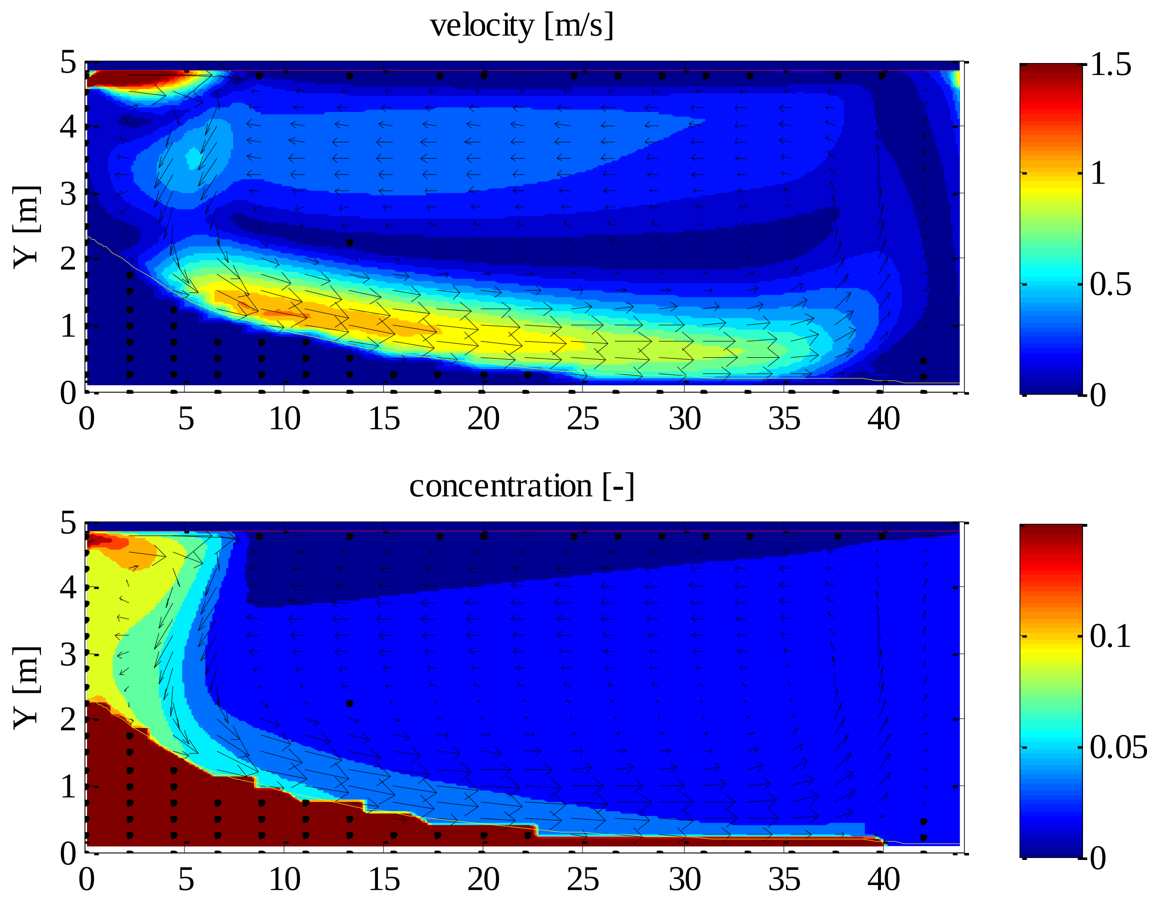
Dredging Processes

Prof.dr.ir. C. van Rhee

8. Hopper sedimentation

Hopper Sedimentation



OE 4626

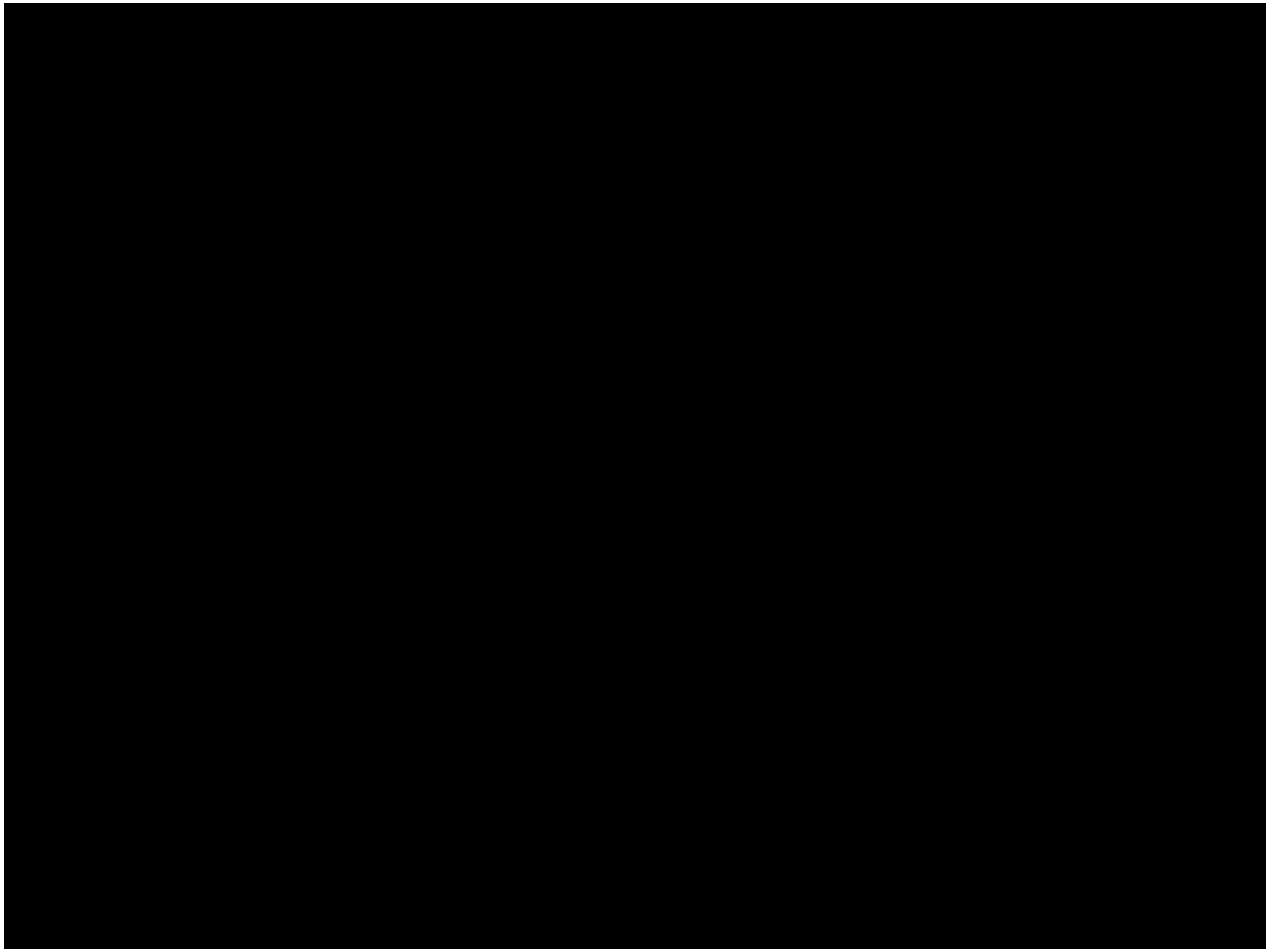
Prof. Dr. ir. C. van Rhee

15 January 2013

Contents Hopper Sedimentation

- Global process overview
- Settling velocity of sediments
    - Settling velocity of a single particle
    - Influence of the concentration
- Modelling of the sedimentation process
- Camp based models
- 2 DV Model
- Examples

Intro Hopper



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rotterdam
[2]


HAM 318
[3]

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Unloading TSHD

[3]

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Application of TSHD

Before 1980

- Maintenance Dredging
  - Deepening of harbours & entrance Channels
    - Maintenance due to siltation
    - Soft sediments (silt clay)
    - Not stationary (wires anchors), so less problems with shipping

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Application of TSHD

- Capital Dredging (new projects)
  - Most Reclamation works
  - Less suitable:
    - Reclamation in combination with deepening
      - Short distance between dredging & reclamation.
      - Dredged material suitable for fill
      - Sediments in dredge area difficult for TSHD

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Doha Airport

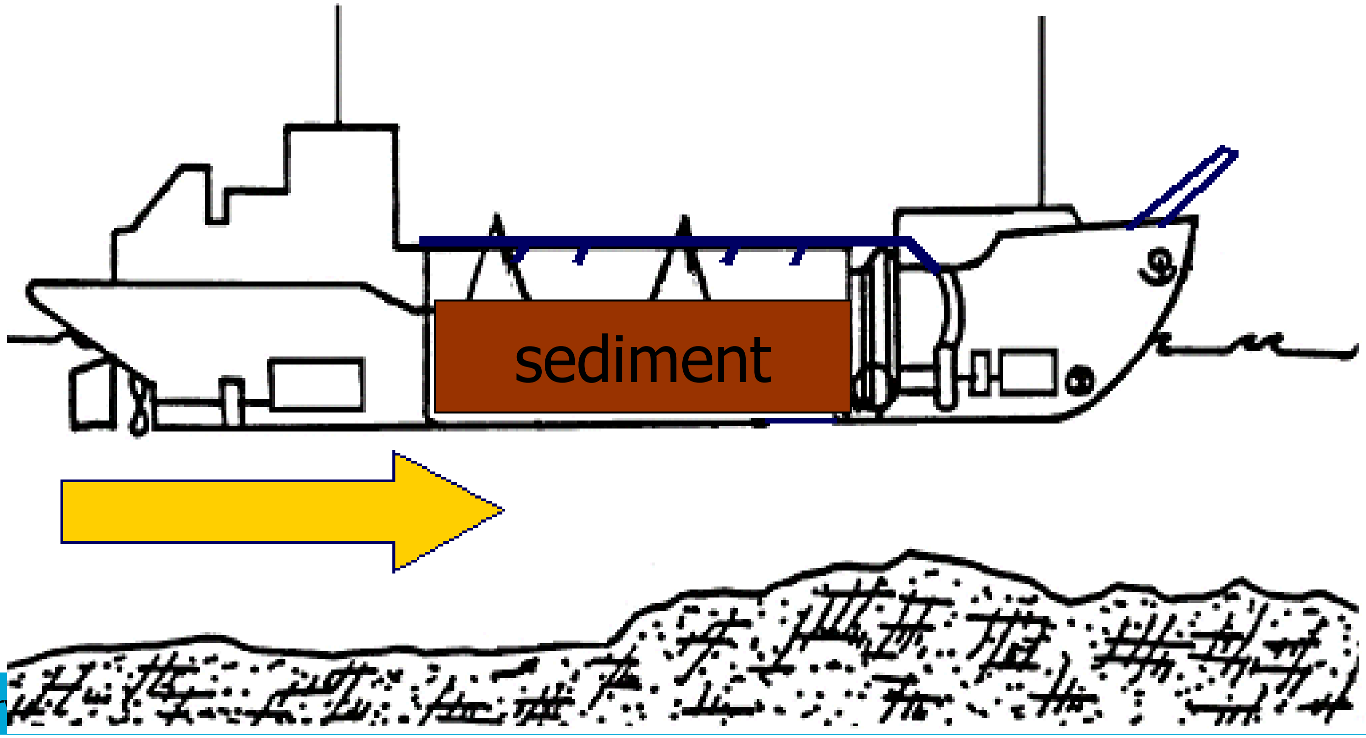
Quatar

(in progress)


[7]

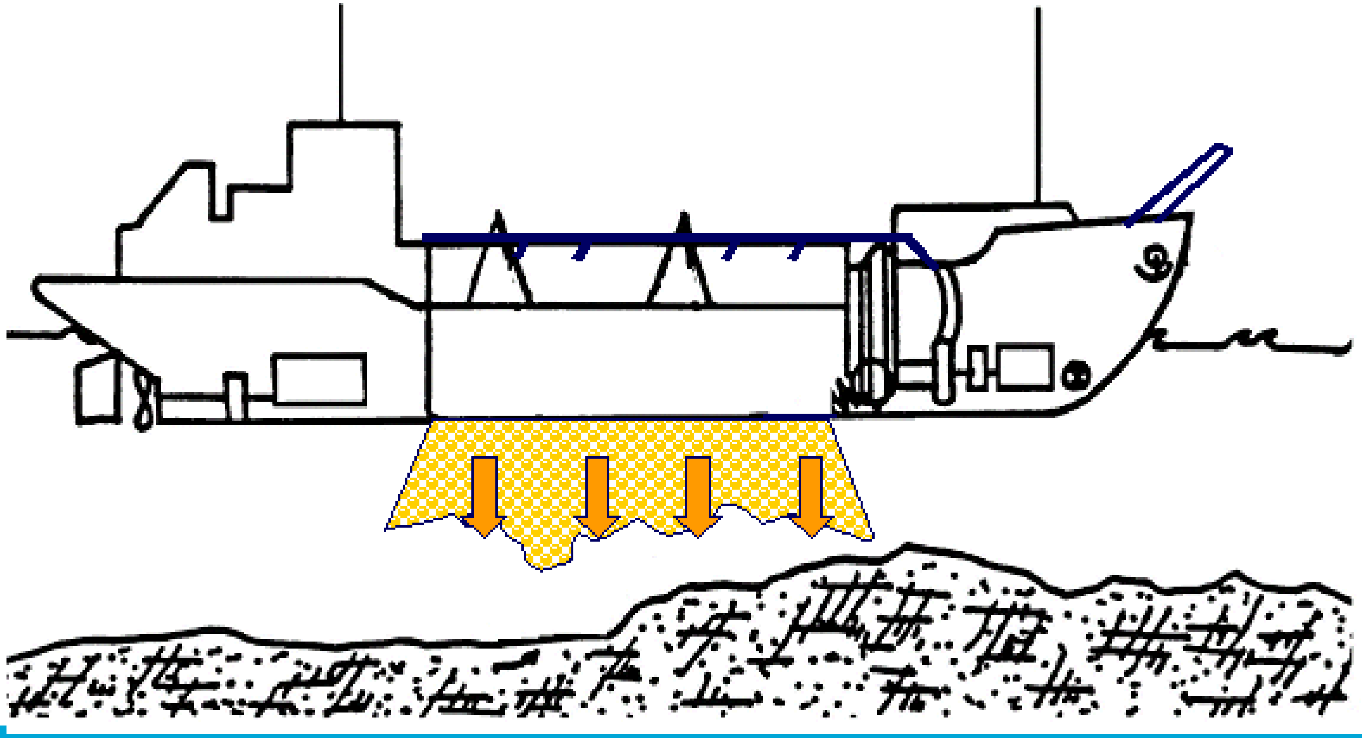
TSHD Process Discription

Sailing loaded



TSHD Process Discription

Discharge



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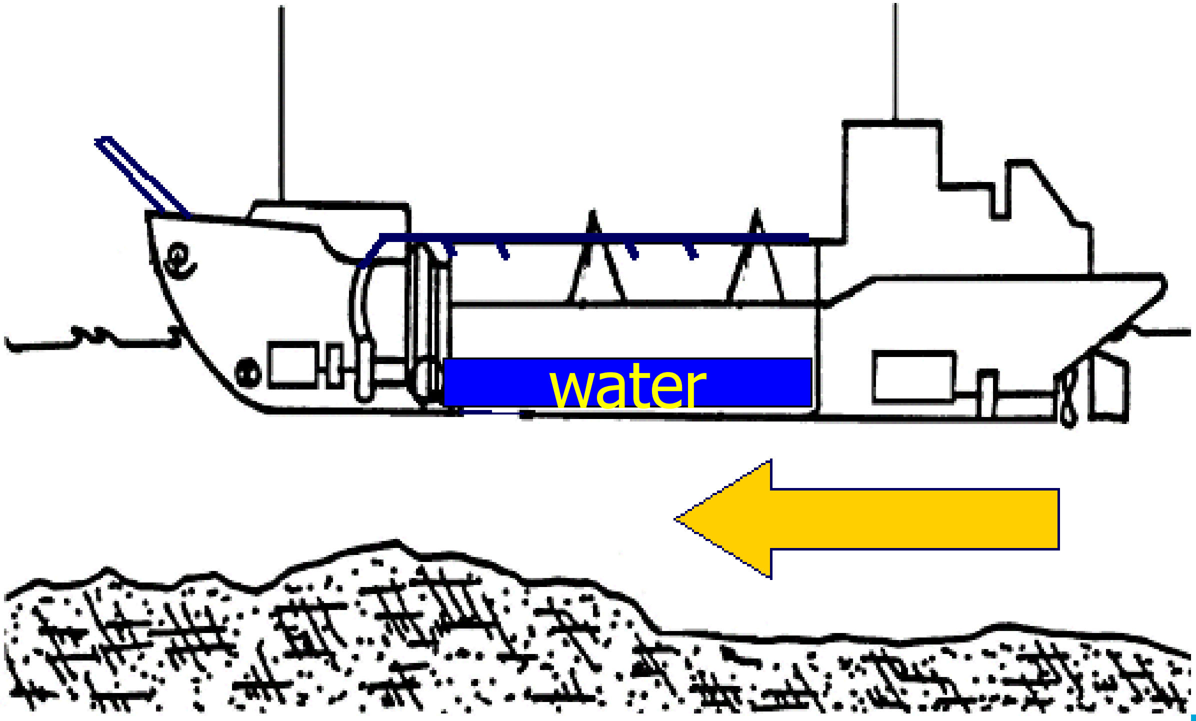
TSHD Process Discription

Sailing empty



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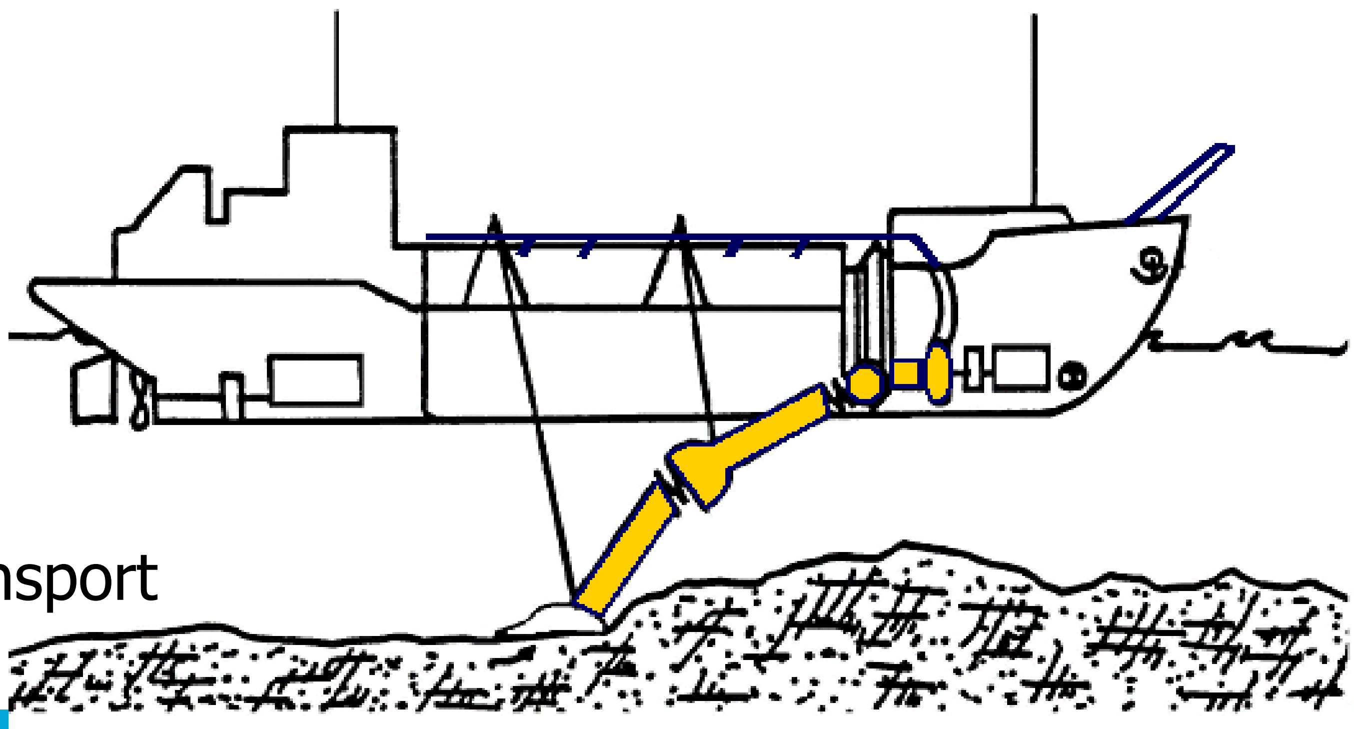
TSHD Process Discription

Suction

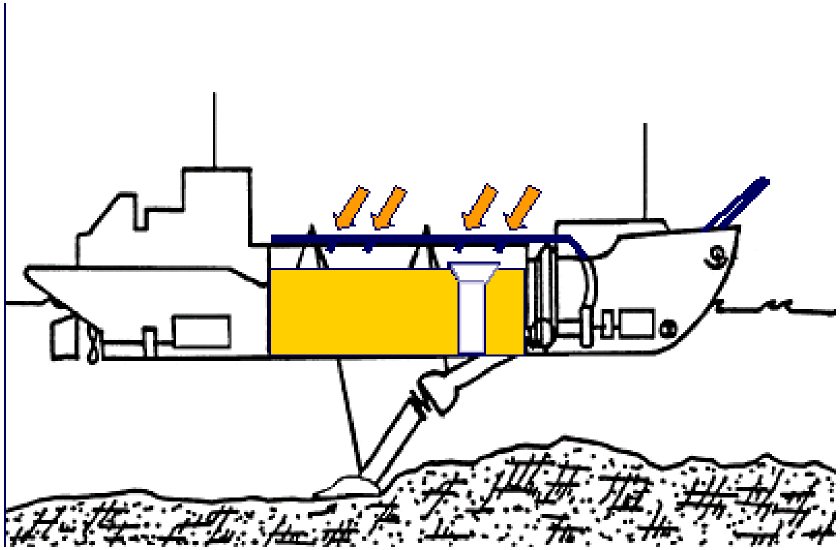


Excavation
Vertical transport

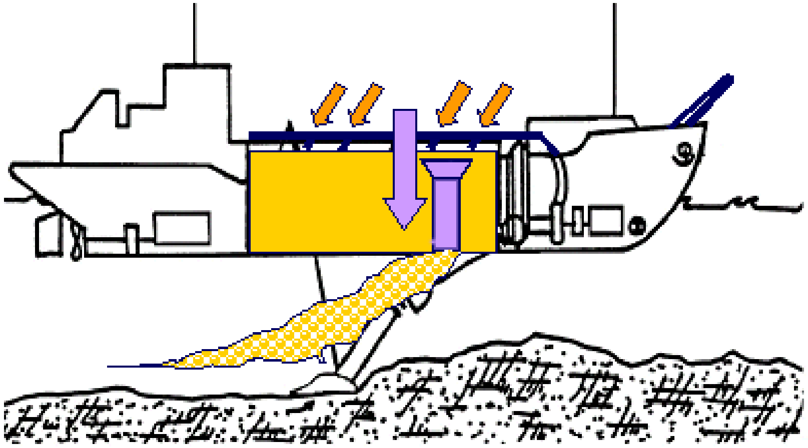
TSHD Process Discription

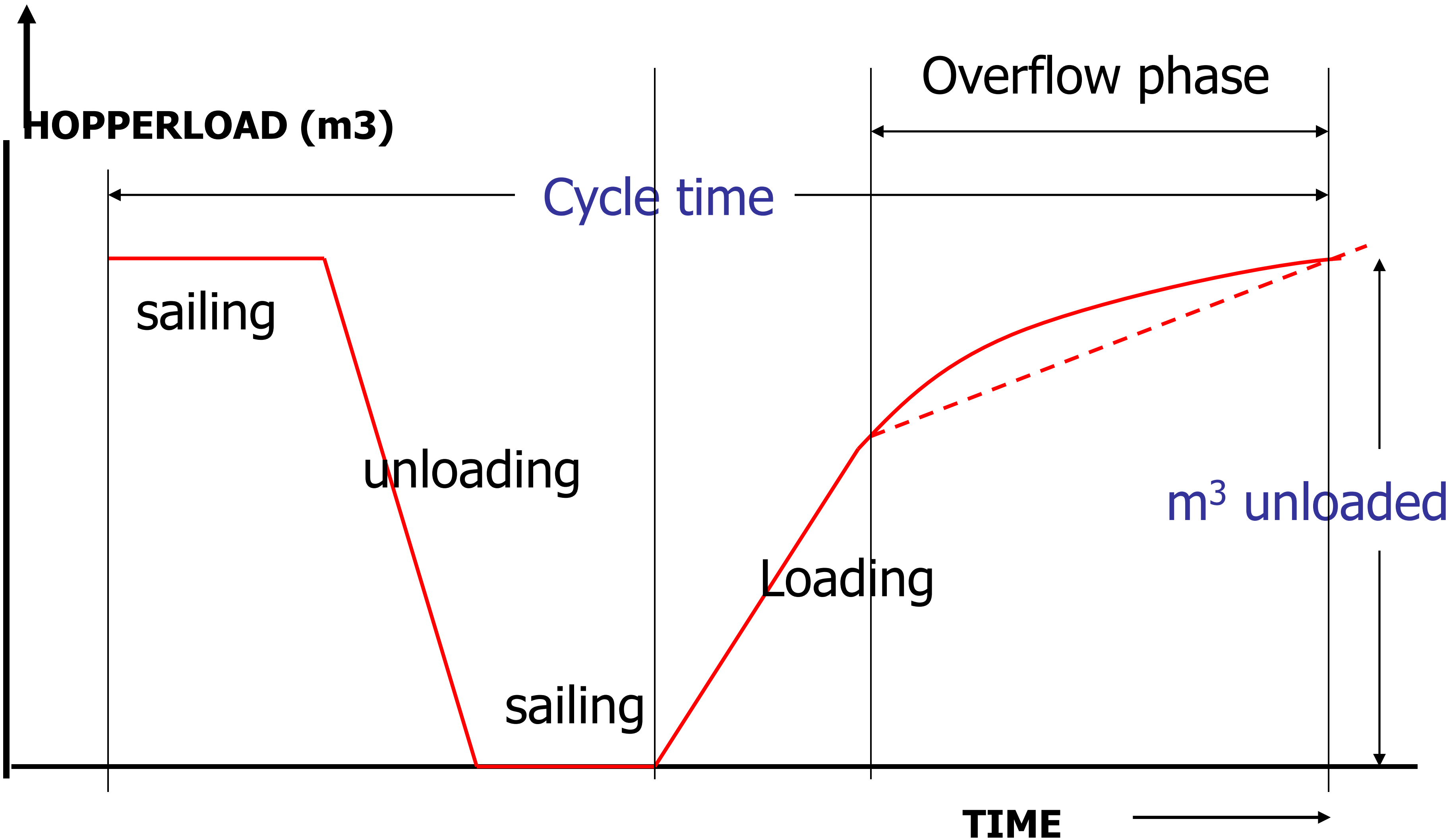
Loading

Hopper sedimentation

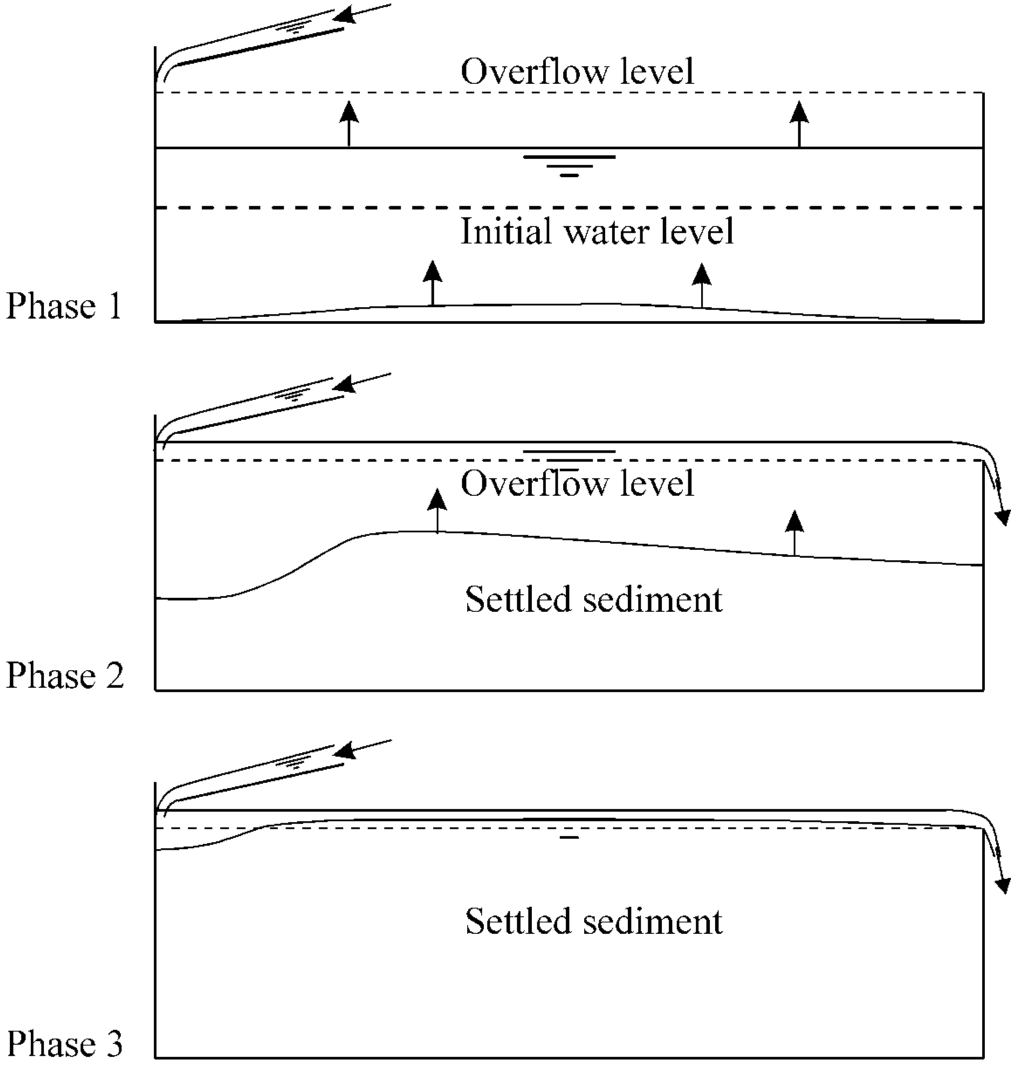


Loading (overflow)




HOPPERLOAD (m3)
Overflow phase
Cycle time
sailing
unloading
sailing
Loading
m3 unloaded
TIME

Proces



Overflow phase

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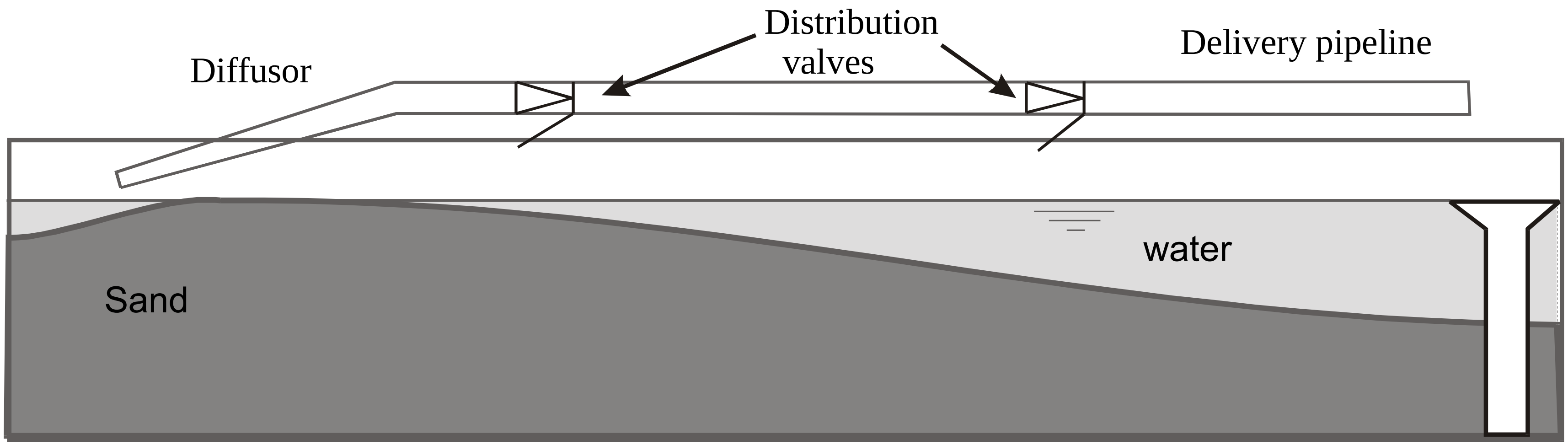
Loading & Overflow system



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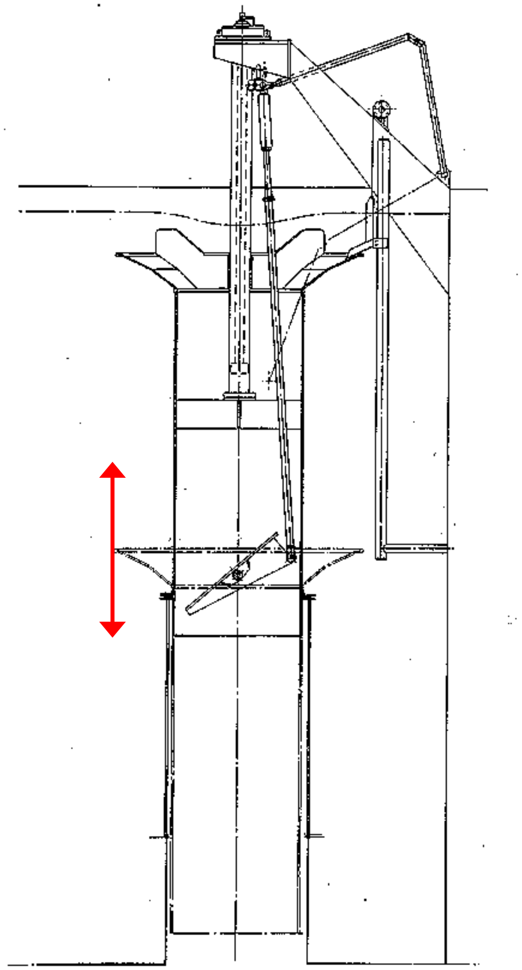
Overflow system



Loading & Overflow system

- Loading system
  - Distribution of sediment
    - Influence on overflow losses
    - Influence on hopper load
    - Influence on trim of the hopper
- Overflow system
  - Adjustable in height

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Overflow Losses

- Important to know:
  - Quantity of losses
  - Which part of the particle size distribution is lost
- Why:
  - Production
  - Sand Quality
  - Environment

Factors influencing overflow losses

- ?

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Factors influencing overflow losses

- Sediment characteristics
  - Particle size distribution } Settling
  - Shape factor } velocity
- Equipment
  - Hopper dimensions (L,H,B)
  - Loading and overflow system
- Operational
  - Discharge
  - Concentration
  - Loading time
  - Loading procedure
  - Water temperature

Most important ?

Factors influencing overflow losses

- Sediment characteristics
  - Particle size distribution } Settling
  - Shape factor } velocity
- Equipment
  - Hopper dimensions (L,H,B)
  - Loading and overflow system
- Operational
  - Discharge
  - Concentration
  - Loading time
  - Loading procedure
  - Water temperature

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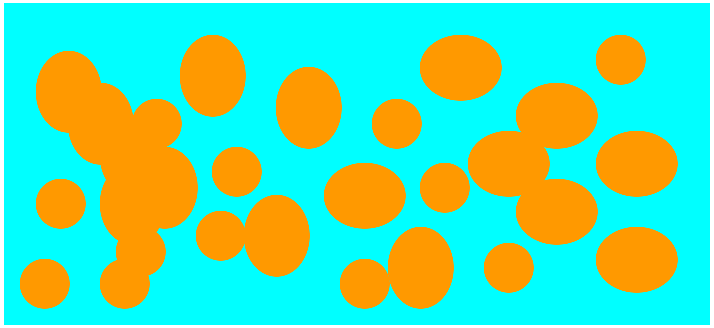
General Properties



Volume particles V_s

Volume water V_w

Total Volume $V_t = V_s + V_w$

Volumetric Concentration $C_v = \frac{V_s}{V_t}$

$$\rho_m = \frac{M_t}{V_t} = \frac{V_s \rho_s + V_w \rho_w}{V_t} = \frac{V_s \rho_s + \left(V_t - V_s\right) \rho_w}{V_t} =$$

$$\rho_m = C_v \rho_s + \left(1 - C_v\right) \rho_w$$

Mixture density

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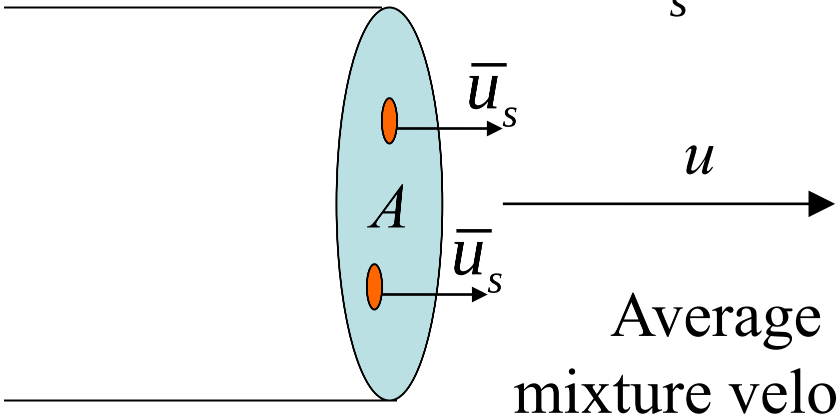
Discharge

$$A_s = Ac_v$$



mixture $\quad Q = A\bar{u}$

solids $\quad Q_s = A_s\bar{u}_s = Ac_v\bar{u}_s$

$Q_s = A\bar{u}c_{vd}$ $\quad C_{vd}$ =delivered concentration

$$c_{vd} = \frac{Q_s}{Q} = \frac{A\bar{u}c_{vd}}{A\bar{u}} = \frac{\bar{u}_s c_v}{\bar{u}} = \frac{\alpha_t \bar{u} c_v}{\bar{u}} = \alpha_t c_v \qquad \alpha_t \leq 1$$

Definition Overflow losses

$$Ov_{mom} = \frac{sandflux\ out}{sandflux\ in} = \frac{\rho_s Q_{out} c_{out}}{\rho_s Q_{in} c_{in}} =$$

$$Ov_{mom} = \frac{c_{out}}{c_{in}} \qquad if\ \ Q_{in} = Q_{out}$$

$$Ov_{cum} = \frac{cum\ sandflux\ out}{cum\ sandflux\ in} = \frac{\int_0^t \rho_s Q_{out} c_{out} dt}{\int_0^t \rho_s Q_{in} c_{in} dt}$$

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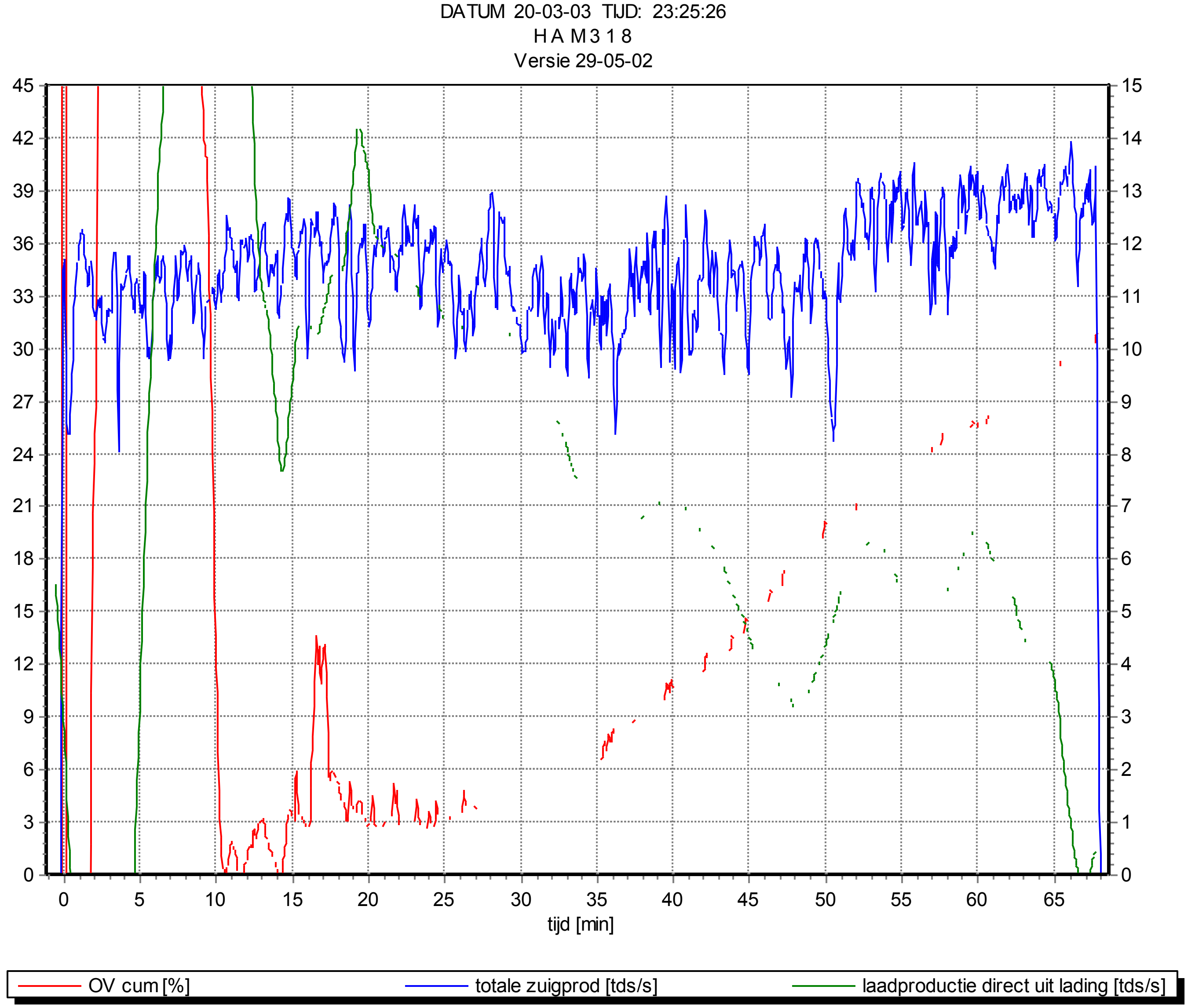
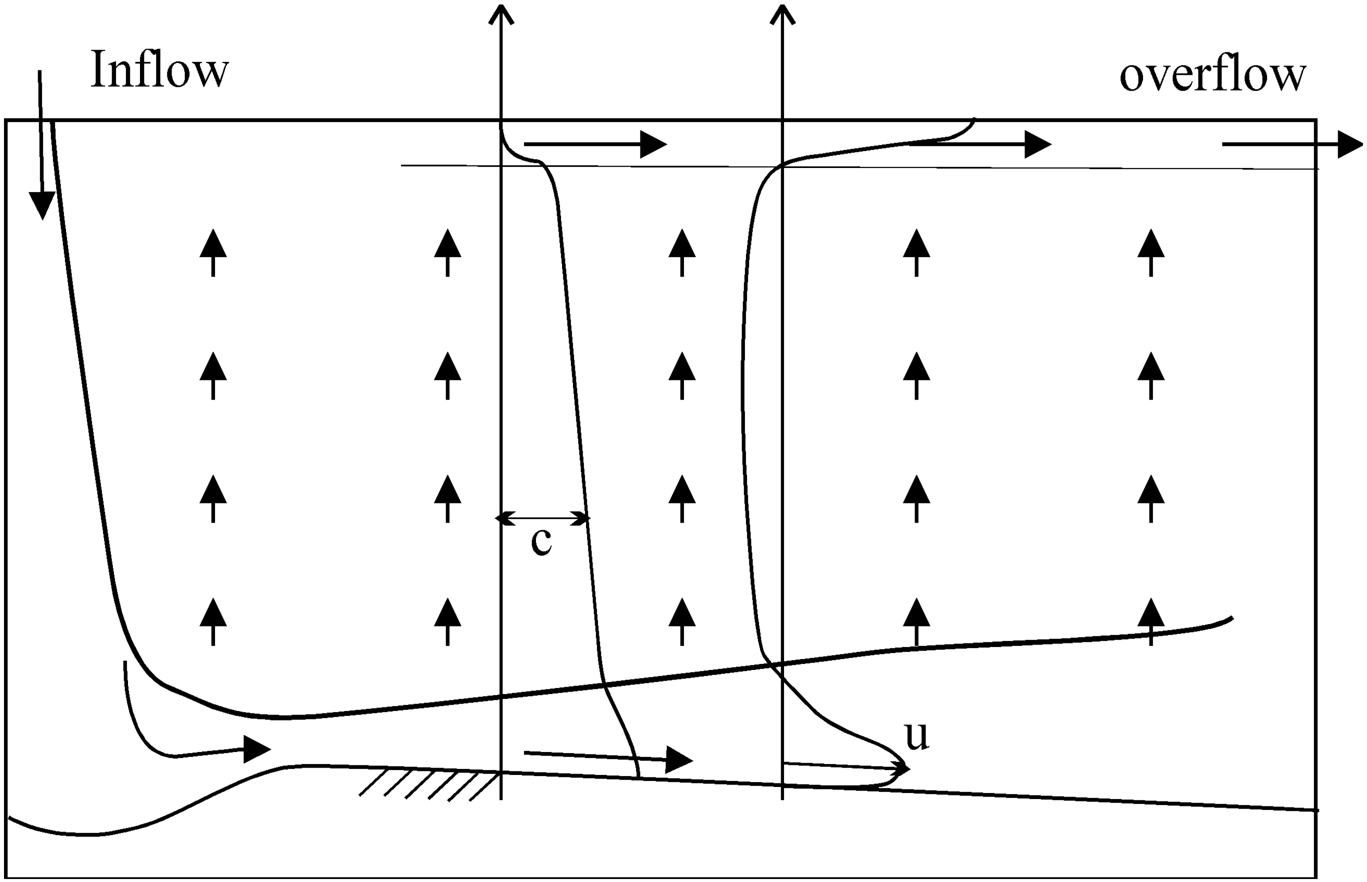

DATUM 20-03-03 TIJD: 23:25:26
H A M 3 1 8
Versie 29-05-02
45
42
39
36
33
30
27
24
21
18
15
12
9
6
3
0
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
tijd [min]
OV cum [%]
totale zuigprod [tds/s]
laadproductie direct uit lading [tds/s]

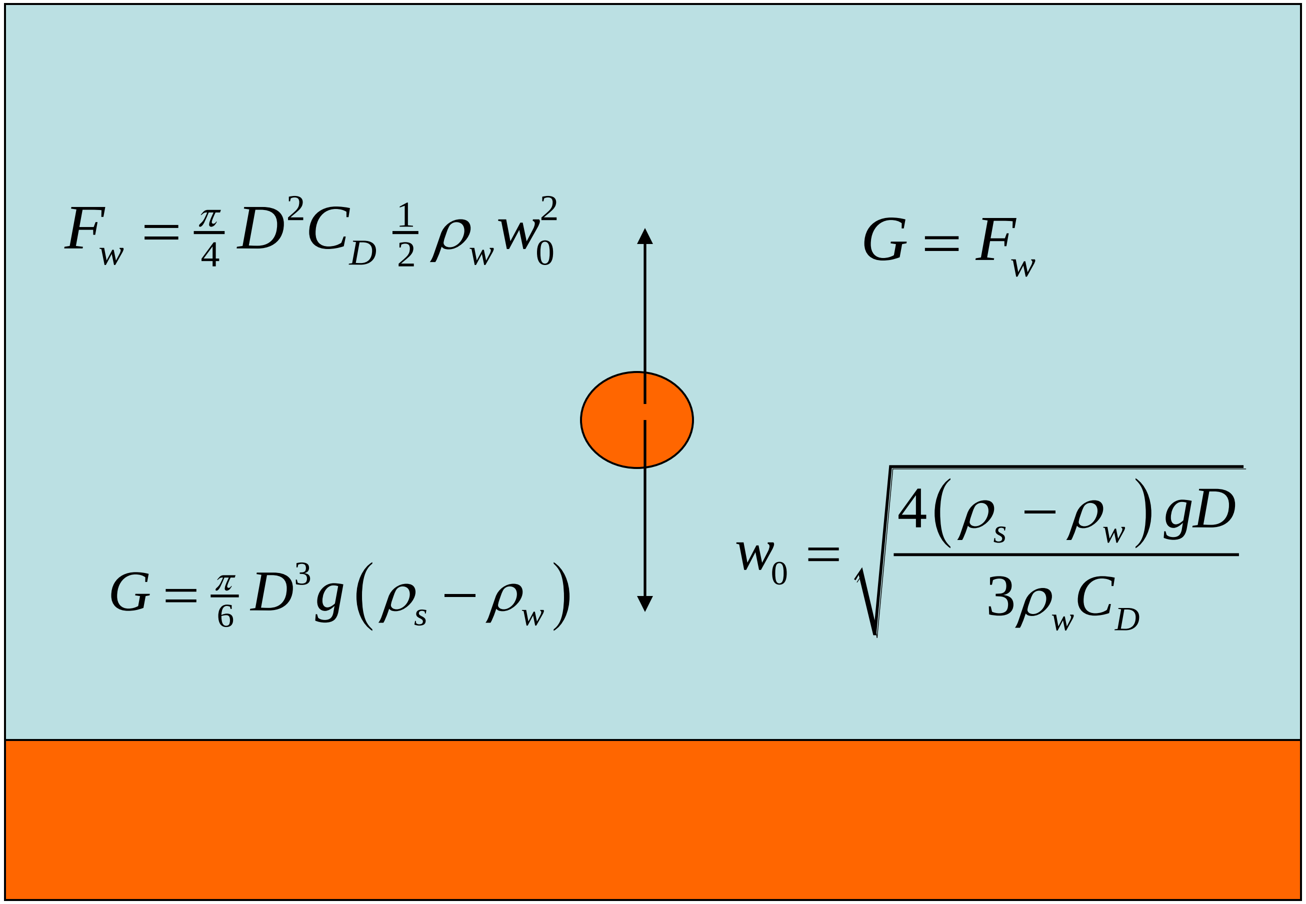
Flow Pattern



Settling velocity

- Derive a general equation for the settling (fall) velocity of a particle below the water surface

Settling Velocity



$$F_w = \tfrac{\pi}{4} D^2 C_D \tfrac{1}{2} \rho_w w_0^2$$

$$G = F_w$$

$$G = \tfrac{\pi}{6} D^3 g \left(\rho_s - \rho_w \right)$$

$$w_0 = \sqrt{\frac{4\left(\rho_s - \rho_w\right) g D}{3 \rho_w C_D}}$$

$$w_0 = \sqrt{\frac{4(\rho_s - \rho_w) g D \psi}{3 \rho_w C_D}}$$

$$C_D = f\left(\frac{w_0 D}{\nu}\right)$$

$$\frac{w_0 D}{\nu} = Re_p$$

Shape factor

$$\psi = \frac{V}{\frac{\pi}{6} D^3}$$

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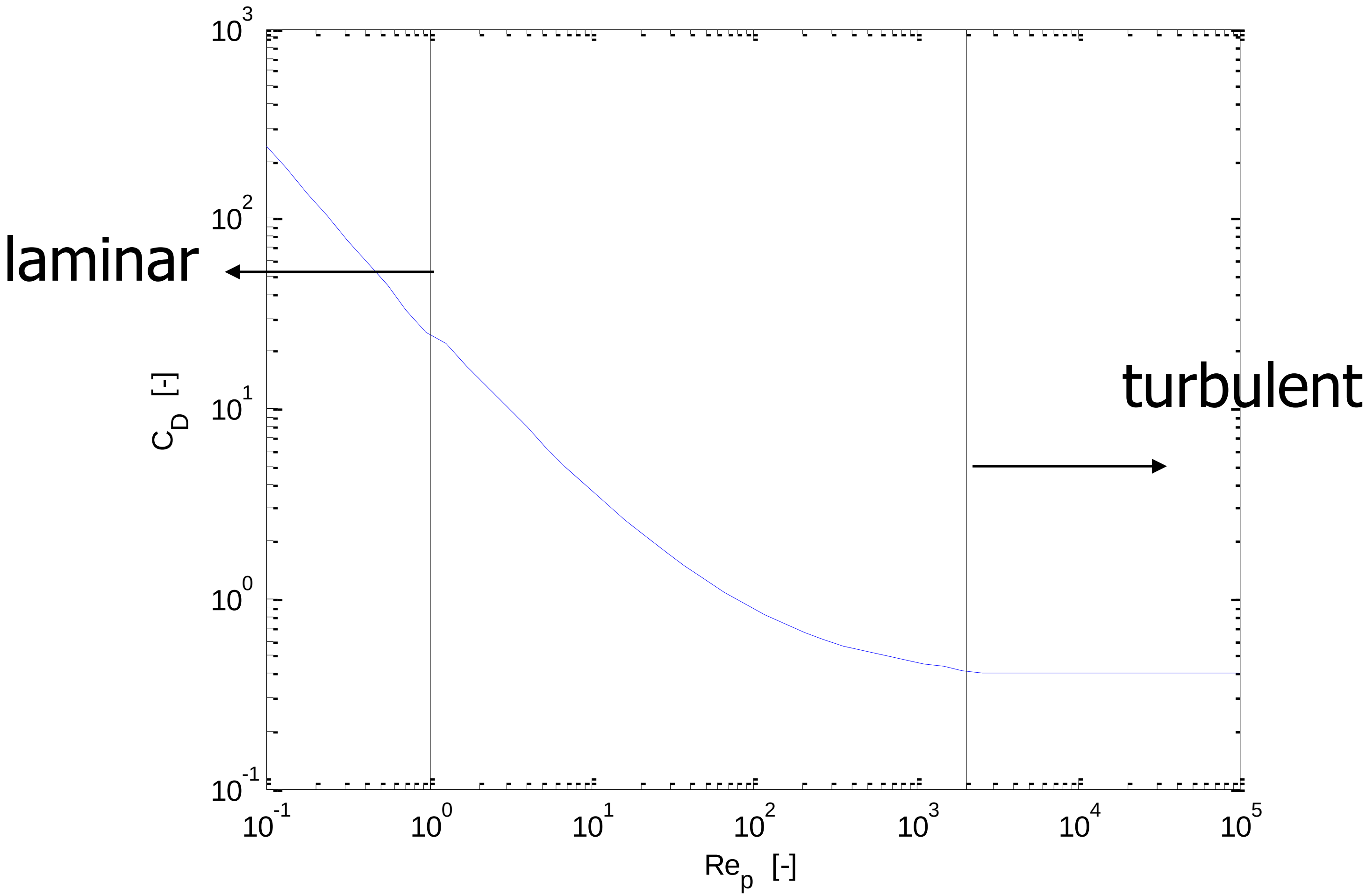
Drag Coefficient CD

$$Re_p < 1 \quad \Rightarrow \quad C_d = \frac{24}{Re_p}$$

$$1 < Re_p < 2000 \quad \Rightarrow \quad C_d = \frac{24}{Re_p} + \frac{3}{\sqrt{Re_p}} + 0.34$$

$$Re_p > 2000 \quad \Rightarrow \quad C_d = 0.445$$

C_d as a function of Re_p



Small particles : Stokes equation

$$w_0 = \sqrt{\frac{4\left(\rho_s - \rho_w\right) g D \psi}{3 \rho_w C_D}}$$

$$w_0 = \frac{\psi \Delta g D^2}{18 \nu}$$

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

$$C_D = \frac{24}{Re_p} = \frac{24 \nu}{w_0 D}$$

Coarse particles : Turbulent regime

$$w_0 = \sqrt{\frac{4(\rho_s - \rho_w) g D \psi}{3 \rho_w C_D}}$$

$$C_D = 0.4$$

$$w_0 = 1.8 \sqrt{\Delta g D \psi}$$

$$\Delta = \frac{\rho_s - \rho_w}{\rho_w}$$

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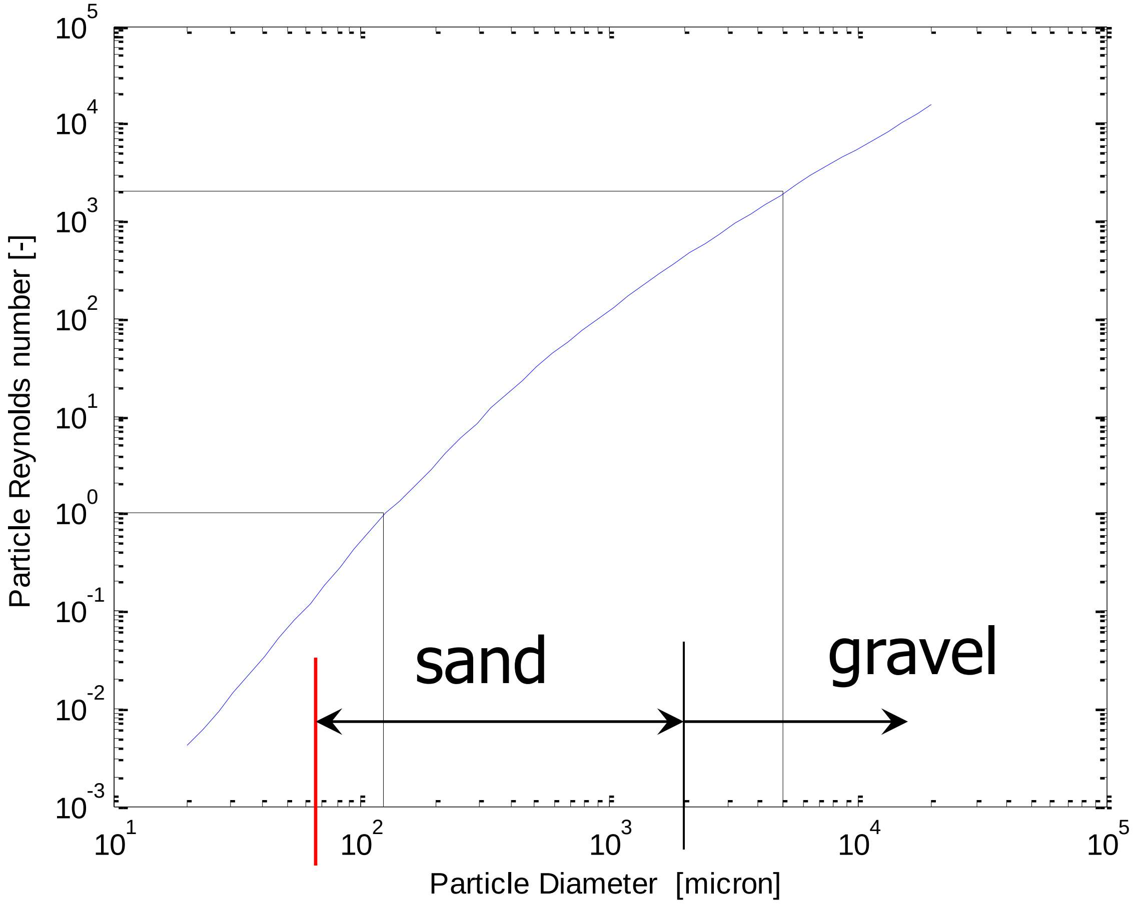
Intermediate Regime

- Iteration of Cd

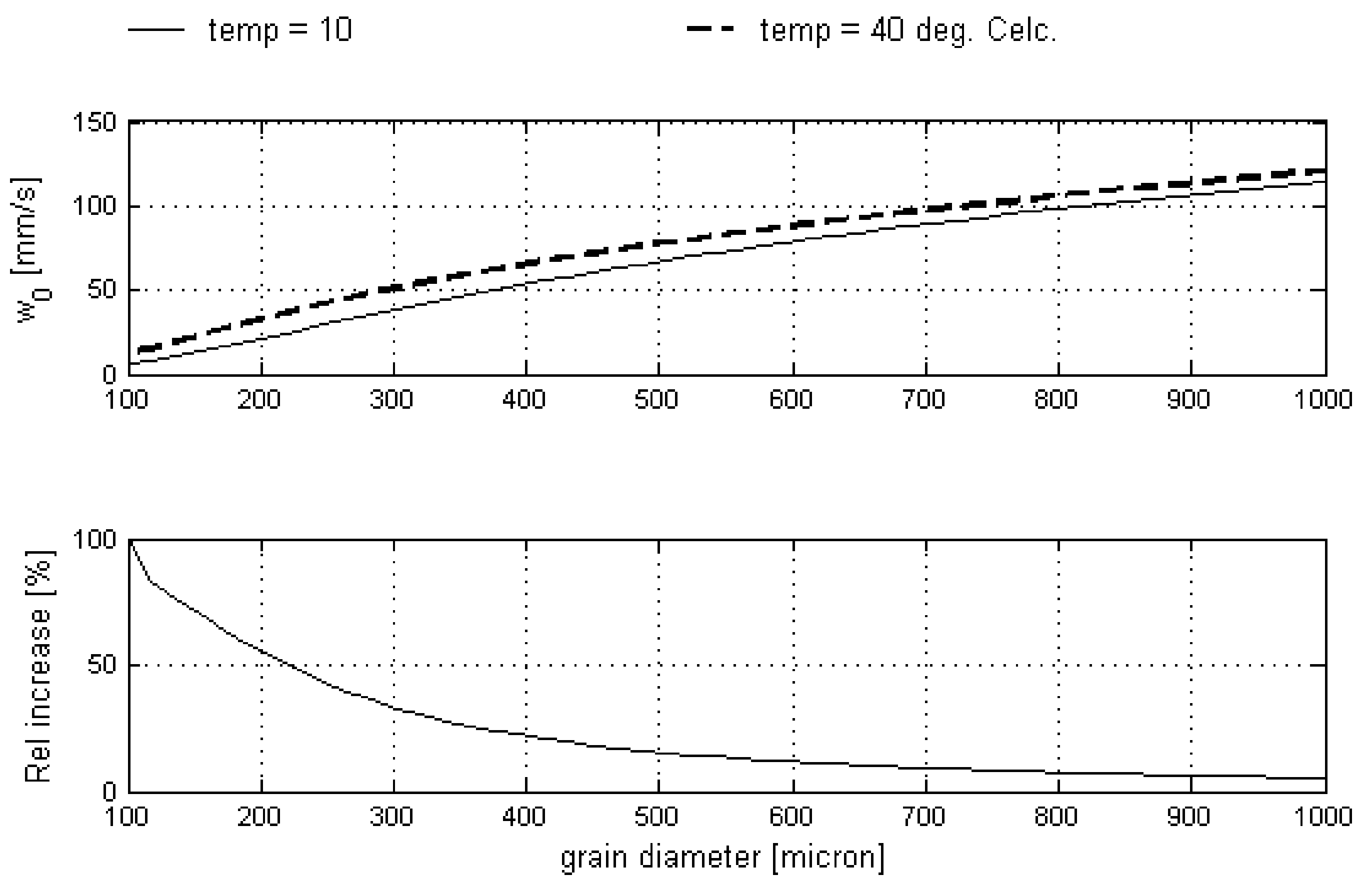
- Or use empirical equations

$$w_0 = \frac{10\nu}{D}\left(\sqrt{1+\frac{\Delta g D^3}{100\nu^2}}-1\right)$$

Particle Reynolds number



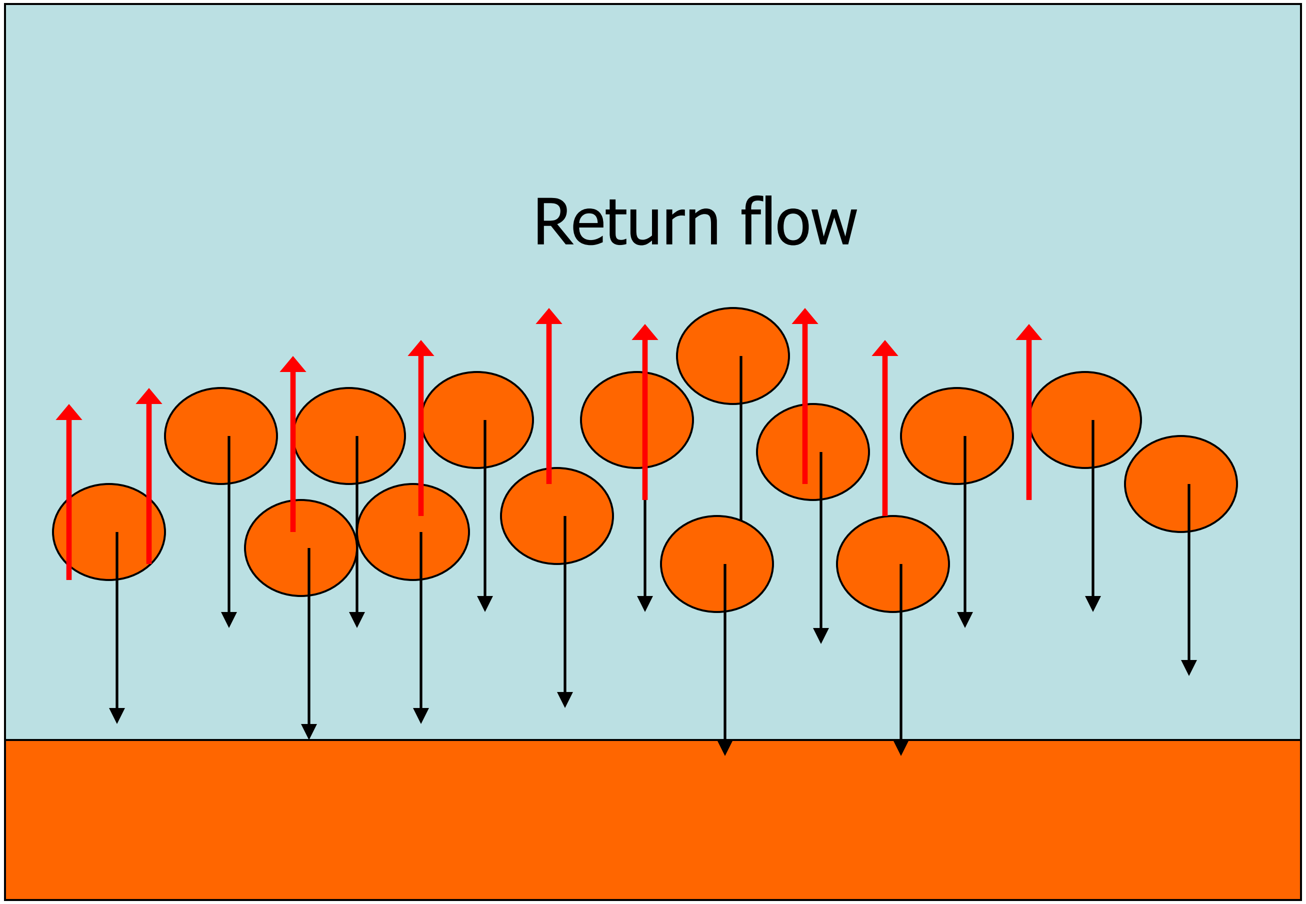
Settling velocity influence temp



Hopper sedimentation

- Section 2

Influence of the concentration



Hindered settling

- Not one particle is settling:
- Mutual influence
    - Return flow
    - Particle – particle interaction
- This effect is called hindered settling
- Settling velocity of single grain is reduced with a factor f

$$w_s = w_0 \cdot f(c)$$

$$f(c) = (1 - c)^n$$

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Hindered settling function

$$w_s = w_0 \cdot f(c)$$

$$f(c) = (1-c)^n$$

$$n = f(Re_p)$$

Richardson & Zaki

$Re_p < 0.2$	$n = 4.65$
$0.2 \le Re_p \le 1$	$n = 4.35 Re_p^{-0.03}$
$1 \le Re_p \le 200$	$n = 4.45 Re_p^{-0.1}$
$Re_p > 200$	$n = 2.39$

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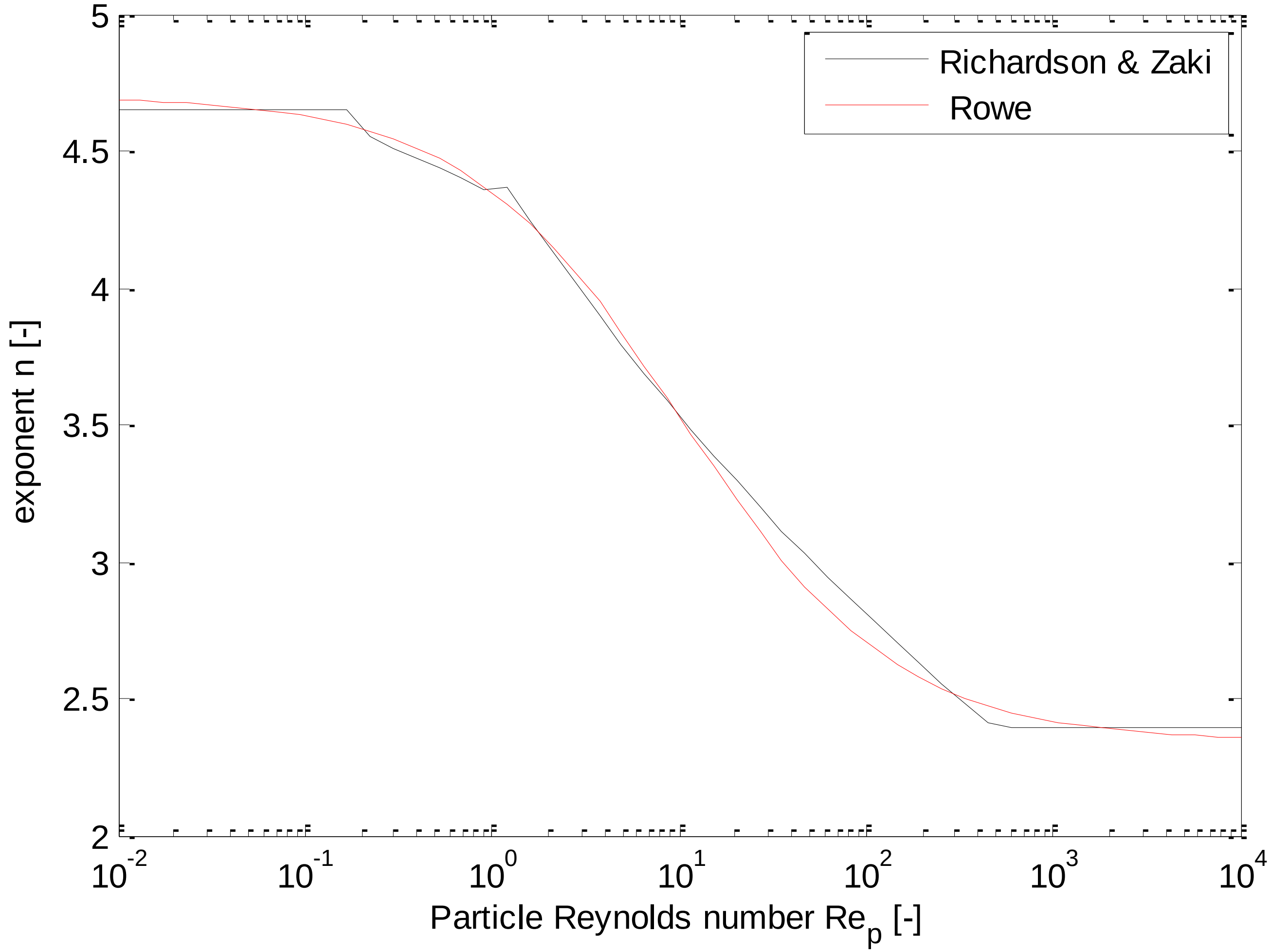
Hindered settling exponent

•Rowe: $$n = \frac{4.7 + 0.41 Re_p^{0.75}}{1 + 0.175 Re_p^{0.75}}$$



Richardson & Zaki
Rowe
exponent n [-]
Particle Reynolds number Re_p [-]
5
4.5
4
3.5
3
2.5
2
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4

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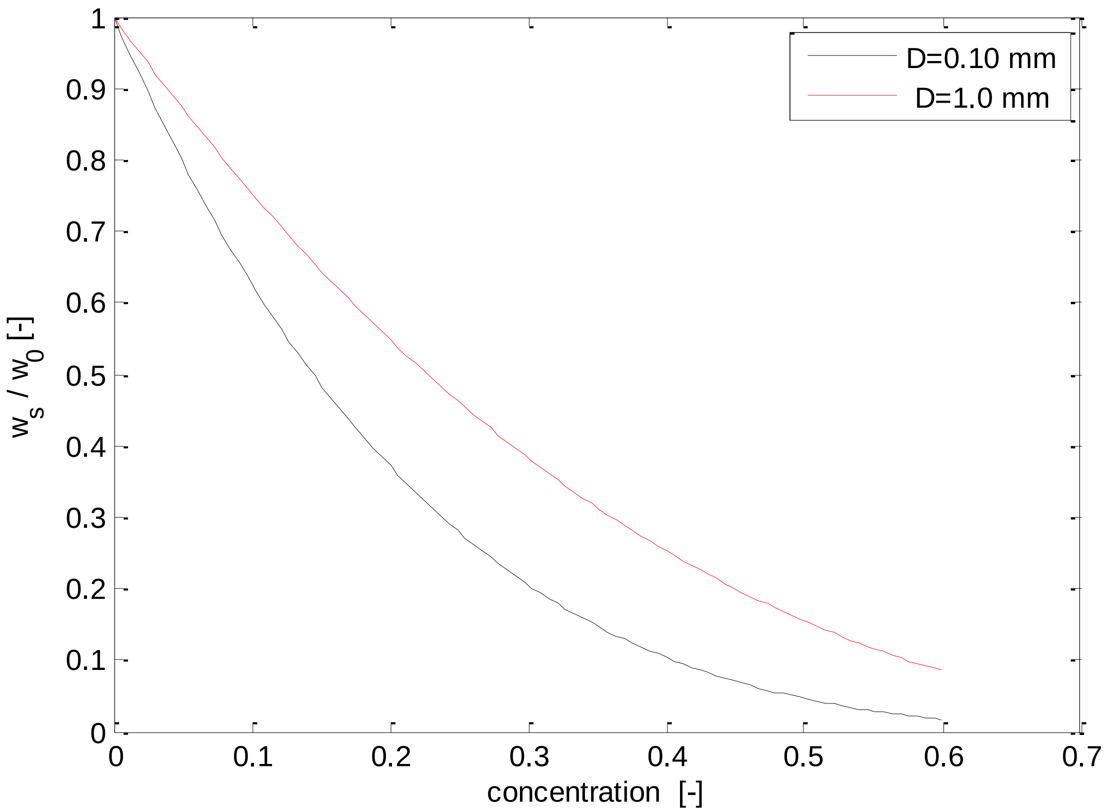
Influence concentration on settling velocity



- Settling velocity decreases with concentration
- And therefore loading velocity decreases also ????
- NO
- Settling flux = product of concentration and settling velocity is important

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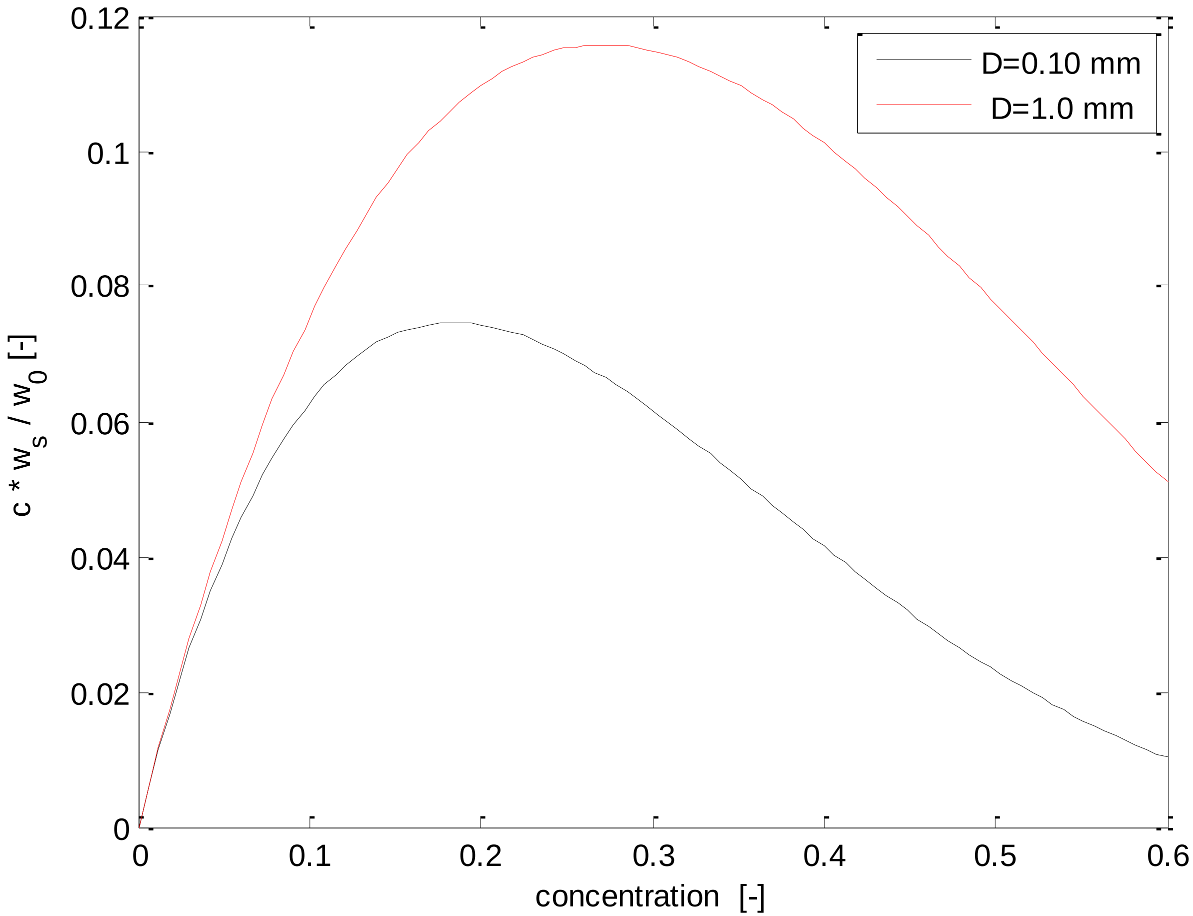
Settling flux = $w_s * c$



Optimal Loading Concentration ??

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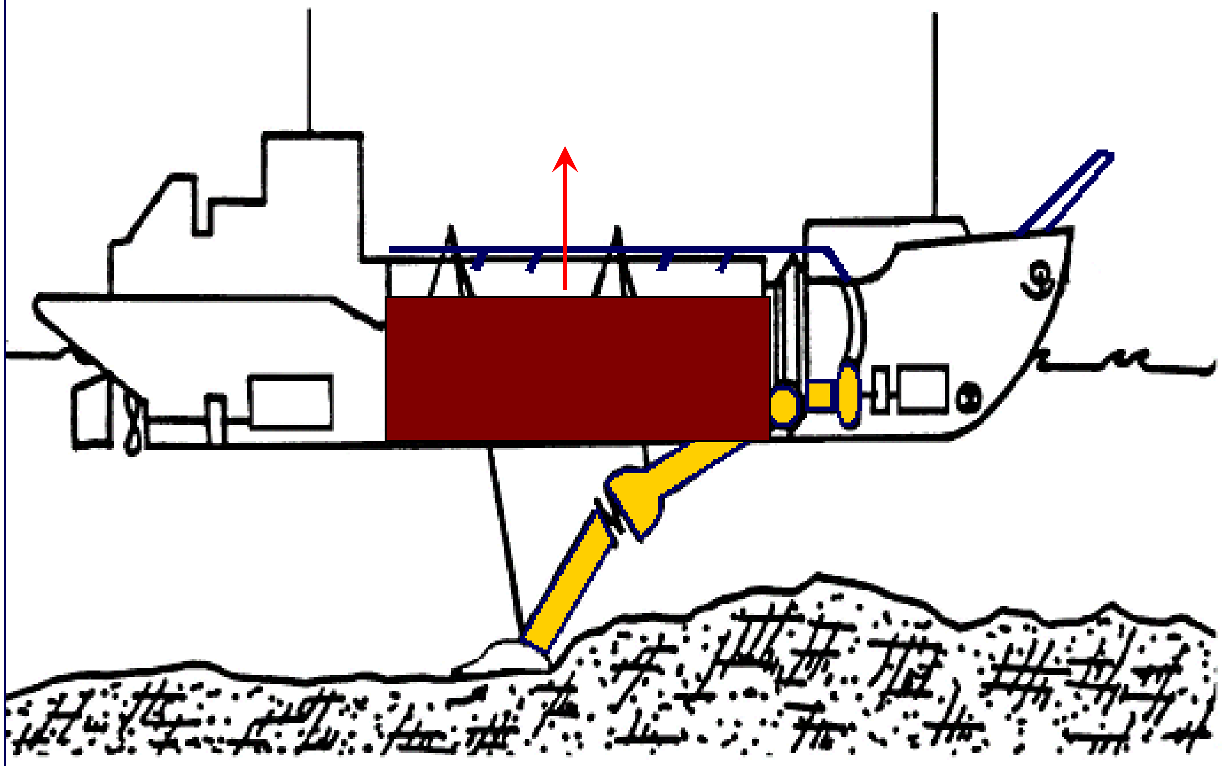
Sedimentation velocity

$$T_{load} = \frac{H}{\bar{v}_{sed}}$$

Is vertical velocity of the settled bed



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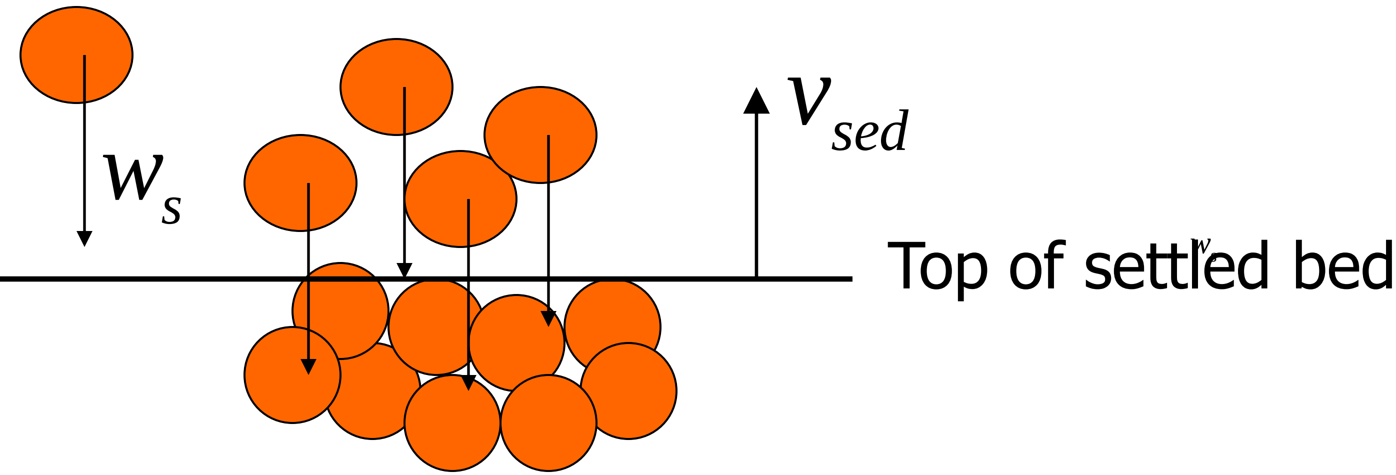
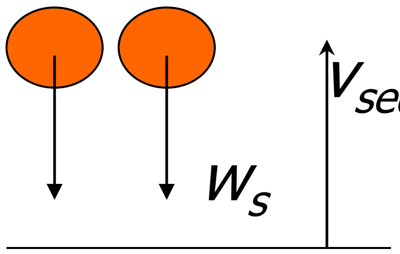
concentration

c



$$c_{bed} = 1 - n_0$$

- Volume of sediment moving along moving interface =
- Volume of sediment stored in bed



$$c\left(w_s + v_{sed}\right) = \left(1 - n_0\right) v_{sed}$$

$$v_{sed} = \frac{c w_s}{1 - n_0 - c} = w_0 \frac{c\left(1-c\right)^n}{1 - n_0 - c}$$

Or:

$$\frac{v_{sed}}{w_0} = \frac{c\left(1-c\right)^n}{1 - n_0 - c}$$

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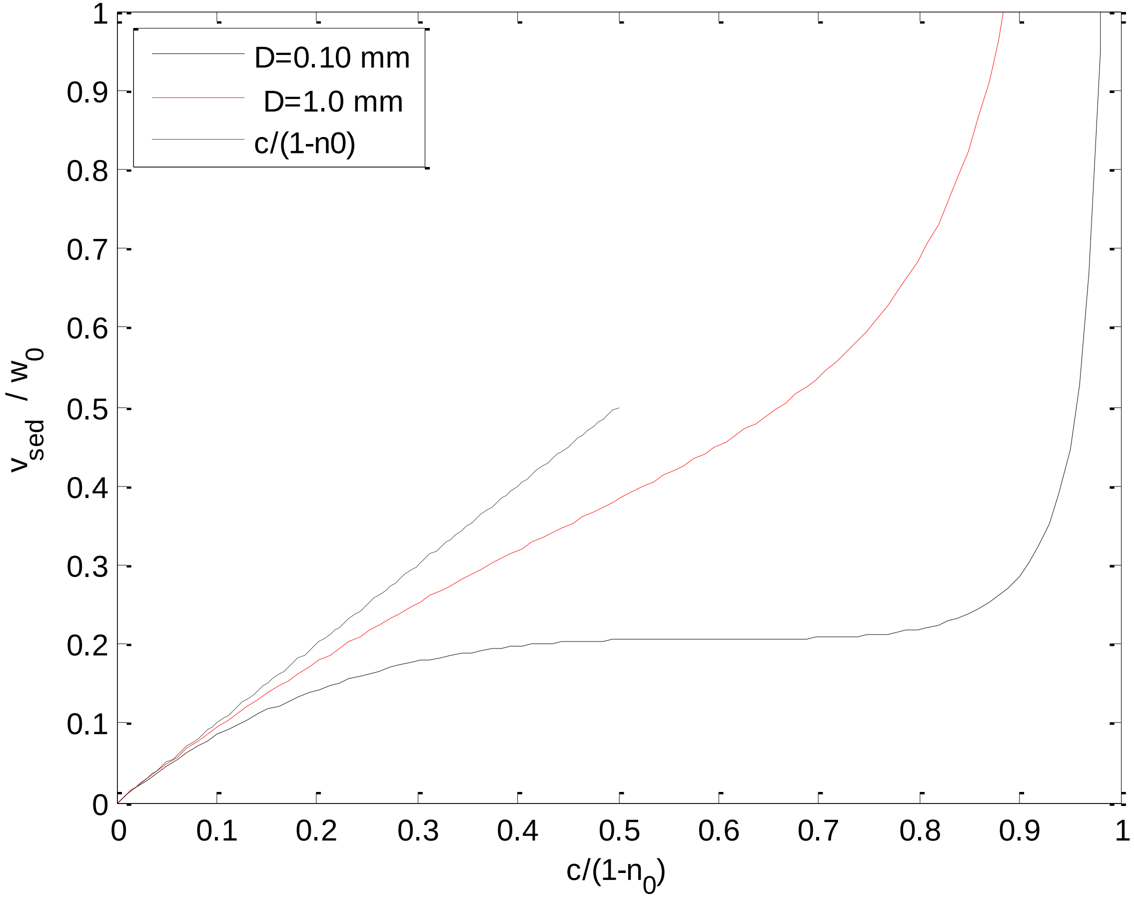

$$\frac{v_{sed}}{w_0} = \frac{c(1-c)^n}{1-n_0-c}$$

Small concentration:

$$\frac{v_{sed}}{w_0} = \frac{1}{1-n_0} c$$

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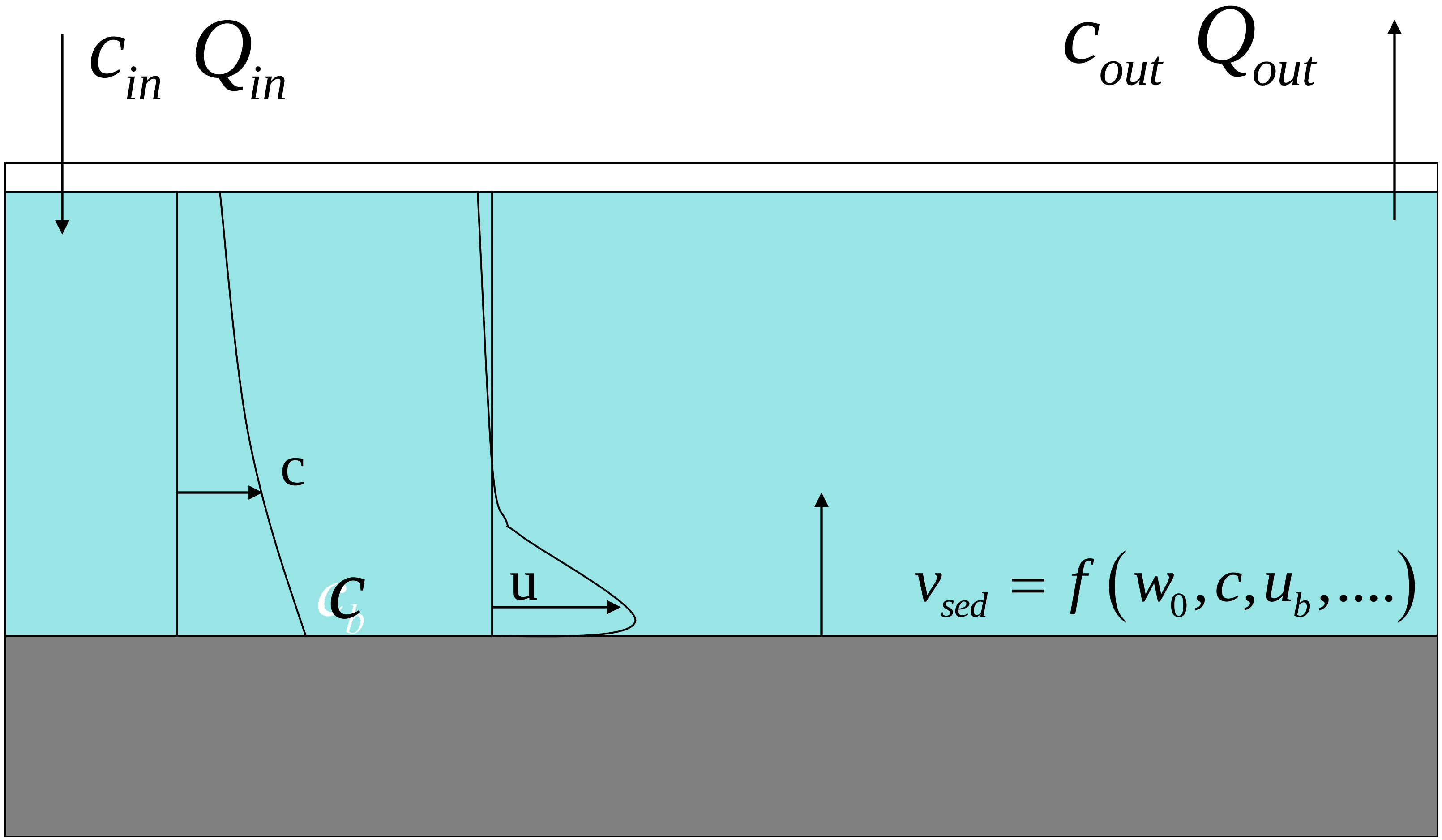
Schematic Process Overview



Sedimentation Velocity

- Vertical velocity of interface between settled sand and mixture above
- So far only sedimentation without flow near the bed
- In general:

$$v_{sed} = \frac{S-E}{\rho_s\left(1-n_0-c\right)} \qquad S = \rho_s c w_s \qquad E = f\left(u, D, c, \ldots ?\right)$$

- S : Sedimentation Flux E : Erosion Flux
- c : Near bed concentration
- n_0 : Porosity

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- Overflow loss correlates good with S*

- Relation cannot be applied in general
  - Based on lab tests (influence erosion?)
  - Influence PSD

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Modelling the settling in a hopper

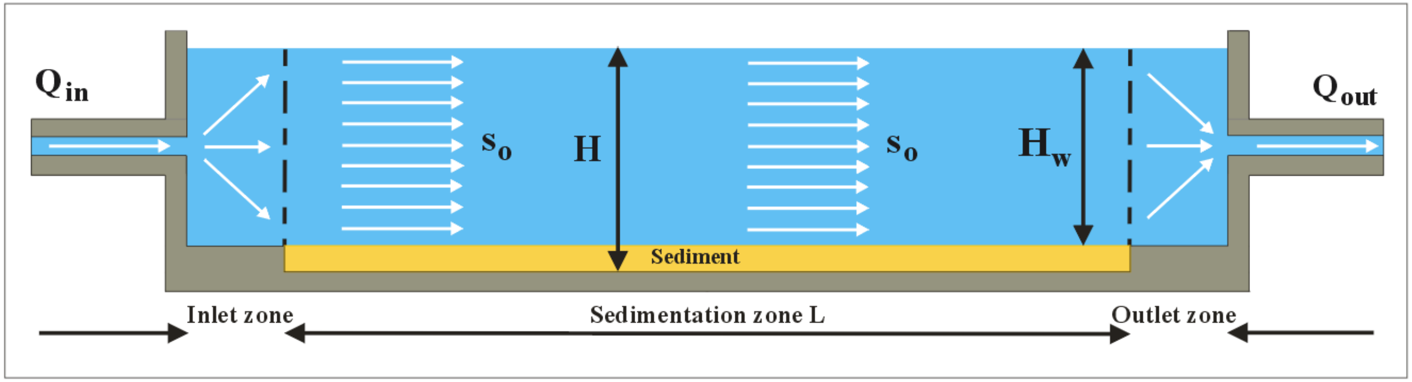
- Camp based models
- 2DV model

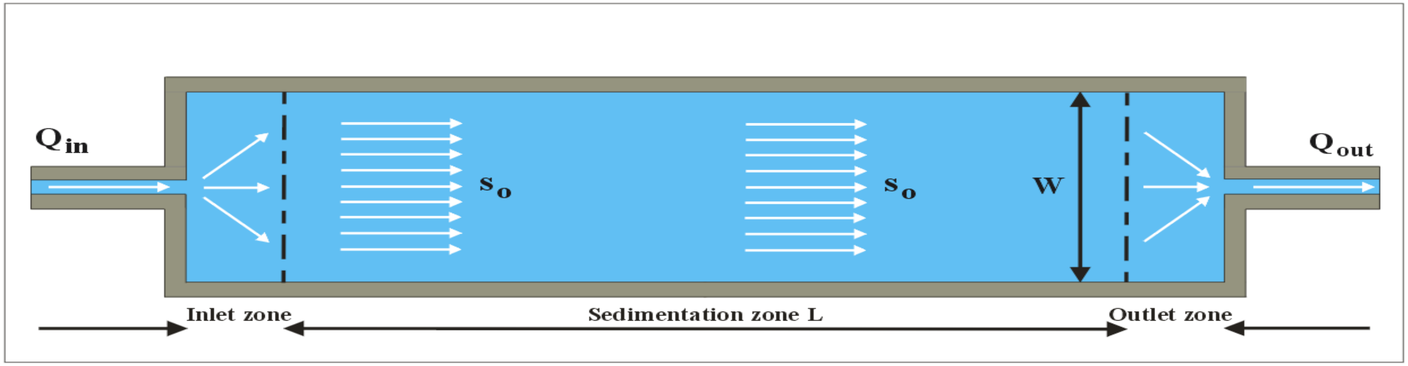
Camp based models

- ‘Ideal’ settling basin
- Originates from clarifiers
- First published by Camp (1946)

- Extended and applied for dredging by Vlasblom & Miedema

Ideal settling basin





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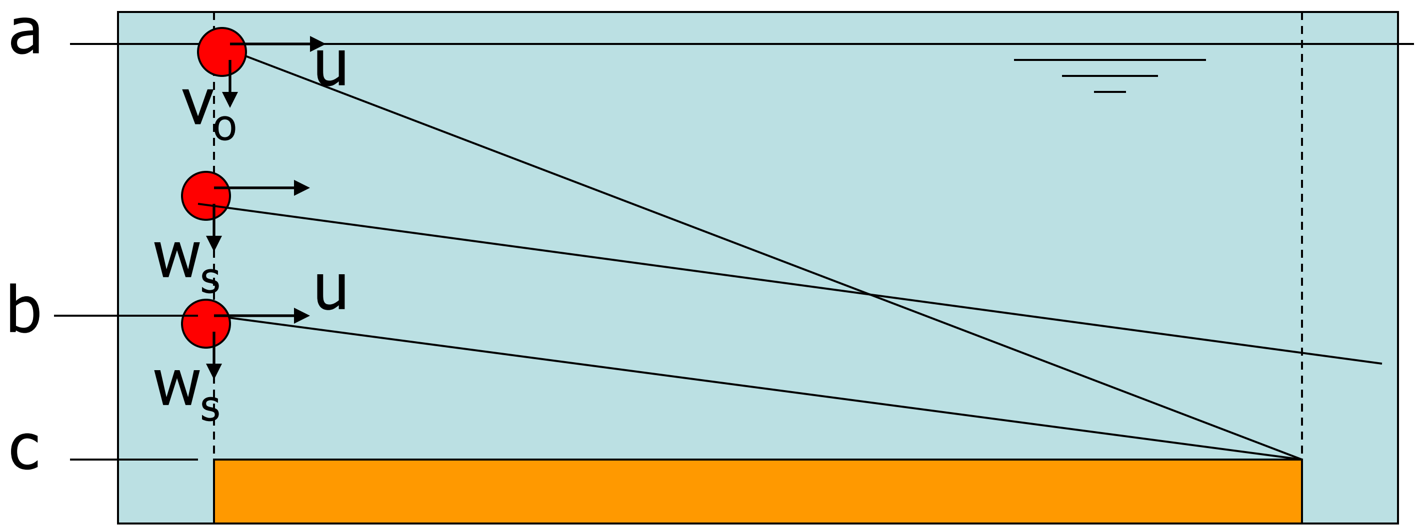

Particles with settling velocity w_s starting between bc will settle

This is $r_g = \frac{\overleftrightarrow{bc}}{\overleftrightarrow{ac}}$ from the total number of particles

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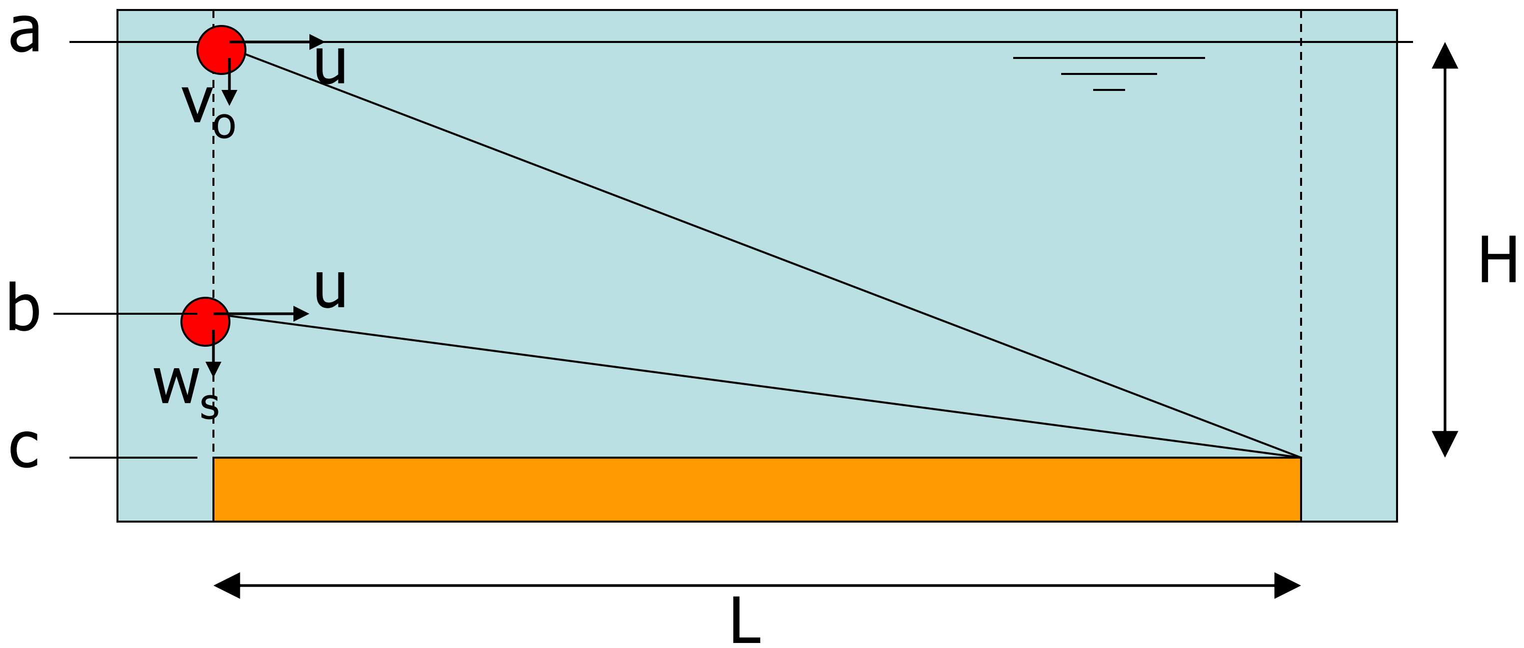

$$\frac{\overleftrightarrow{bc}}{L} = \frac{w_s}{u} \qquad \frac{\overleftrightarrow{ac}}{L} = \frac{H}{L} = \frac{v_0}{u} \qquad \Rightarrow \quad r_g = \frac{\overleftrightarrow{bc}}{\overleftrightarrow{ac}} = \frac{w_s}{v_0}$$

$$v_0 = u\frac{H}{L} \qquad u = \frac{Q}{BH} \quad \Rightarrow \quad v_0 = \frac{Q}{BL}$$

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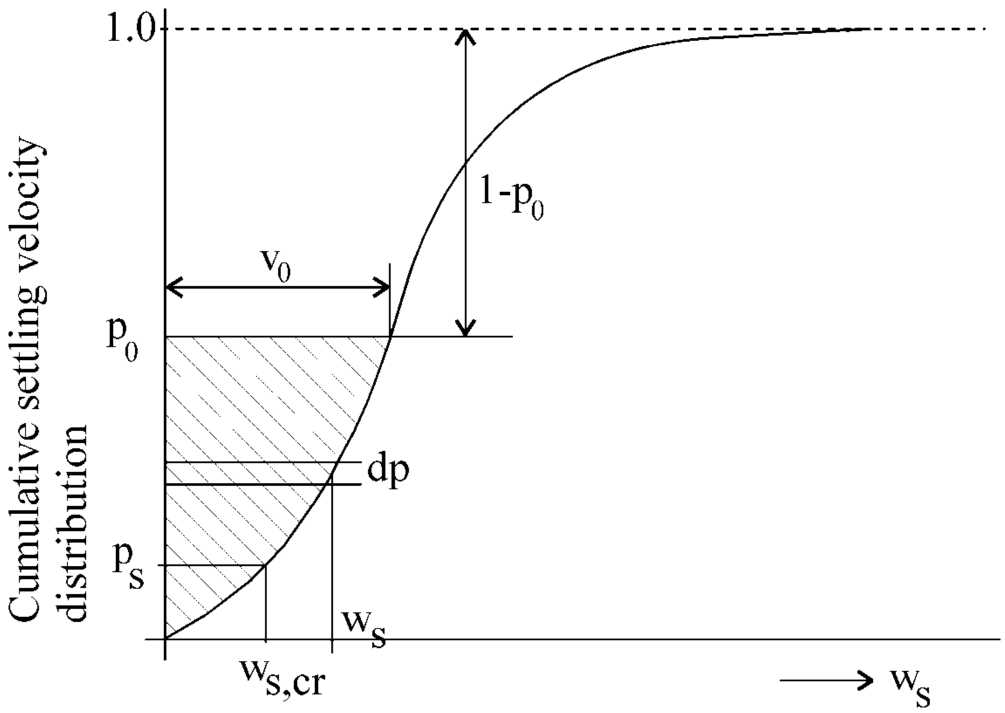
Influence Particle Size Distribution



$$dr_g = \frac{w_s(p)}{v_0} dp$$

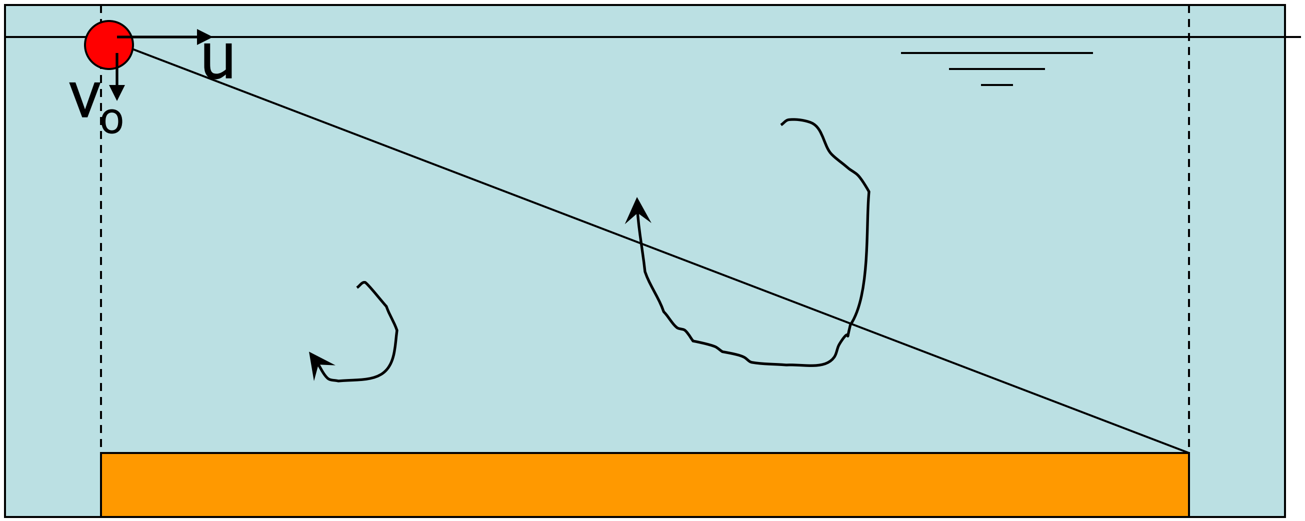
$$r_r = 1 - p_0 + \frac{1}{v_0} \int_0^{p_0} w_s dp$$

Influence of turbulence

- The particle trajectories in the previous slides were straigth lines. Only possible in laminar flow
- Reynolds number with u=0.1 m/s H=10 m:

$$Re = \frac{uH}{\nu} = \frac{0.1 \cdot 10}{10^{-6}} = 10^{6}$$

-> Turbulent flow !


u
v
o

Including turbulence

- Continuity equation: Advection – diffusion equation
- Control volume
- Rate of change of sediment inside volume = equal to the fluxes through the boundaries
- Fluxes through the boundaries are resultion from:
- Advection : particles are carried with the flow
- Diffusion: mixing through the effect of turbulent eddies

$$\frac{\partial c}{\partial t}+\frac{\partial (uc)}{\partial x}+\frac{\partial (vc)}{\partial y}=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial c}{\partial y}\right)$$

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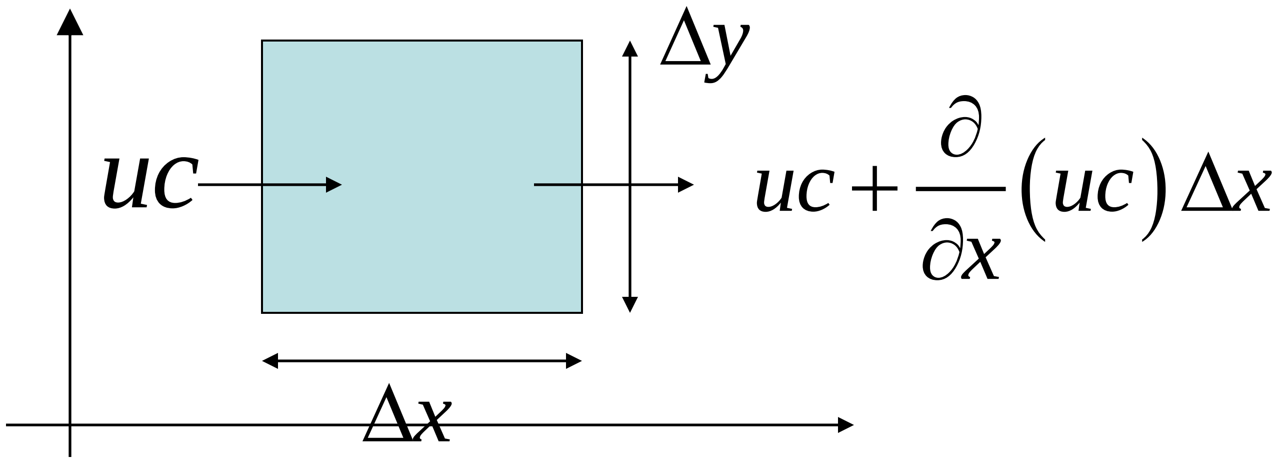
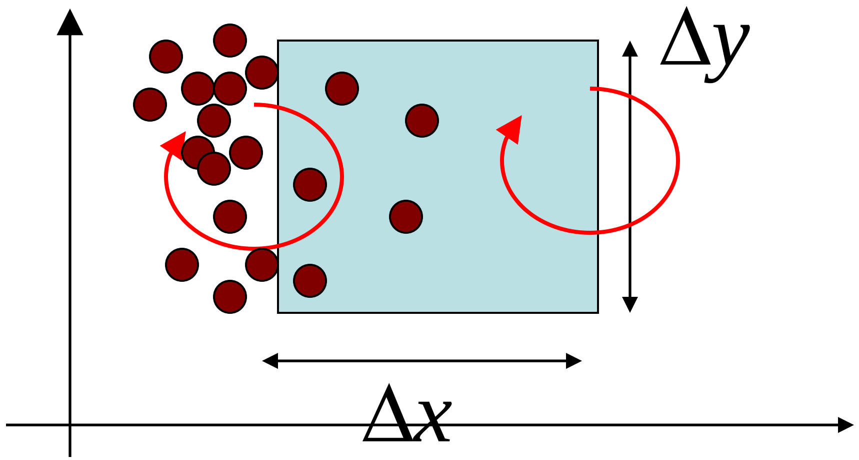
Only horizontal Advection:



$$\frac{\partial c}{\partial t}\Delta x \Delta y = uc\Delta y - \Delta y\left(uc + \frac{\partial}{\partial x}(uc)\Delta x\right)$$

$$\frac{\partial c}{\partial t} + \frac{\partial}{\partial x}(uc) = 0$$

Only horizontal diffusion:



If a difference in concentration is present over the boundary Sediment will be transported

Transport Through left wall: $-\varepsilon \dfrac{\partial c}{\partial x}\Delta y$

Difference : $\dfrac{\partial}{\partial x}\left(\varepsilon \dfrac{\partial c}{\partial x}\right)\Delta y \Delta x$

$$\frac{\partial c}{\partial t}\Delta x \Delta y = \frac{\partial}{\partial x}\left(\varepsilon \frac{\partial c}{\partial x}\right)\Delta y \Delta x$$

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(\varepsilon \frac{\partial c}{\partial x}\right)$$

Horizontal advection + diffusion :

$$\frac{\partial c}{\partial t}+\frac{\partial}{\partial x}\left(uc\right)=\frac{\partial}{\partial x}\left(\varepsilon\frac{\partial c}{\partial x}\right)$$

Horizontal and vertical advection + diffusion :

$$\frac{\partial c}{\partial t}+\frac{\partial}{\partial x}\left(uc\right)+\frac{\partial}{\partial y}\left(vc\right)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial c}{\partial y}\right)$$

u and v are particle velocities

General equation:

$$\cancel{\frac{\partial c}{\partial t}} + \frac{\partial}{\partial x}(Uc) + \frac{\partial}{\partial y}(vc) = \cancel{\frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial c}{\partial x}\right)} + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial c}{\partial y}\right)$$

$$U\frac{\partial c}{\partial x} + w_s \frac{\partial c}{\partial y} = \varepsilon \frac{\partial^2 c}{\partial y^2}$$

Approximations

Horizontal diffusion is small compared with horizontal advection

Stationary flow

Vertical velocity is equal to w_s and not a function of c

Horizontal particle velocity = flow velocity and uniform

Diffusion is constant

Analytical solution by separation of variables

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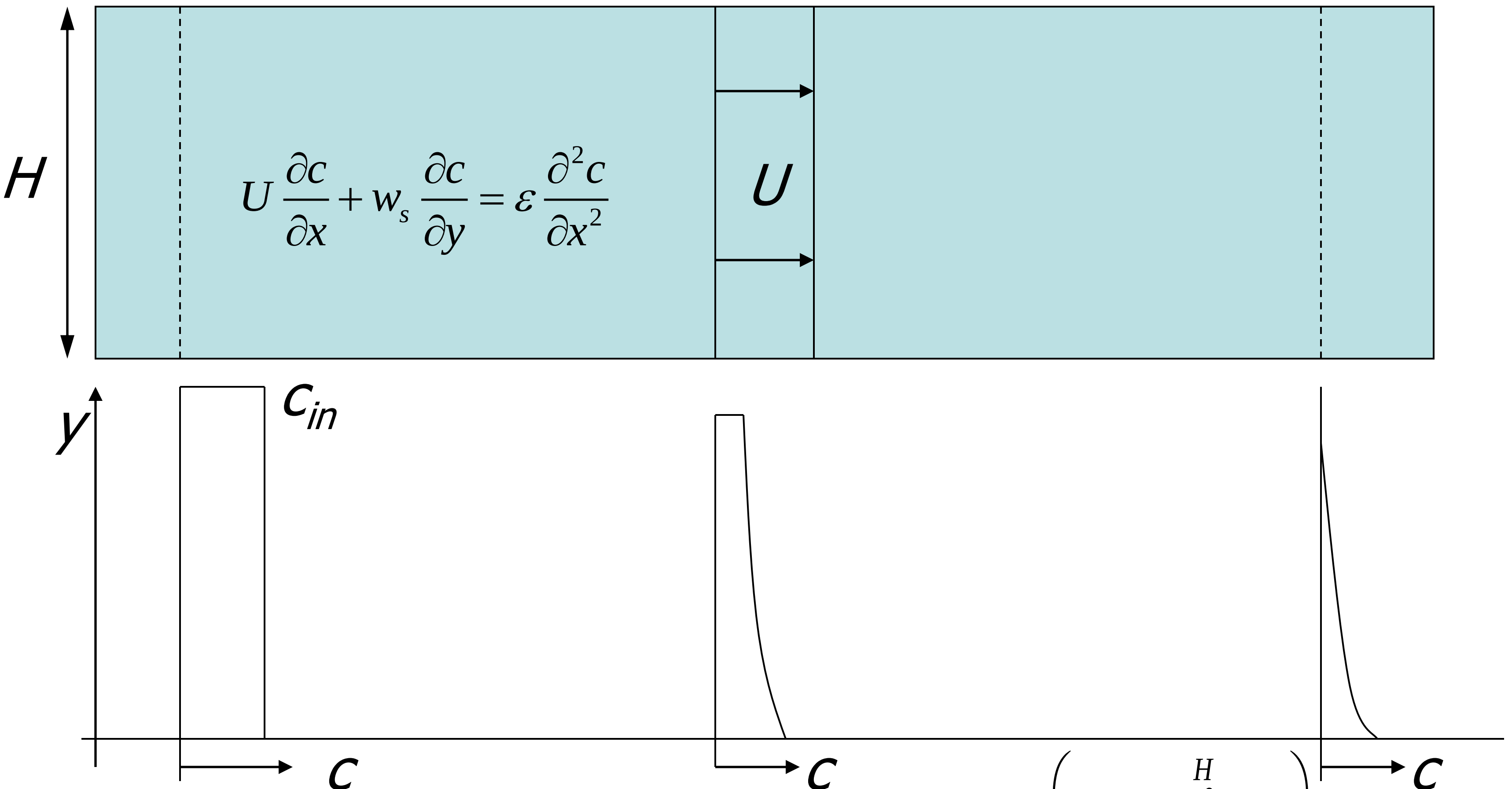
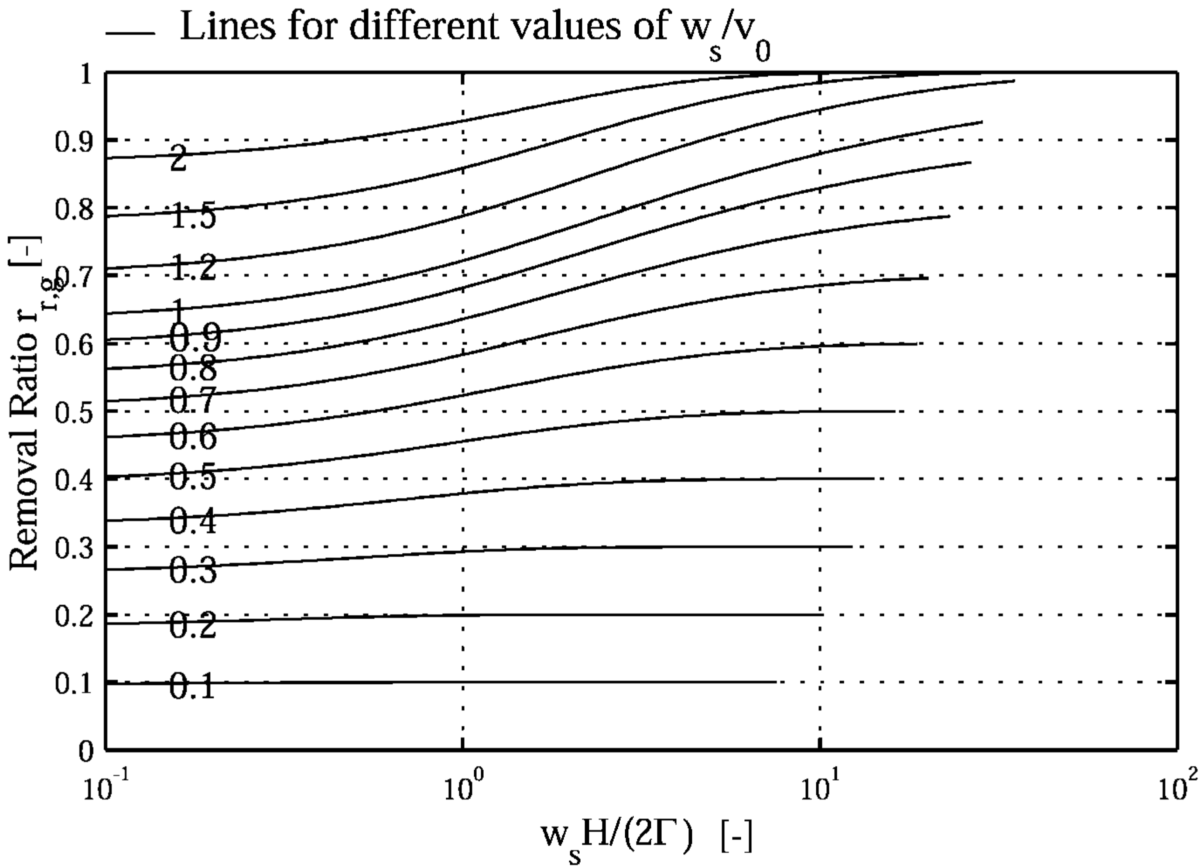


In: UHc_{in} Out: $U\int_0^H c\,dy$

$$r_r = \frac{U\left(Hc_{in} - \int_0^H c\,dy\right)}{UHc_{in}}$$



$$\Gamma = \varepsilon$$

$$\Gamma = 0.075 H u_*$$

$$u_* = \sqrt{\frac{\tau}{\rho}} = \sqrt{\frac{f}{8}}\, U$$

$$\frac{w_s H}{2\Gamma} = \frac{1}{0.15\sqrt{f/8}} \frac{w_s}{U}$$

← Increasing influence turbulence

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Influence horizontal flow velocity

- Advection (transport from inlet to outlet zone)
- Turbulence: “stirring up” of sediment
- Hindered sedimentation due to bed shear stress
    - Often called erosion or scour
- Review general sedimentation equation:

$$v_{sed} = \frac{S - E}{\rho_s \left(1 - n_0 - c\right)} \quad S = \rho_s c w_s \quad E = f\left(u, D, c, ...?\right)$$

- E is sediment pick-up

How to determine sediment pick-up ?

- Needed:
  - Velocity distribution in the hopper and especially near the bed
    - Often assumed as uniform or logarithmic
- Relation between E, shear stress, particle size and concentration
  - Problem: Conditions in a hopper very different from normal encountered in nature (high concentration)

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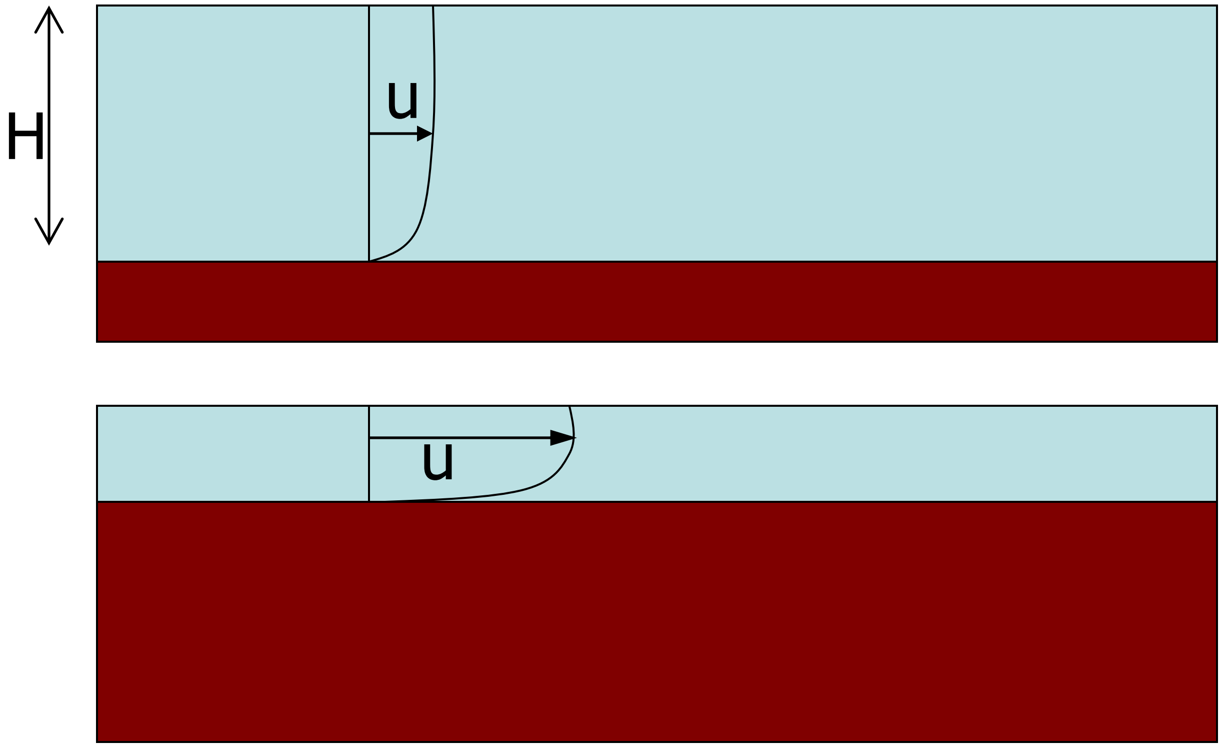
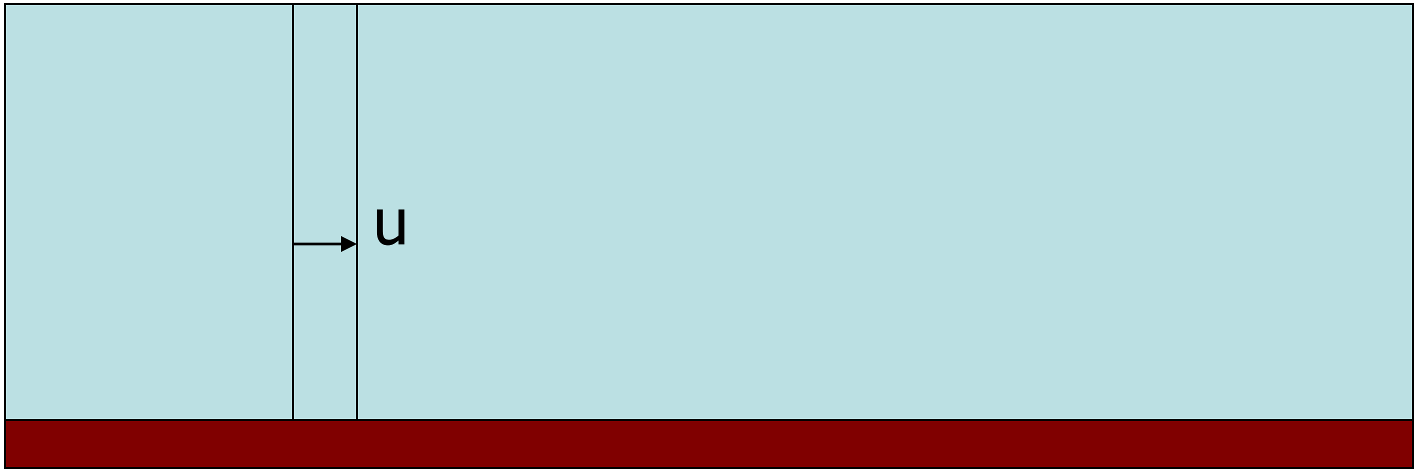
Uniform or logarithmic profile



$$\bar{u} = \frac{Q}{BH}$$

Flow velocity increases with bed level (time)

Camp Approach



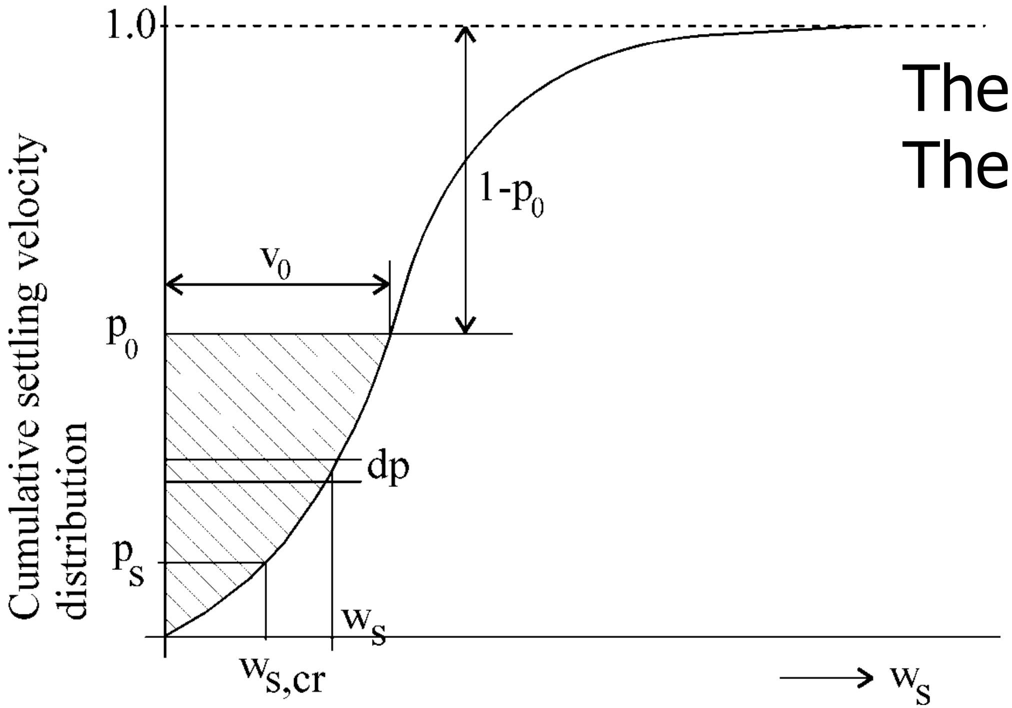
For a certain critical flow velocity a particle with a diameter D
Will not settle anymore in the bed due to bed shear stress

$$u_{cr} = \sqrt{\frac{8(1-n_0)\mu\Delta g D}{f}} \quad \rightarrow D_{cr} = \frac{f}{8(1-n_0)\mu\Delta g}u^2$$

Influence Particle Size Distribution

From a D_{cr} calculate a critical settling velocity $w_{s,cr}$

Particles with a smaller settling velocity will not settle:

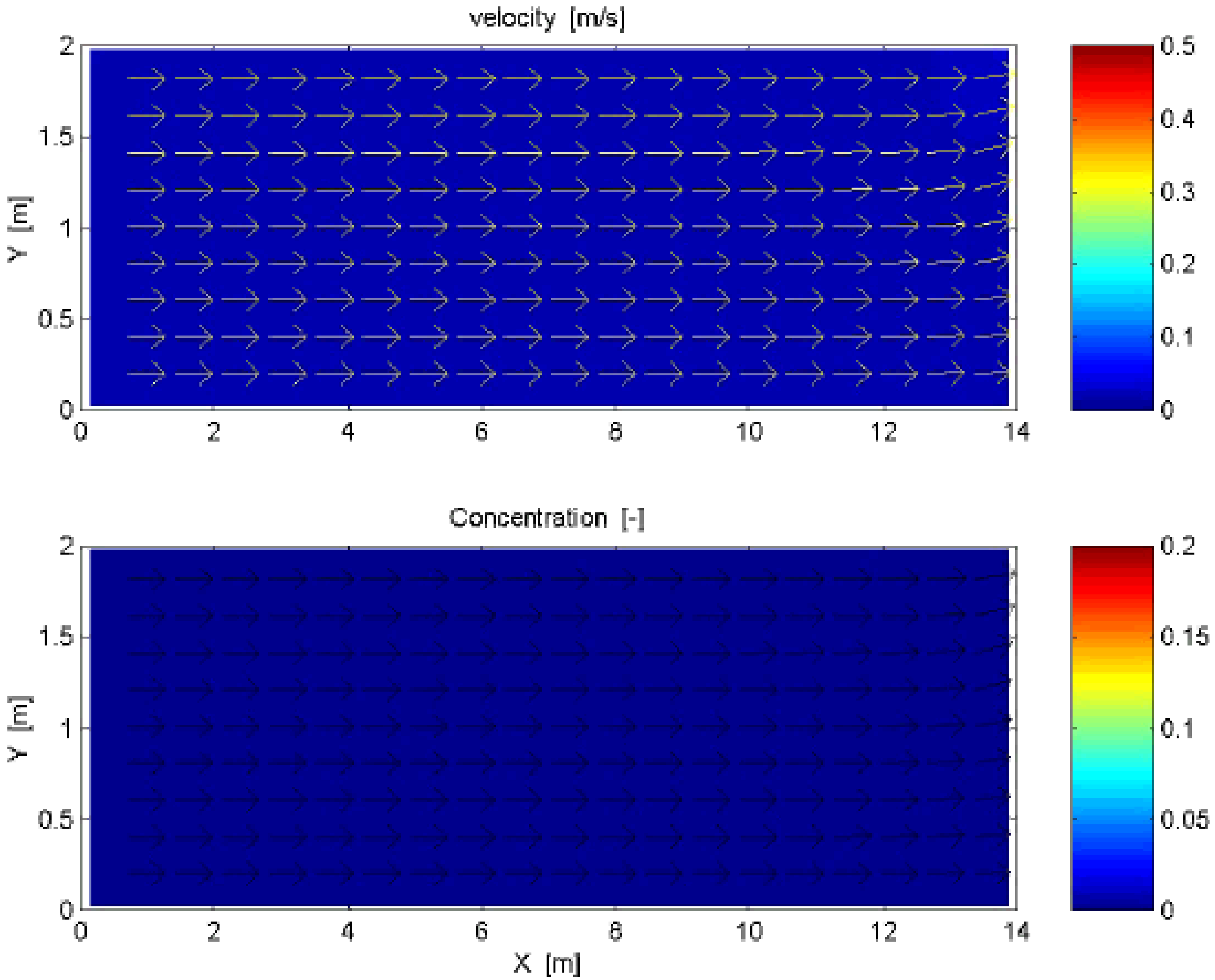


Therefore the lower boundary for
The integral is p_s

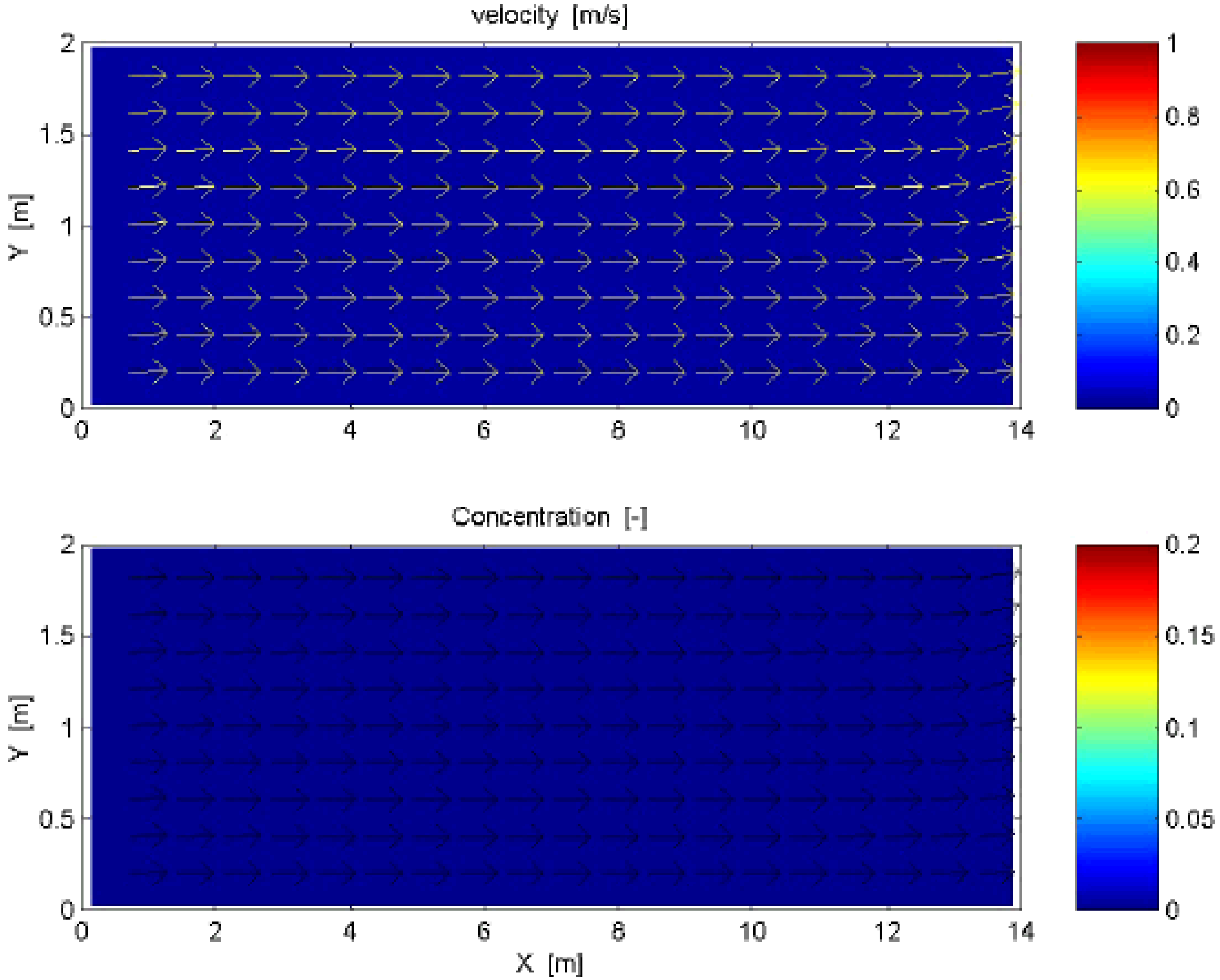
$$r_r = 1 - p_0 + \frac{1}{v_0} \int_{p_s}^{p_0} w_s \, dp$$

- In practice this method does not have large influence on results due to
  - Assumption uniform flow
  - Therefore Flow velocity < ucr
  - No influence apart from the very last loading stage (almost totally filled hopper)

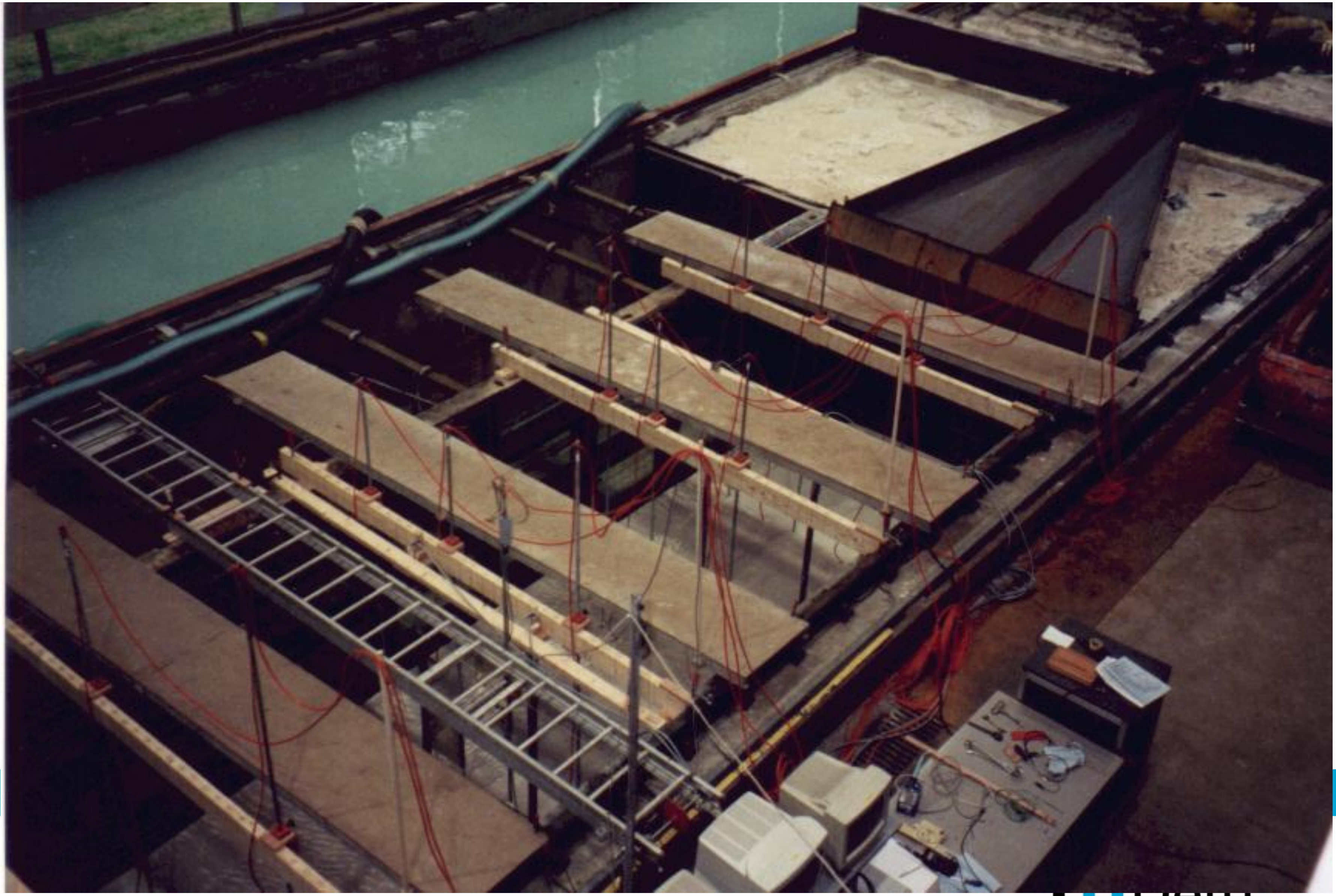
Ideal settling basin



Coupling between concentration and velocity distribution



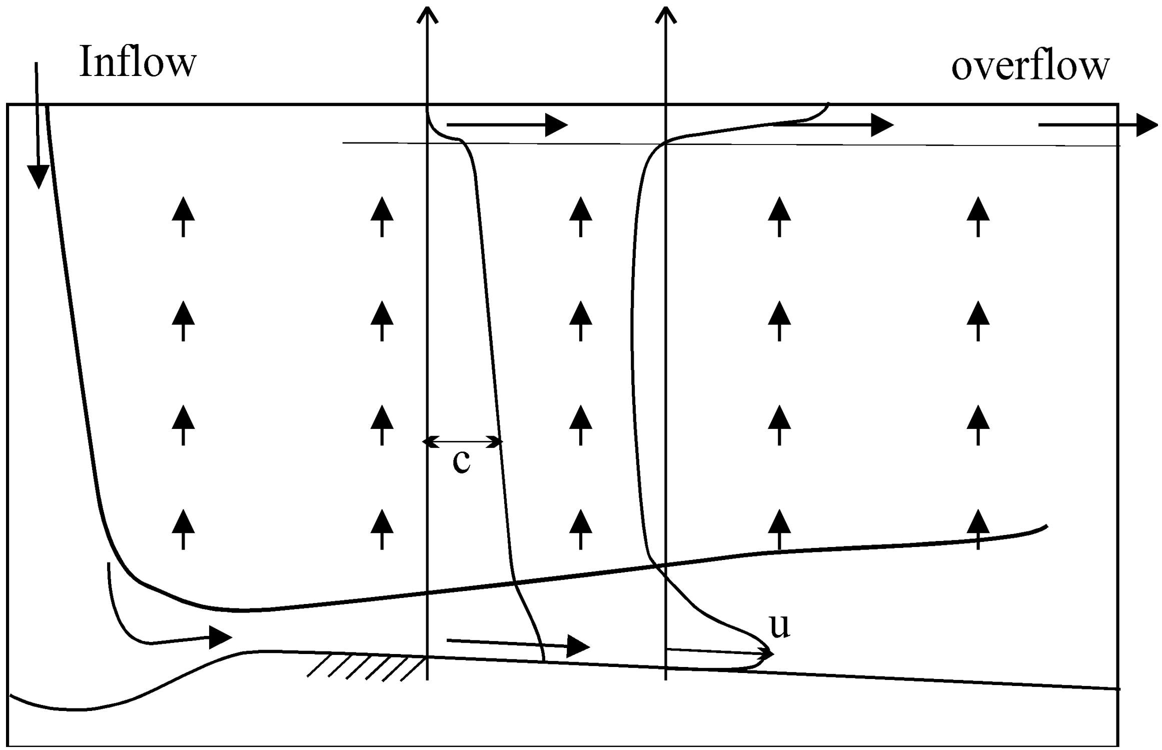
Modelhopper Top view



Modelhopper + EMS

Discharge pipe

Actual Flow Pattern



Due to difference in density flow is concentrated near the bed. Flow velocity is higher compared with uniform distribution

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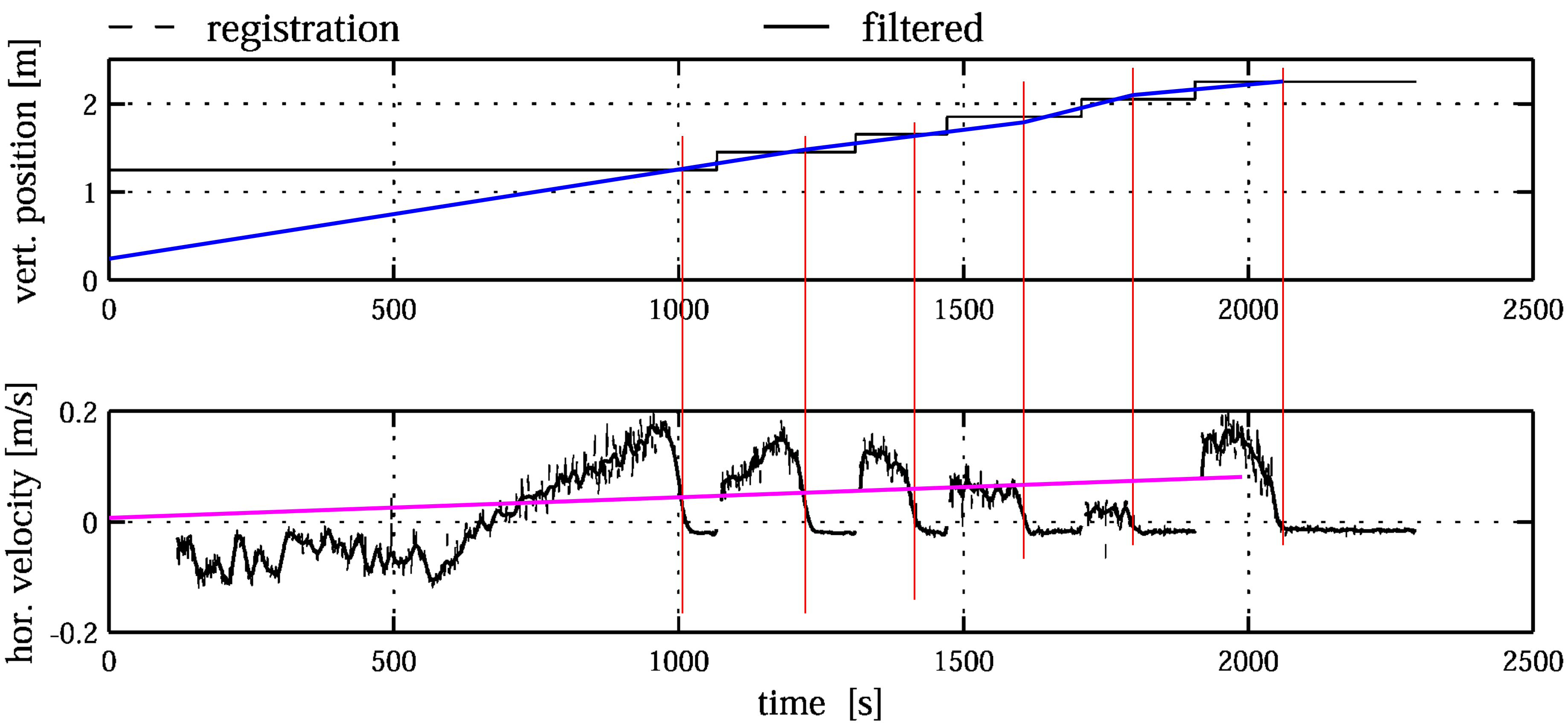
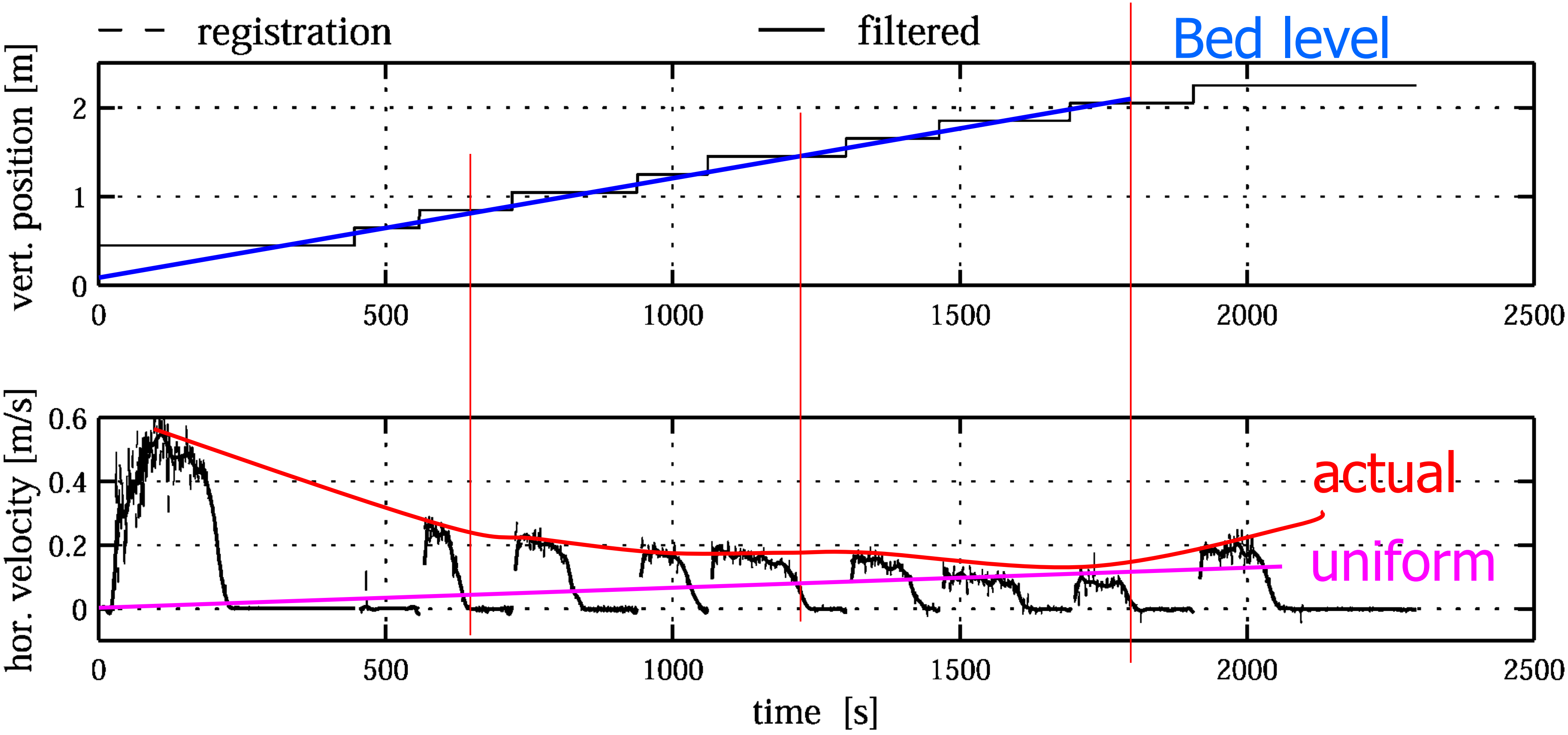
Measured flow velocity in hopper




registration
filtered
Bed level
vert. position [m]
0
1
2
0
500
1000
1500
2000
2500
hor. velocity [m/s]
0
0.2
0.4
0.6
actual
uniform
time [s]

Conclusion Camp model

- Shortcomings Camp approach:
  - Flowfield prescribed
    - In reality density currents
    - Influence bed shear stress on sedimentation
  - Inflow and outflow zone not modeled
    - Variation in location not possible
- But gives a good estimate for overflow loss for optimal loading situation

2 DV model

- In Camp model (with Turbulence) the sediment transport equations were solved using a prescribed velocity field
- Separate equations have to be solved to determine the flow field:
- 2DV **R**eynolds **A**veraged **N**avier-**S**tokes
  - mixture model (no multi-phase flow)
- Hydrodynamic (non-hydrostatic)
- Coupling momentum - sediment transport equations
  - Buoyancy (density currents)
- k-eps turbulence modelling

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2 DV model (continued)

- Moving bed
  - Erosion - Sedimentation boundary condition
- Moving Water surface
  - filling of hopper, variation overflow level
- influence PSD by n fractions mutually coupled
- Loading and Discharge location
  - variation of position and quantity (in time)
  - Inlet conditions (velocity, turbulence intensity)

Reynolds Averaging:

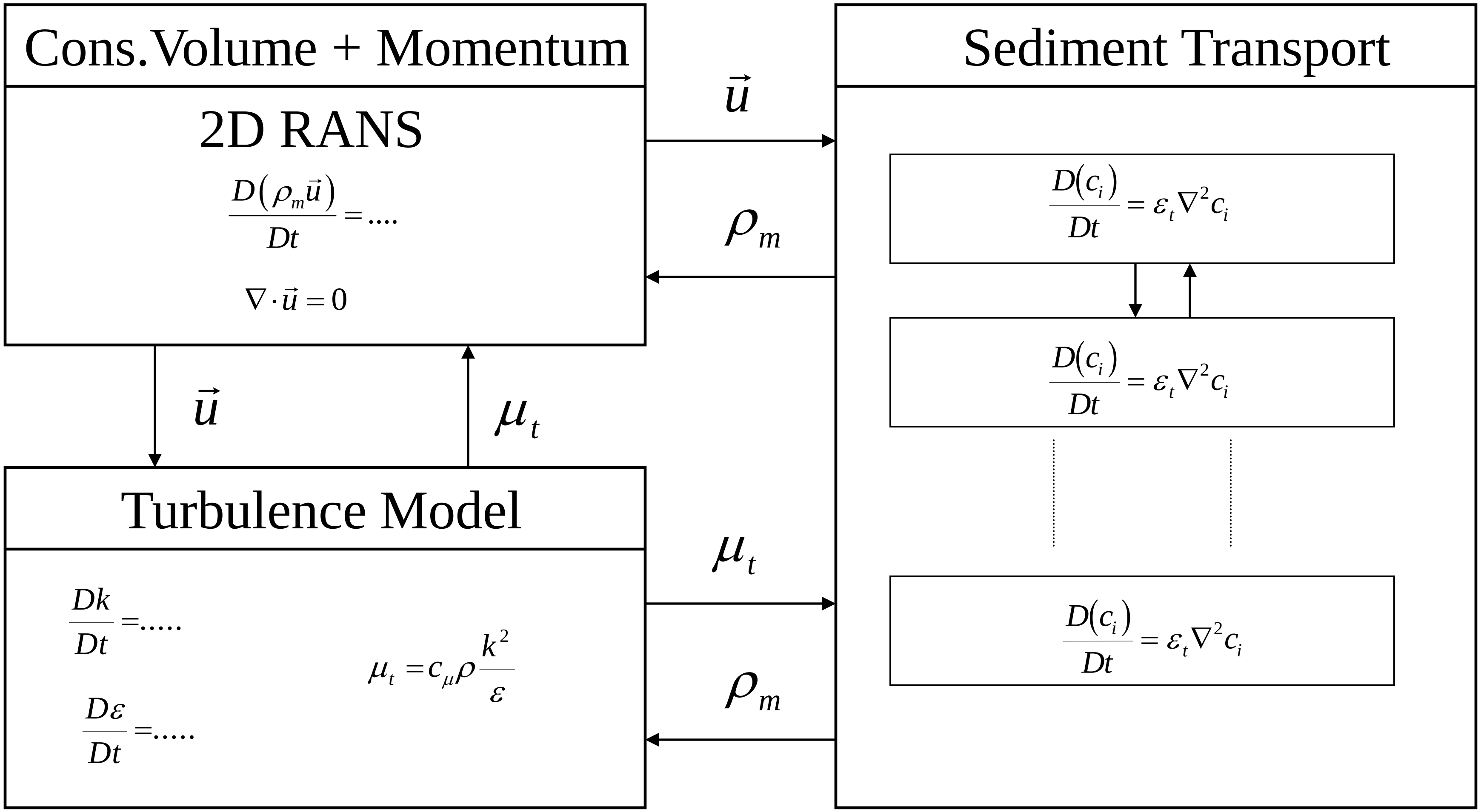
- Reynolds stresses are assumed to be analog to viscous stresses, for instance

$$\overline{\rho u'w'} = -\rho \nu_e \frac{\partial u}{\partial z}$$

- 'eddy viscosity'

$$\nu_e = c_\mu \frac{k^2}{\varepsilon}$$

Overview 2DV Model



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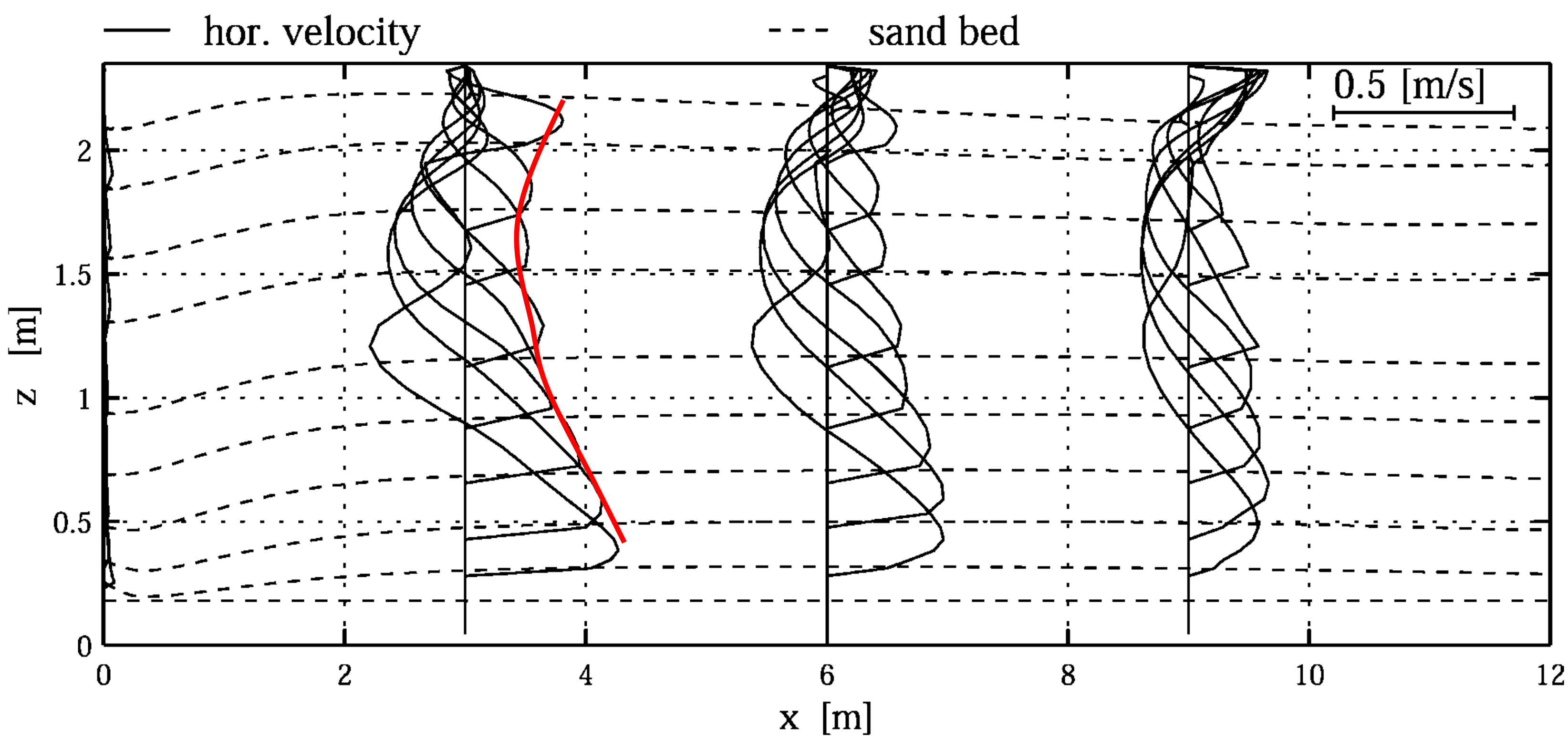
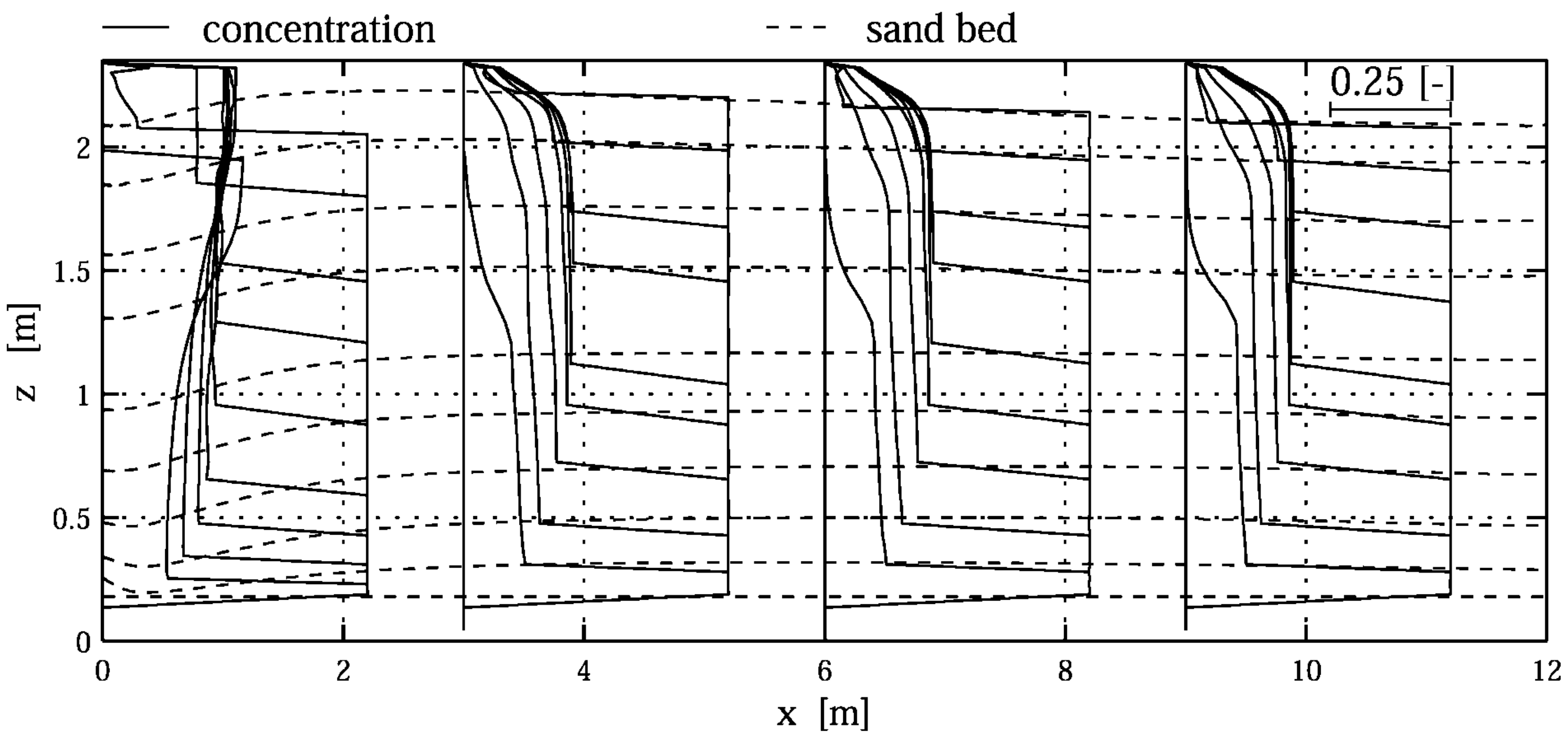
Computed hor. Velocity in hopper



Computed Concentration in the hopper



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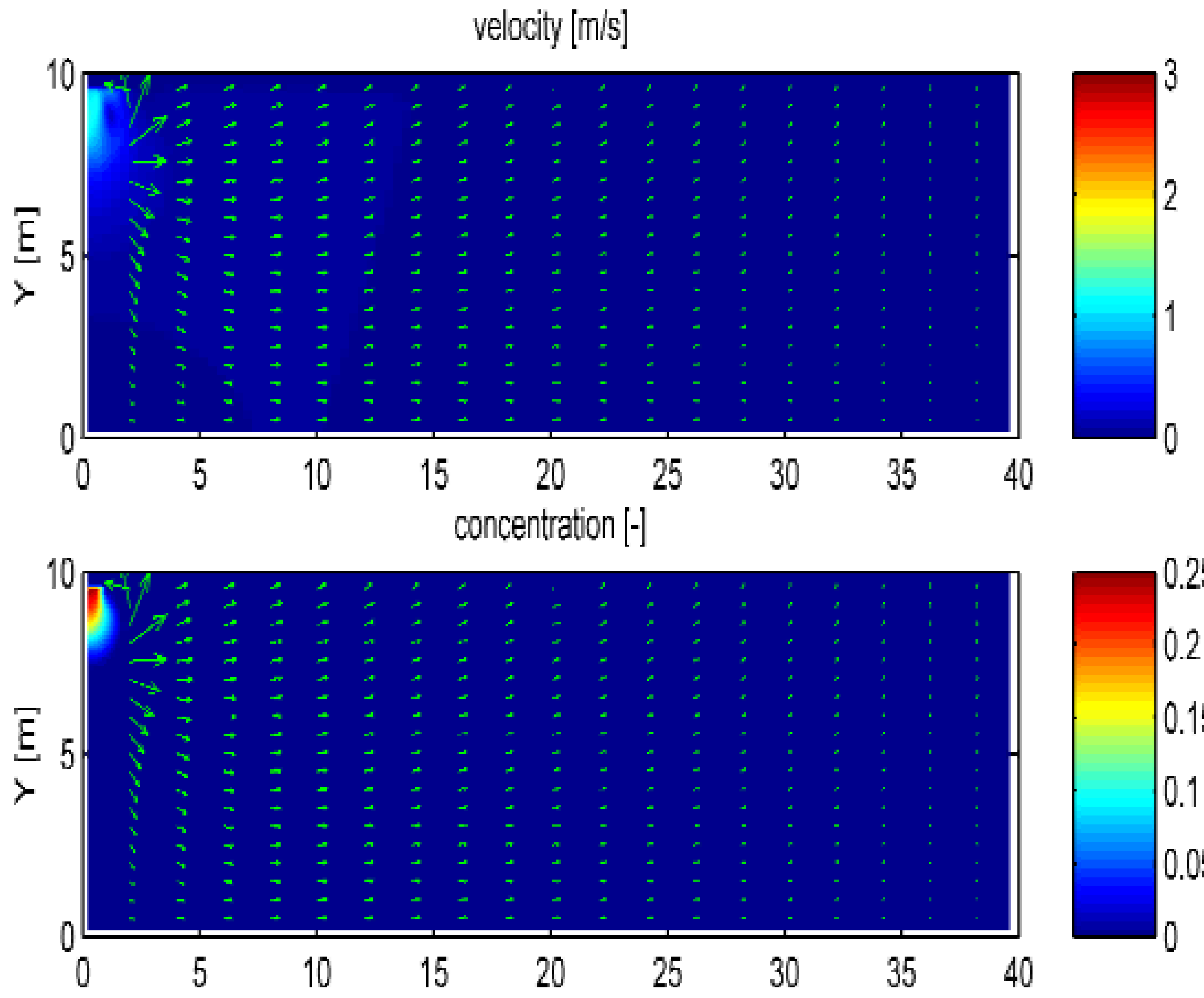
velocity [m/s]
Y [m]
10
5
0
0
5
10
15
20
25
30
35
40
3
2
1
0
concentration [-]
Y [m]
10
5
0
0
5
10
15
20
25
30
35
40
0

Modelling the hopper sedimentation process

- Very simple 'model':
- If s_{sed} is the mass settling in the bed and s_{in} the mass of sediment loaded in the hopper one could expect that :
- $OV=f(s_{in} / s_{sed})$

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- Inflow mass: $$s_{in} = \rho_s Q c_{in}$$
- Settling flux: $$s_{sed} = \rho_s \left(1 - n_0\right) v_{sed} BL$$
- BL = width * Length of hopper
- With : $$v_{sed} = \frac{S - E}{\rho_s \left(1 - n_0 - c\right)} \qquad S = \rho_s c w_s$$
- ratio $$\frac{s_{in}}{s_{sed}} = \frac{1 - n_0 - c}{1 - n_0} \cdot \frac{c_{in}}{c w_s - E / \rho_s} \cdot \frac{Q}{BL}$$

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•In case E=0 (no erosion)

$$S^* = \frac{s_{in}}{s_{sed}} = \frac{c_{in}}{c} \cdot \frac{1-n_0-c}{1-n_0} \cdot \frac{Q}{w_s BL} \qquad H^* = \frac{Q}{w_s BL}$$

•S* is a product of a function f(c) and the dimensionless overflow rate H*

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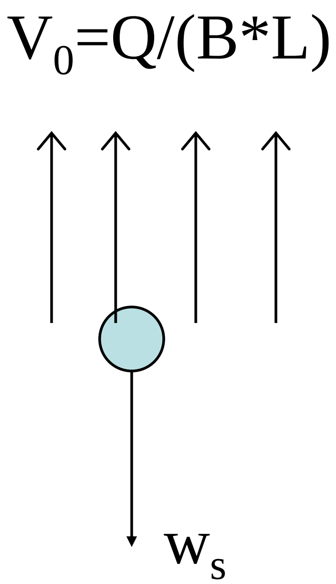
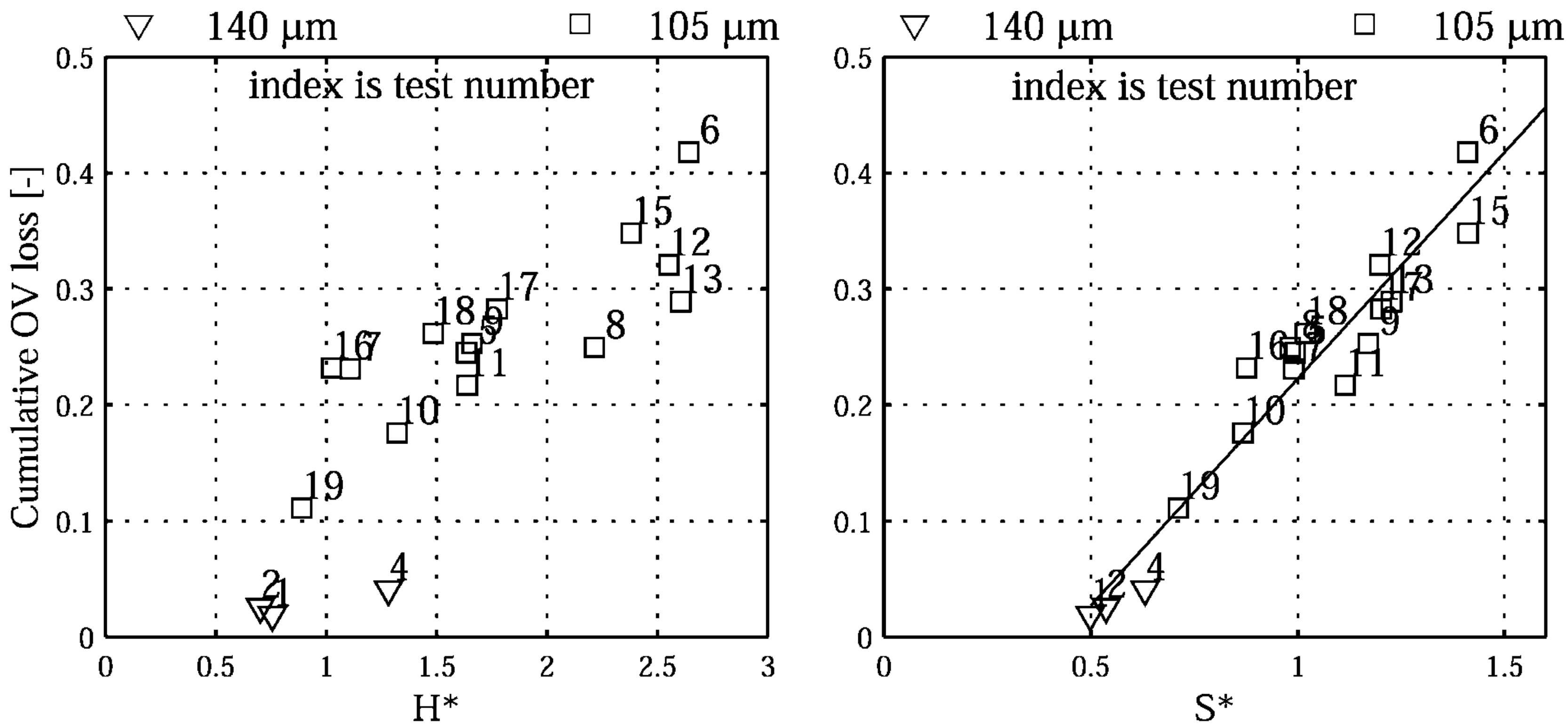


Ratio between vertical velocity and settling velocity:

$$H^* = \frac{v_0}{w_s} = \frac{Q}{BLw_s}$$

Cum OV versus H* en S* (Lab tests)



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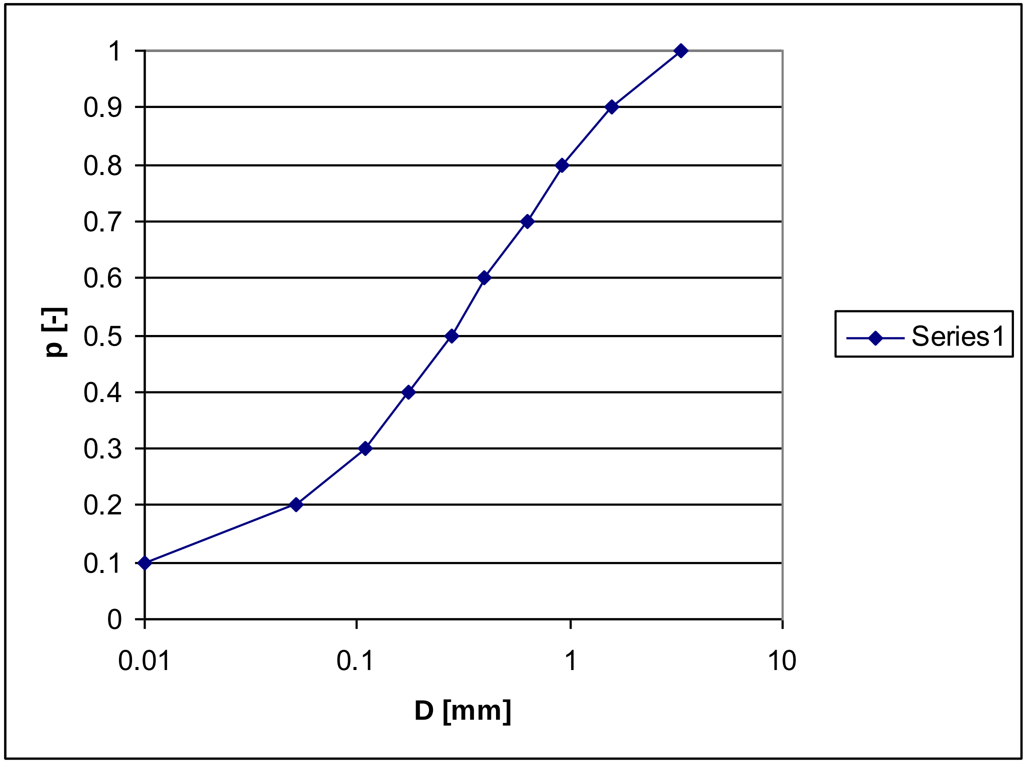
example

- Hopper (HAM 318 old):
- L= 79.2 B = 22.5
- Q= 14 m^3/s

- PSD →



Example Camp no turbulence and no hindered settling

L= 79.2 m
B= 22.5 m
Q= 14 m

v0 7.856341 mm/s

fraction	p	D	w0	w0/v0	r_g	r_r
			mm/s	[-]		
	[-]	[mm]				
1	0.1	0.01	0.06	0.007	0.007217	0.000722
2	0.1	0.052	1.53	0.195	0.195065	0.019507
3	0.1	0.11	6.86	0.873	0.872645	0.087265
4	0.1	0.174	14.09	1.794	1	0.1
5	0.1	0.275	29.69	3.779	1	0.1
6	0.1	0.398	50.26	6.398	1	0.1
7	0.1	0.631	87.33	11.116	1	0.1
8	0.1	0.912	126.07	16.047	1	0.1
9	0.1	1.585	199.40	25.380	1	0.1
10	0.1	3.311	329.71	41.967	1	0.1
					total:	0.807493
					Ov_cum=	19%

Camp no turbulence , including hindered settling

L=	79.2	m
B=	22.5	m
Q=	14	m
c_in	0.17	[-]
v0	7.856341	mm/s

fraction	p	D	ws	ws/v0	r_g	r_r
			mm/s	[-]		
	[-]	[mm]				
1	0.1	0.01	0.02	0.003	0.003004	0.0003
2	0.1	0.052	0.65	0.082	0.082367	0.008237
3	0.1	0.11	3.03	0.385	0.385345	0.038534
4	0.1	0.174	6.65	0.847	0.847048	0.084705
5	0.1	0.275	15.29	1.946	1	0.1
6	0.1	0.398	27.58	3.510	1	0.1
7	0.1	0.631	50.84	6.471	1	0.1
8	0.1	0.912	75.84	9.653	1	0.1
9	0.1	1.585	124.25	15.815	1	0.1
10	0.1	3.311	210.61	26.807	1	0.1
					total:	0.731776
					Ov_cum=	27%

Calculation of PSD in hopper

1	2	3	4	5		
				=4*1	=5/Sum	
p	p_cum	D	r_g	r_r	frac in hopp	frac in hopp cumulative
0.1	0.1	0.01	0.003	0.000	0.000	0.000
0.1	0.2	0.052	0.082	0.008	0.011	0.012
0.1	0.3	0.11	0.385	0.039	0.053	0.064
0.1	0.4	0.174	0.847	0.085	0.116	0.180
0.1	0.5	0.275	1.000	0.100	0.137	0.317
0.1	0.6	0.398	1.000	0.100	0.137	0.453
0.1	0.7	0.631	1.000	0.100	0.137	0.590
0.1	0.8	0.912	1.000	0.100	0.137	0.727
0.1	0.9	1.585	1.000	0.100	0.137	0.863
0.1	1	3.311	1.000	0.100	0.137	1.000
			Sum:	0.731776		

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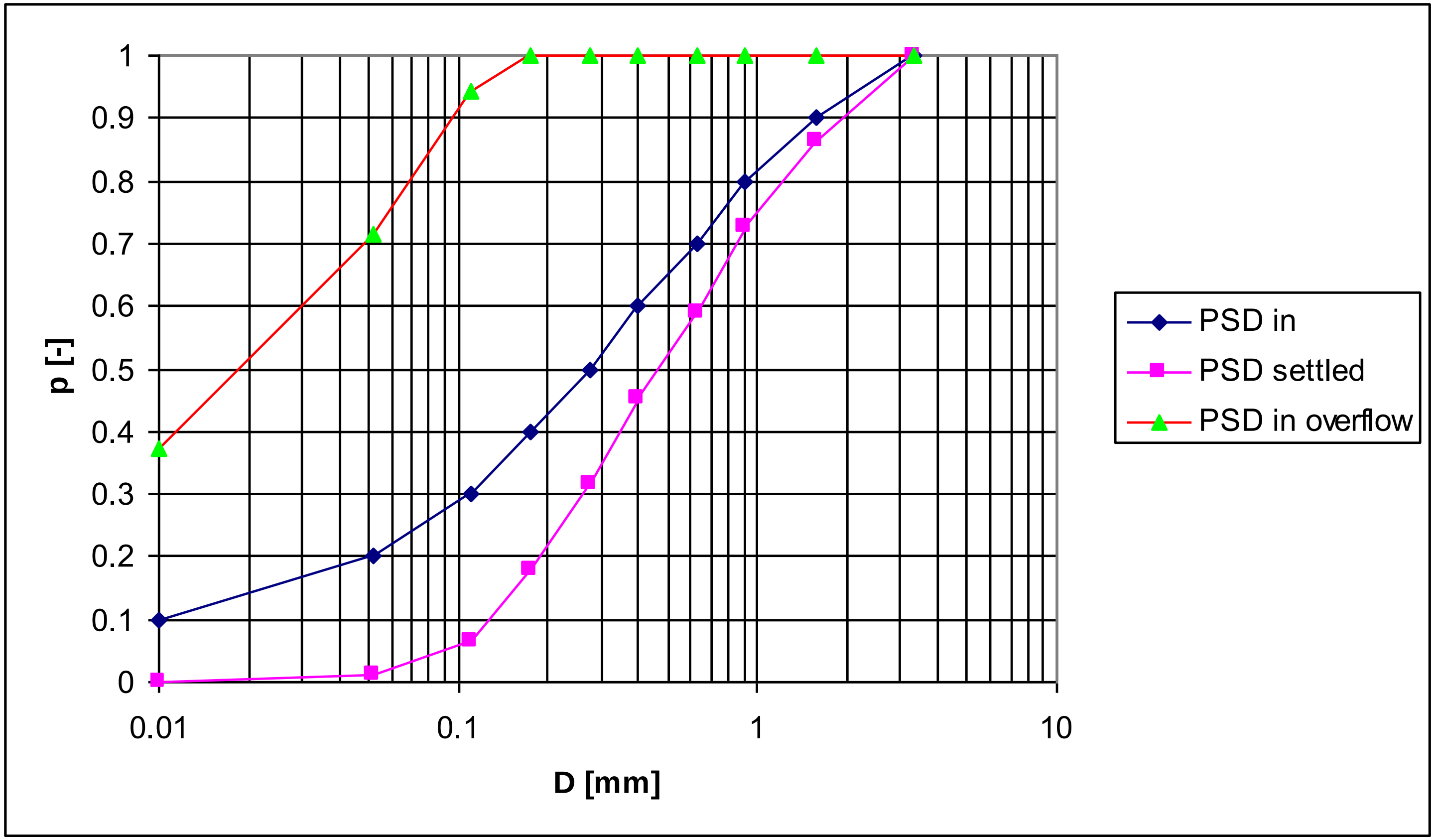
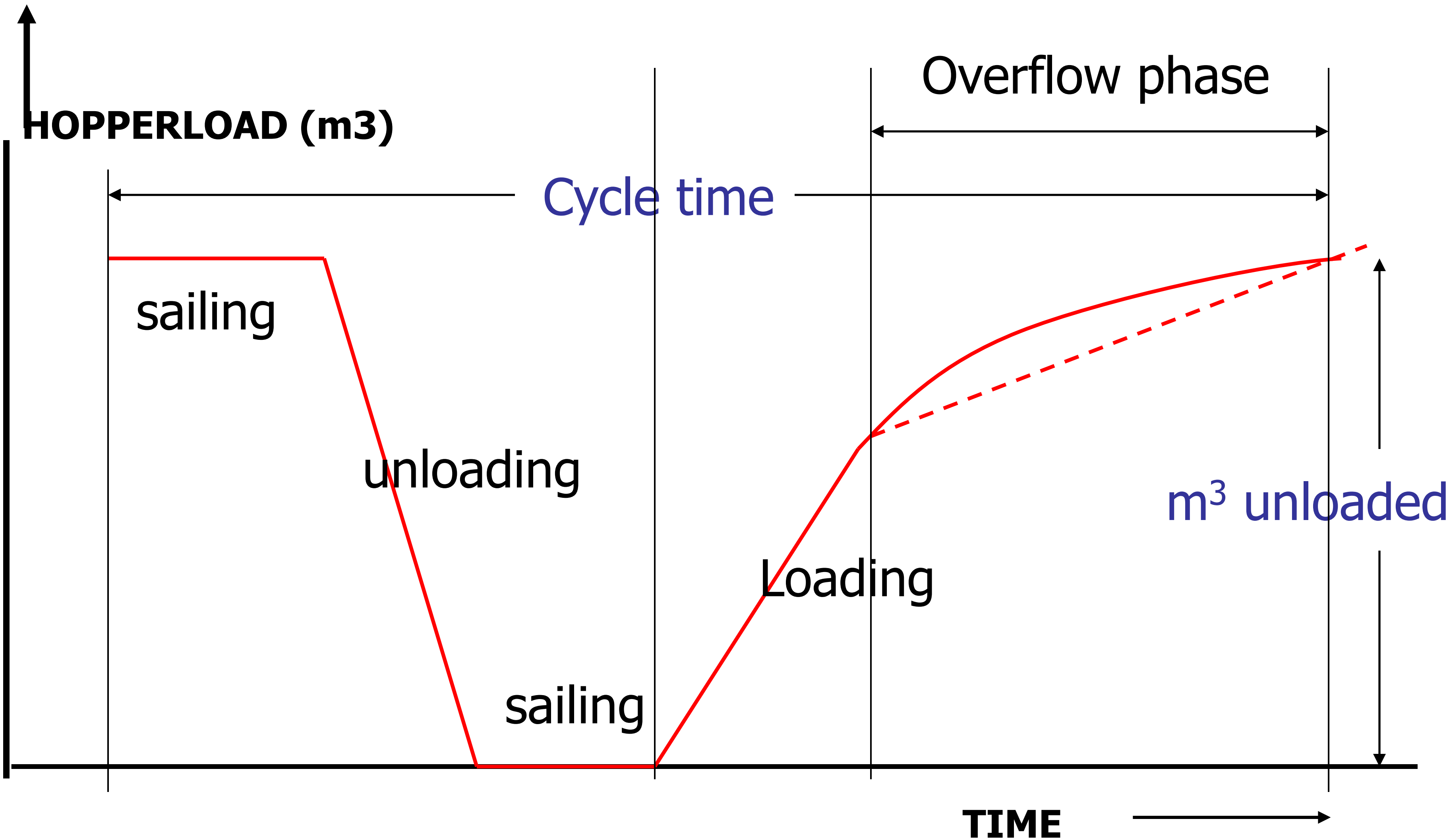
PSD's



1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
p [-]
0.01
0.1
1
10
D [mm]
PSD in
PSD settled
PSD in overflow

Optimal loading time



Overflow phase
HOPPERLOAD (m3)
Cycle time
sailing
unloading
m3 unloaded
Loading
sailing
TIME

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Cycle production

$$P_{cycle} = \frac{m^3 unloaded}{cycle\ time} \quad \left[m^3 / s \right]$$

Ham 318		
hopper load	20,000	m3
Sailing empty	300	min
Loading	70	min
Sailing loaded	330	min
Unloading	15	min
turning etc.	10	min
Total	725	min
Cycle. Prod	27.59	m3/min

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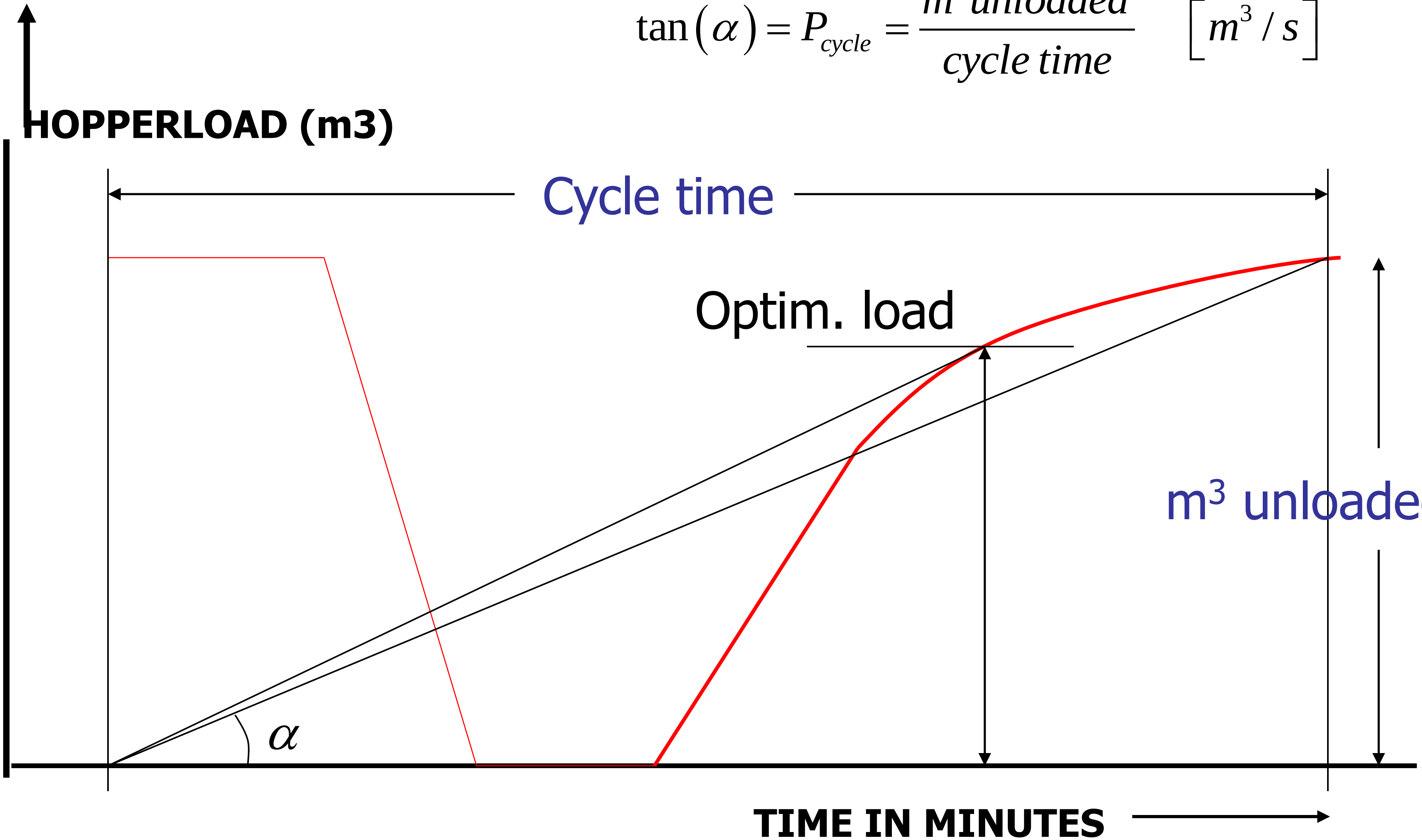
$$\tan(\alpha) = P_{cycle} = \frac{m^3 unloaded}{cycle\ time} \quad \left[m^3/s\right]$$



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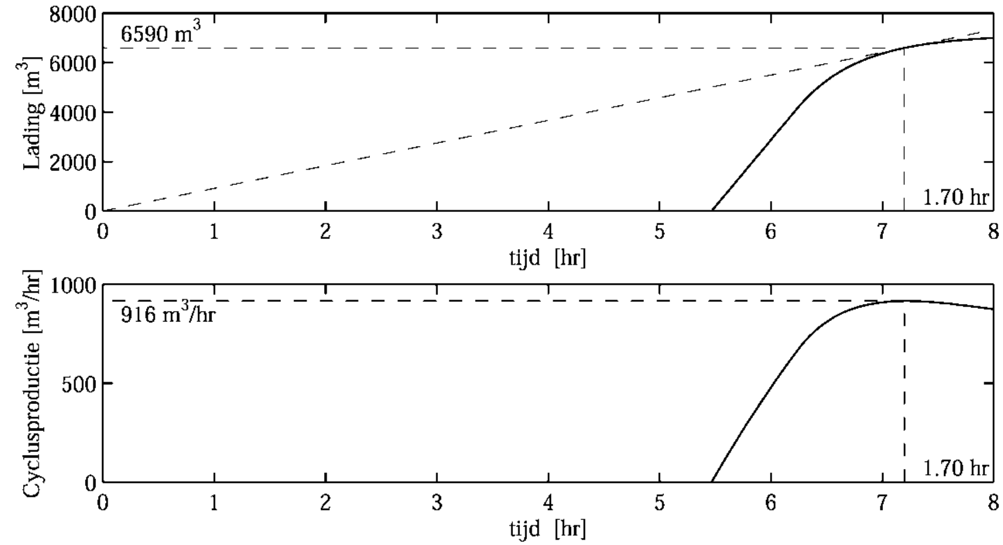
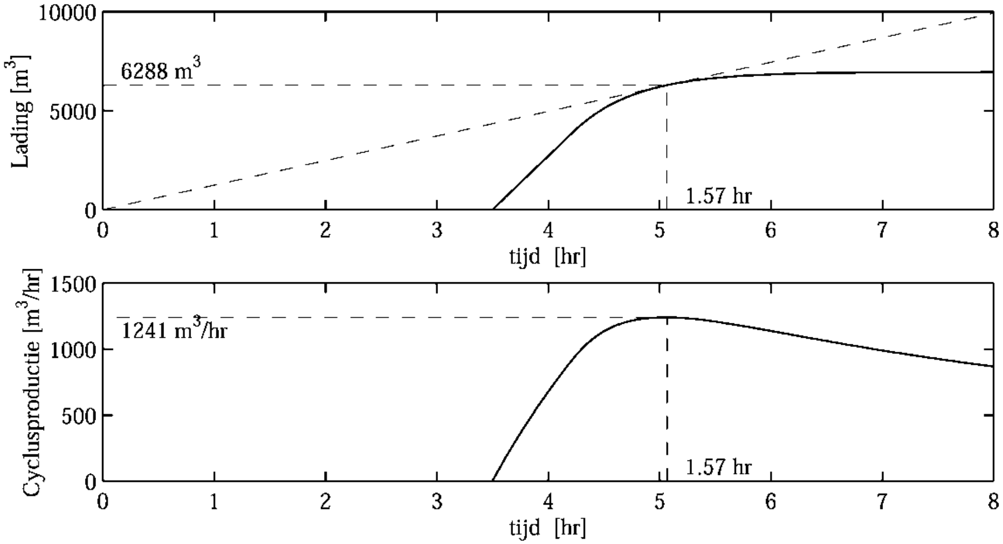


Long sailing distance



Short sailing distance

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Questions?

Sources images

1. Trailing Suction Hopper Dredger, source: unknown.
2. Rotterdam, source: Van Oord.
3. HAM 318, source: Van Oord.
4. HAM 311, source: Van Oord.
5. Maasvlakte 2, source: Royal Haskoning.
6. The World, Dubai. Source: unknown.
7. Federation Island, Sochi, Russia. Source: Russkie Prostori.