]
100.000
10.000
1.000
0.100
0.010
0.001
0.0001
0.001
0.01
0.1
1
10
horizontal flow velocity v_0 [m/s]
$v^s < 0.05$ m/s
Cp > 10^{-5}
Re < 2,000
horizontal flow sedimentation tanks
tilted plate sedimentation