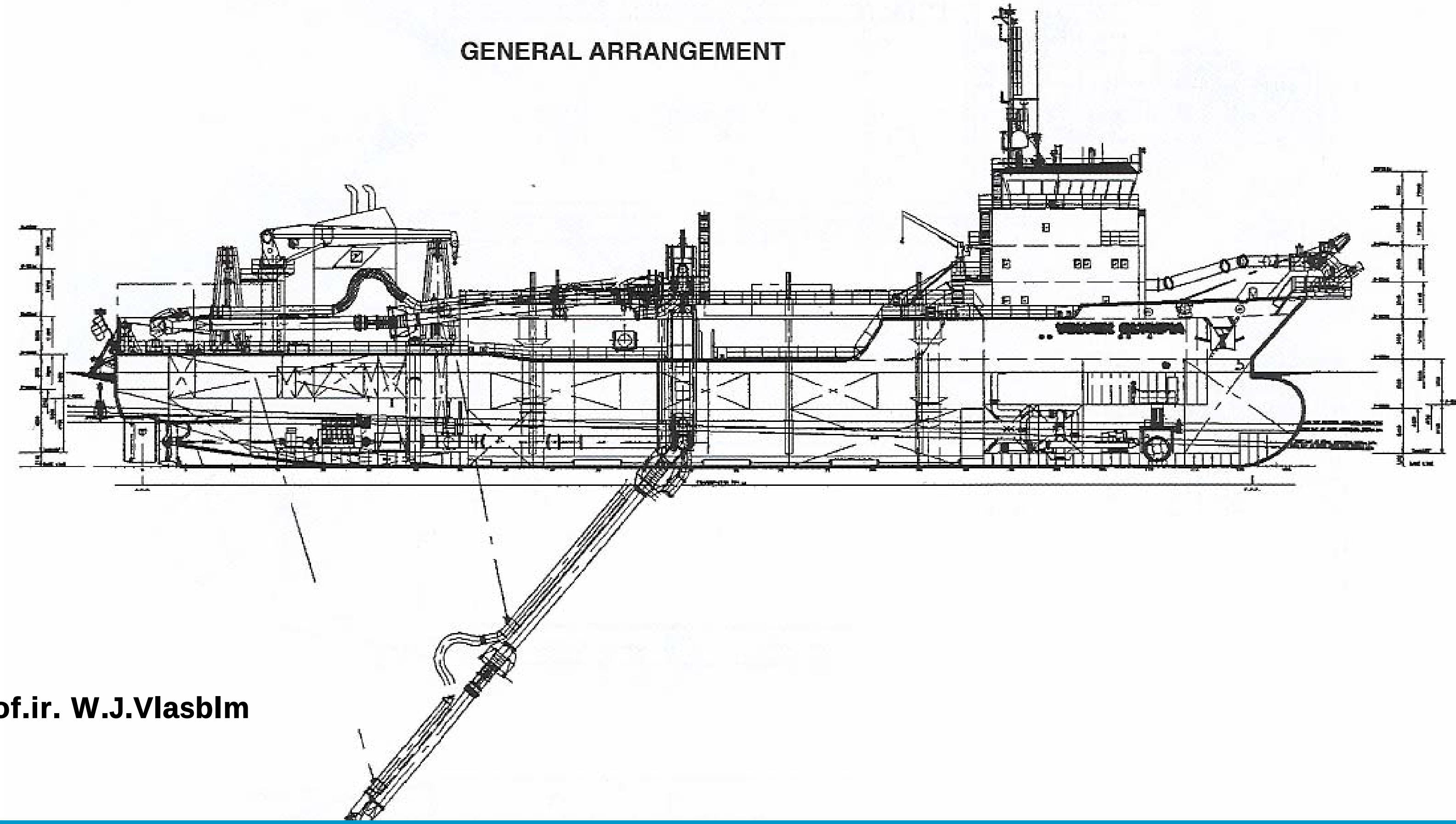
Designing Dredging Equipment
OE4671/WB3408



Prof.ir. W.J.Vlasblm

12 September 2006

Section Dredging engineering

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Purpose of the lecture

- To design a particular type of dredger on basis of (simple) dredging processes.
- Such a method can be used for many design problems!

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Course development

- Introduction lecture in the 5^{th} quarter
- Assignment for one or two persons can be done the whole year around.
- Total 4 credits (ECT)

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Assignments for hydraulic dredgers

- Trailing Suction Hopper Dredger (TSHD) for large reclamation works
- Multi Purpose TSHD for maintenance and beach nourishments
- Gravel Trailing Suction Hopper Dredgers
- Cutter Suction Dredger
- Environmental Dredger
- Plain Suction Dredger
- Dustpan Dredger

Assignments for mechanical dredgers

- The backhoe dredger
- The grab dredger
- Bucket ladder dredger

Trailing Suction Hopper Dredger

Cutter Dredger

Plain Suction Dredger

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Plain Suction Dredger

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Dustpan Dredger

The Environmental Dredger

The Backhoe Dredger

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The Grab or Clamshell Dredger

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Bucket Ladder Dredger

Work Load

The assignment for

- the TSHD, CSD are for 2 students
- The other ones are for 1 student

Designing Dredging Equipment

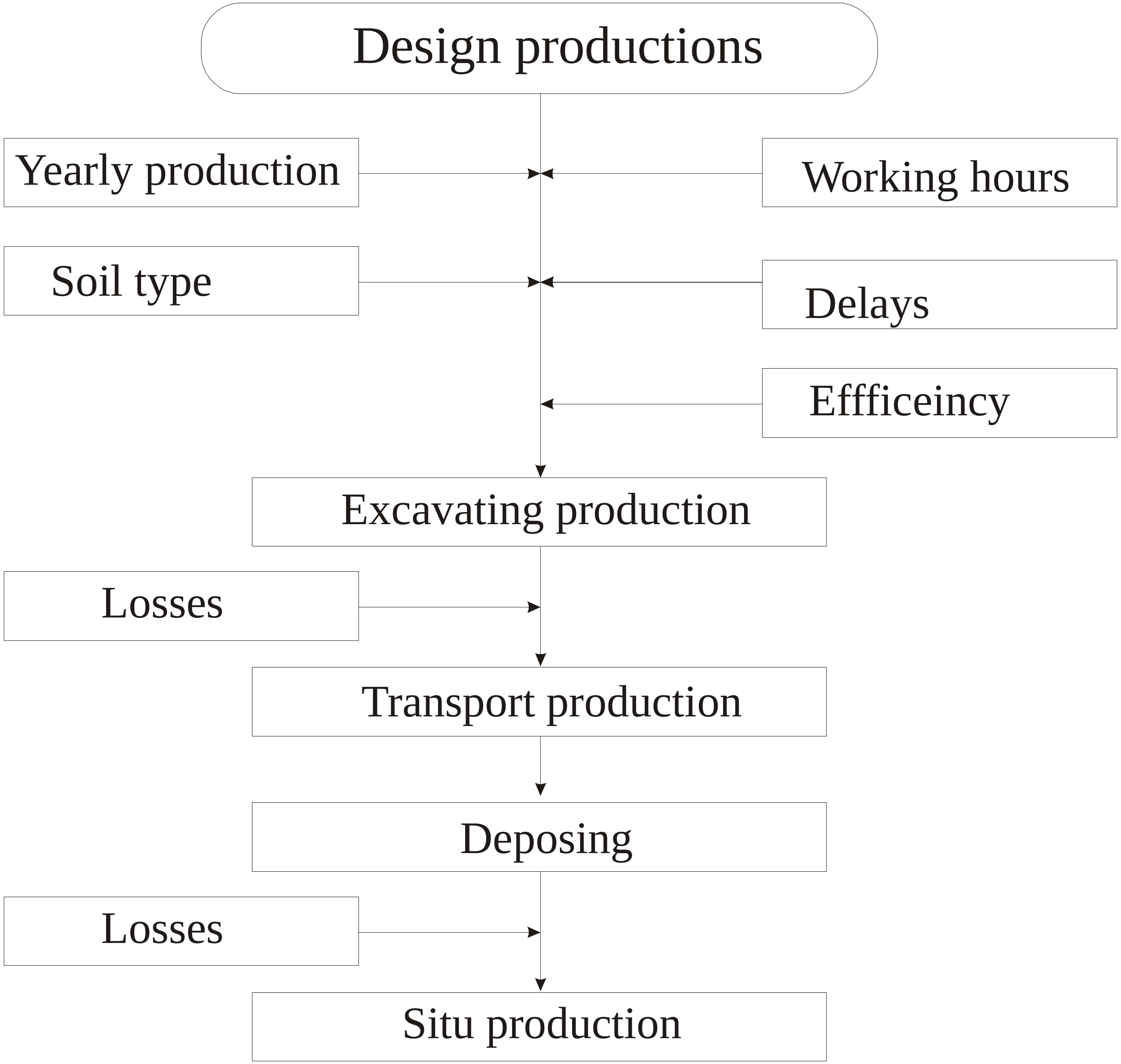
Productions

Dredging installation

Propulsion (optional)

Prime movers (main engines)

General layout


Design productions
Yearly production
Working hours
Soil type
Delays
Effficeincy
Excavating production
Losses
Transport production
Deposing
Losses
Situ production

Design basis = yearly output in m^3 (production)

- To be translated to the significant design parameters.
- Depends on the scale (or cycle) of the process.
- Large scales
  - Hopper dredger $\Rightarrow$ volume and load per trip
  - Barge unloader dredger $\Rightarrow$ Barge volume
  - Backhoe dredger $\Rightarrow$ the volume per cycle
- Continuous operating dredgers or equipment m^3/week or m^3/month

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Design Basis (2)

- Small scale:
  - “Wall” speed of a breach — mm/s
  - Pump — output in m^3/s
  - Cutter head — Excavated output in m^3/s
  - Bucket ladder dredger — Buckets/min
  - Backhoe dredger — Bucket volume/cycle
  - Grab dredger — Grab volume/cycle

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Problems during translation

- Change of volumes
- In many cases the contractor is paid in volumes removed, but many processes are based on mass.
- Working hours per week (168 or 84 or 40)
- Down time
- Overhaul & Maintenance
- Bunkering, crew changes, etc
- Delays due to weather conditions

Concentration (1/3)

- By volume $$C_v = \frac{Volume\ sand}{Mixture\ volume} = \frac{U_s}{U_m}$$
- By weight $$C_w = \frac{Sand\ mass}{Mixture\ mass} = \frac{\rho_s U_s}{\rho_m U_m} = \frac{\rho_s}{\rho_m} C_v$$
- Delivered $$C_{vd} = \frac{U_s / time}{U_m / time} = \frac{Q_s}{Q_m}$$

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Concentrations (2/3)

- Ratio between C_{vd} & C_v follows from:

$$C_{vd} = \frac{Q_s}{Q_m} = \frac{v_s A C_v}{v_m A} \Rightarrow \frac{C_{vd}}{C_v} = \frac{v_s}{v_m}$$

- Ratio between C_w & C_v

$$C_w = \frac{\rho_s}{\rho_m} C_v \quad \Rightarrow \quad \frac{C_w}{C_v} = \frac{\rho_s}{\rho_m}$$

Concentrations (2/3)

$$\frac{C_{vd}}{C_v} = \frac{v_s}{v_m}$$

- In horizontal transport $v_s < v_m \rightarrow$ slip
- In vertical transport $v_s \approx v_m$ the difference is the settling velocity

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Mixture Densities $\Leftrightarrow$ Volumetric Concentration

- $\text{Mass}_{\text{mixture}} = \text{mass}_{\text{liquid}} + \text{mass}_{\text{solids}}$

$$\rho_m U_m = \rho_f U_f + \rho_s U_s \ \ with \ \ C_v = \frac{U_s}{U_m}$$

$$\rho_m = \rho_f (1 - C_v) + \rho_s C_v$$

$$C_v = \frac{\rho_m - \rho_f}{\rho_s - \rho_f}$$

"Note U is volume"

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Volume changes

- When removing soil the insitu density will change; mostly from a dense to a loose state
  - $\Rightarrow$Increase in porosity; f.I. From 40 to 50%
  - $\Rightarrow$Porosity n is ratio pore volume over total volume
  - $\Rightarrow$Condition: $V_1(1-n_1)=V_2(1-n_2)$

Examples:

- $\Rightarrow$Sand; $n_1=0.4$ and $n_2=.5$ gives $V_2/ V_1=0.6/0.5=1.2$
- $\Rightarrow$Rock; $n_1=0$ and $n_2=.4$ gives $V_2/ V_1=1/0.6=1.7$

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Losses

Every dredging process can have losses, called spillage

- More excavated than picked up by the flow or bucket
- Non removed loads in TSHD’s, particular when the loads is pumped ashore or rainbowed.
- Unstable slopes after dredging (plain suction dredgers)
- In accurate placing of material
- Losses due to current and waves

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Excavating production

Mechanically

Hydraulically

Mechanical excavation
Specific Energy Concept (SPE)

Energy required to excavated 1m^3 of soil

Dimension is Joule/m^3

or per unit of time J/s/m^3/s=W/m^3/s,

That equals a power over production

$$SPE = \frac{power}{production} \Rightarrow \; power = SPE \times production$$

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Mechanical Excavating

Mechanical Excavating

Mechanical Excavating

Hydraulic excavation
Momentum of flow

A reasonable assumption is that the jet- production is linear with the total momentum flux of the jet system independent of the trail speed.

$$Q_{sand} = (1-n)Q_{dredged}$$

$$M_{sand} = Q_{sand}\rho_{sand} = (1-n)Q_{dredged}\rho_{sand}$$

$$\mathrm{M}_{\mathrm{sand}} = \alpha \cdot \mathrm{I} = \alpha\rho_{\mathrm{w}} \cdot \mathrm{Qu} = \alpha\rho_{\mathrm{w}} \cdot \mathrm{Q}\sqrt{\frac{2\mathrm{p}}{\rho_{\mathrm{w}}}} = \alpha\sqrt{2\rho_{\mathrm{w}}}\,\frac{\mathrm{P}_{\mathrm{power}}}{\sqrt{\mathrm{p}_{\mathrm{pressure}}}}$$

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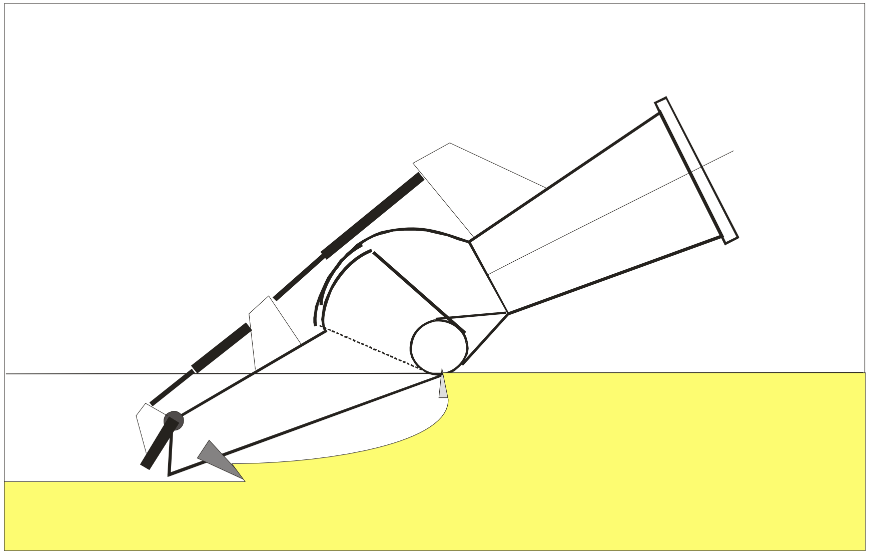
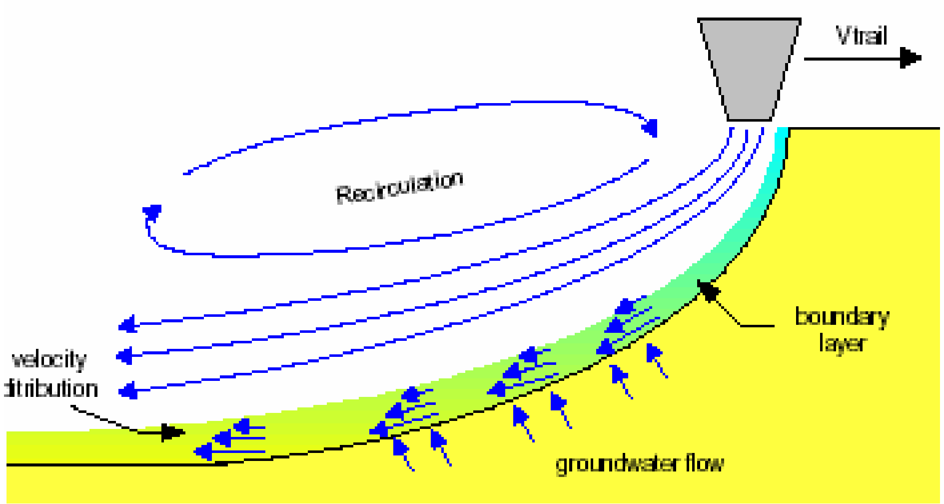
Excavation by dragheads is hydraulically





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Water injection dredger

Transport production

Mechanically
ship/barge conveyor

Hydraulically
pipeline

Mechanical transport

- Trailing suction hopper dredger
- Barges

- Be aware of the effective load, because the unloading is not always 100%

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Transport by barges

By Trailing Suction Hopper Dredgers

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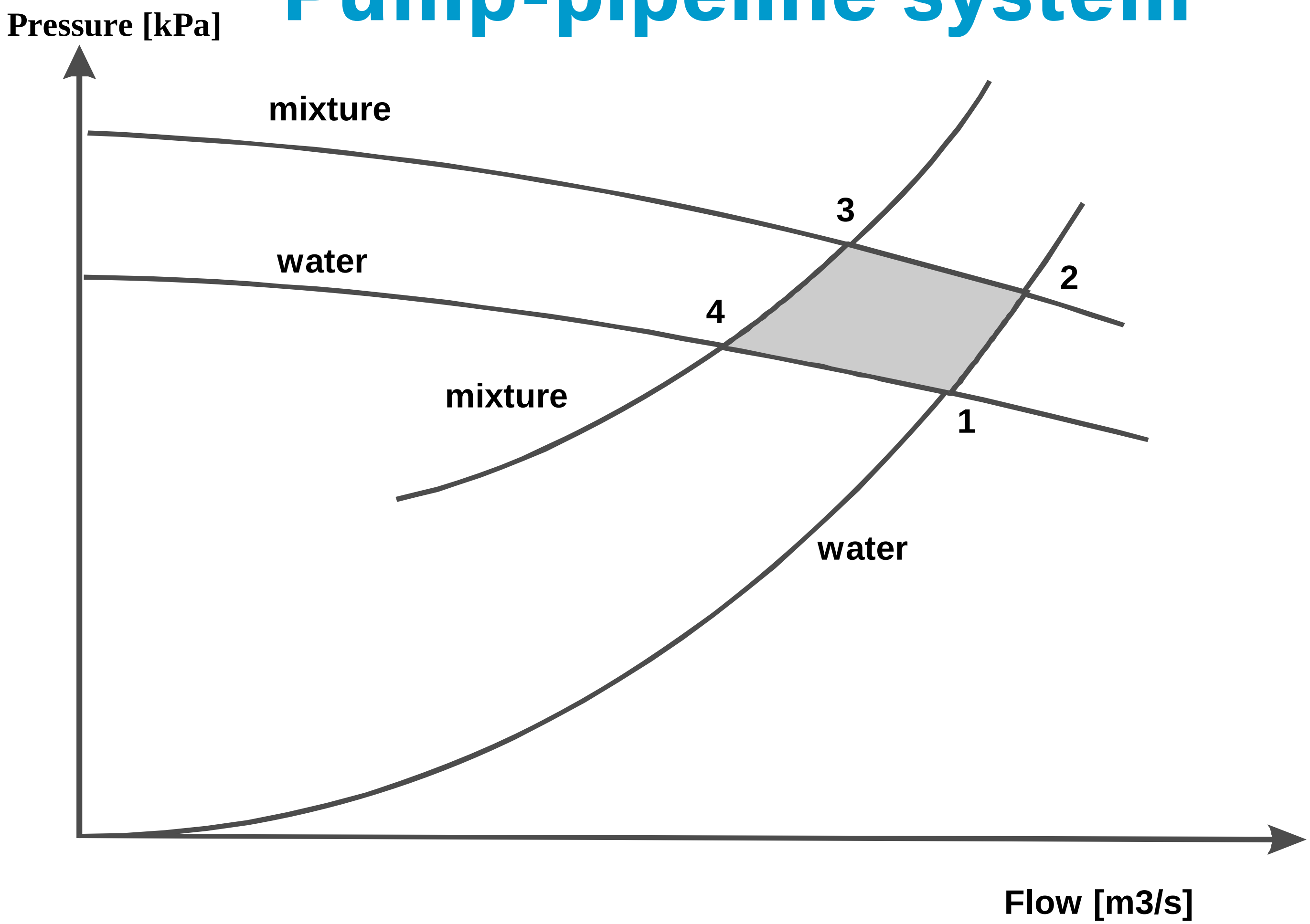
Hydraulic transport
Pump-pipeline system



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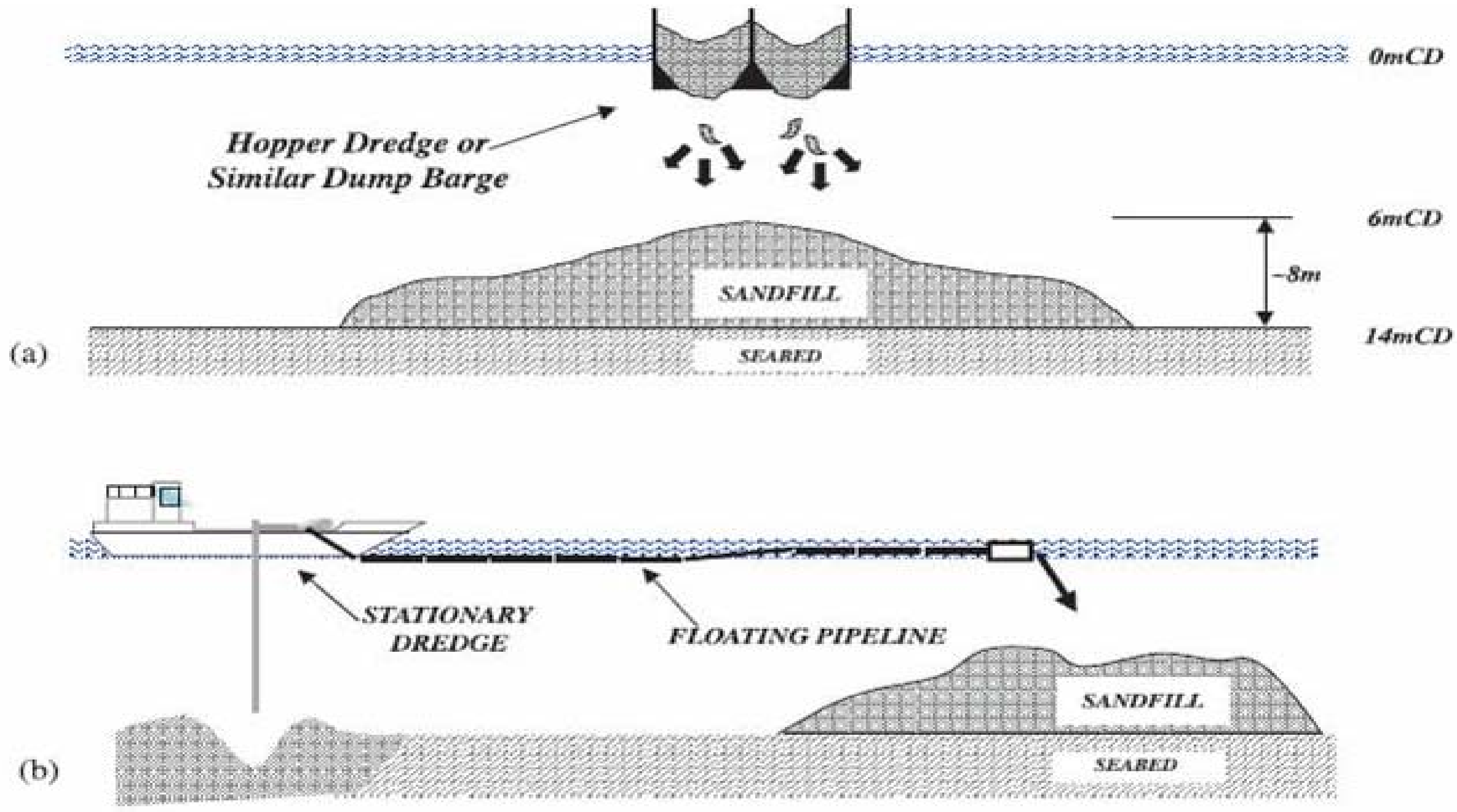
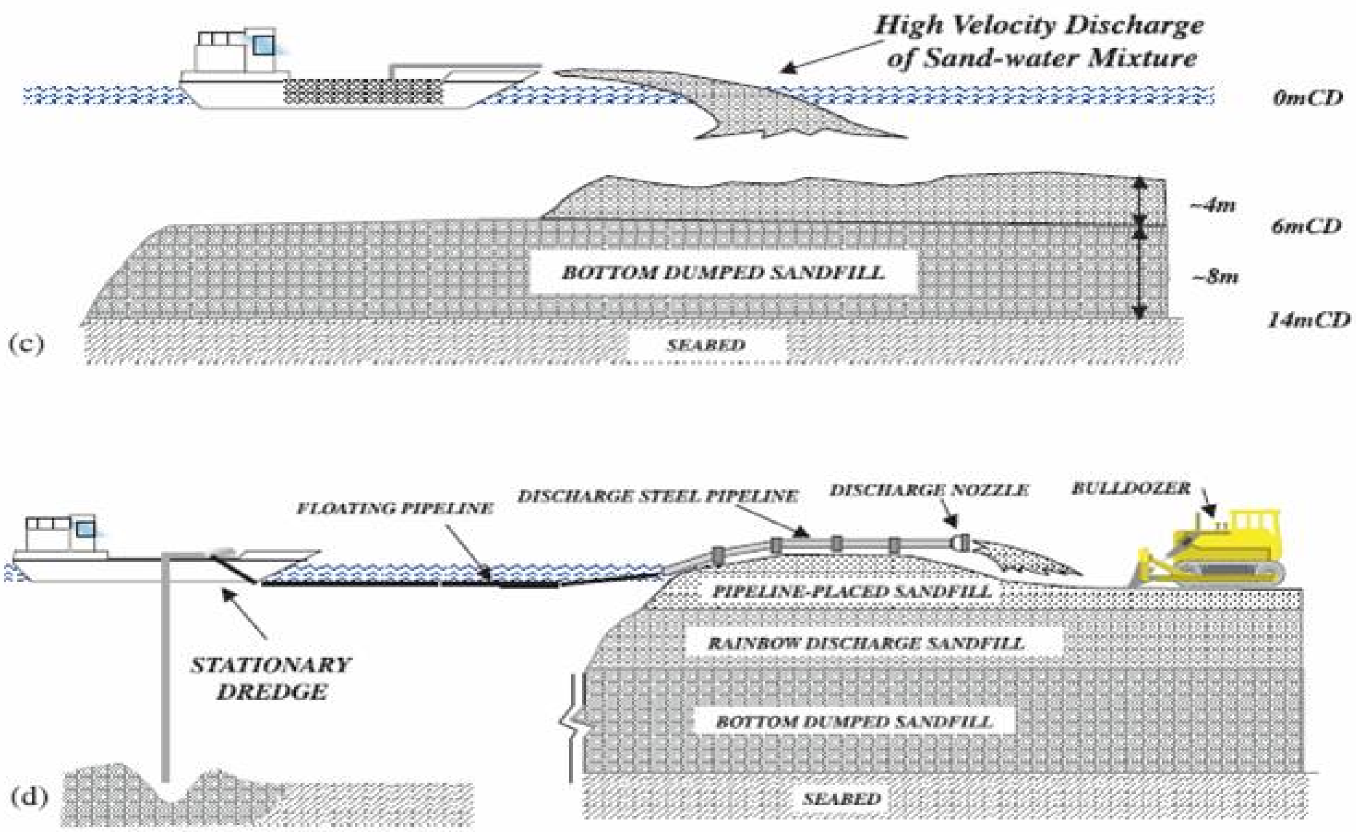
Hydraulic transport

Methods of deposing (1/2)



Methods of deposing (2/2)



disposing

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Rainbowing

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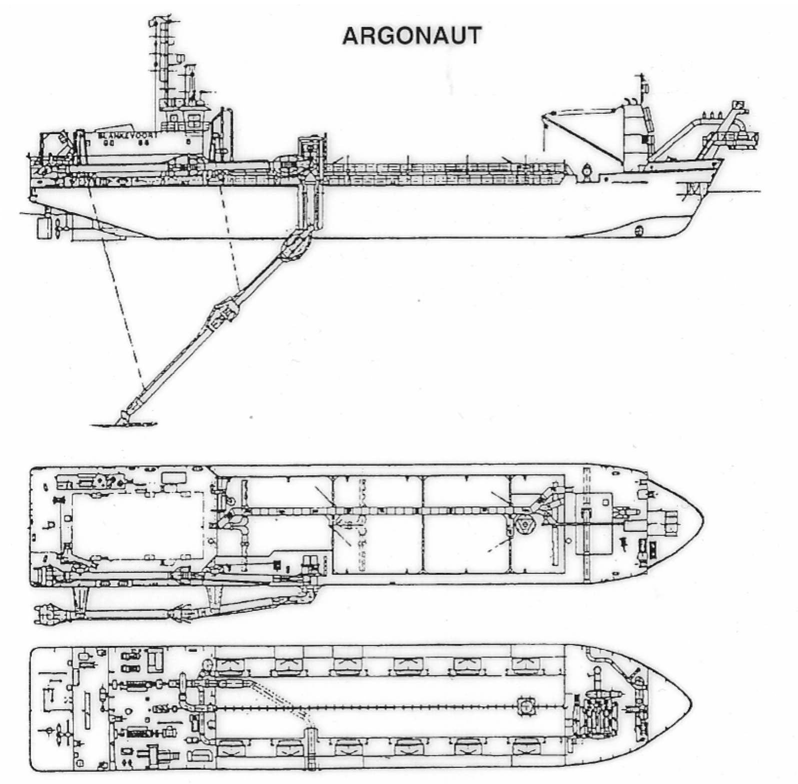
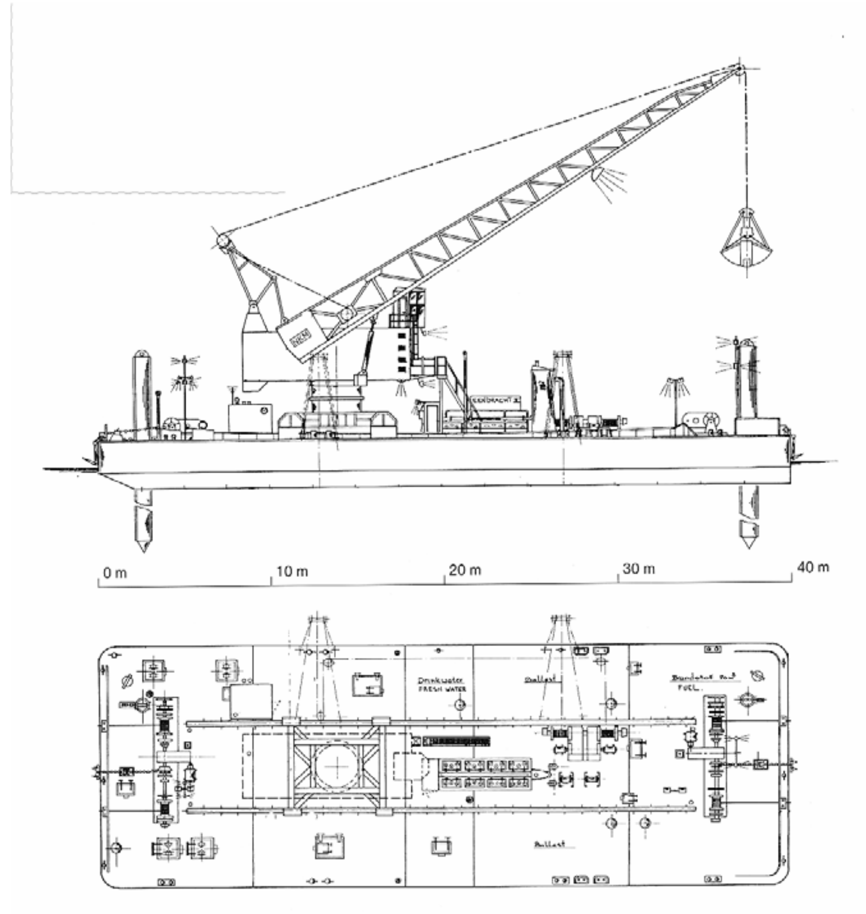
Mechanical Assistance

Design examples





TSHD

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Example 1

Design a Trailing Suction Hopper Dredger that can dredge yearly 5 Mm^3 coarse sand & gravel at 75 nautical miles from a port.

The dredger works 5 days at 24 hours

Bunkers will be taken in the weekend

Overhaul 2 weeks

Weather delays 3 weeks

Workability 95%

Christmas 1 week

Designing TSHD

Main dimensions

↓

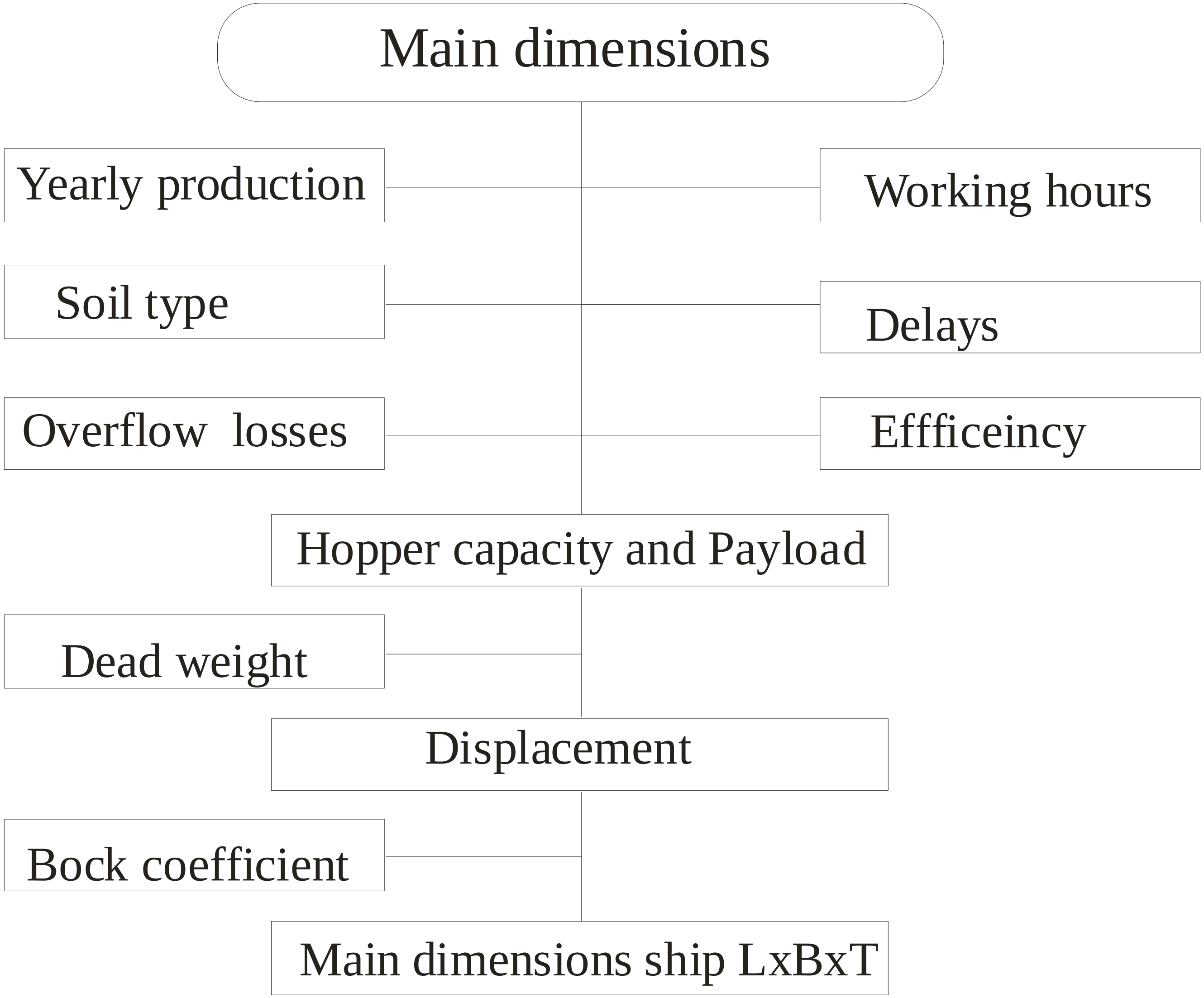
Dredging installation

↓

Propulsion

↓

General layout


Main dimensions
Yearly production
Working hours
Soil type
Delays
Overflow losses
Efficiency
Hopper capacity and Payload
Dead weight
Displacement
Bock coefficient
Main dimensions ship LxBxT

Cycle time

First estimate of dredge cycle:

Sailing to the dredging area: 75/15	=3.0 hr
Loading	=1.5
Sailing to the unloading area:	=3.0
Unloading	=1.5
Total	=9.0 hr

Required load / trip

Available hours: (52-6)x5x24=5520

Effective hours: 0.95x 5520=5244

Number of trips per year: 5244/9= 582

Required volume per trip: 5,000,000/582=8591 m^3

In coarse sand & gravel max.filling hopper is 90%

Required hopper volume: 8591/.9=9546 $\Longrightarrow$ 10000 m^3

Density of sand & gravel in hopper 2000 kg/m^3

PayLoad is: 8600x2=17200 ton

Hopper density: load/volume=1.72 t/m^3.

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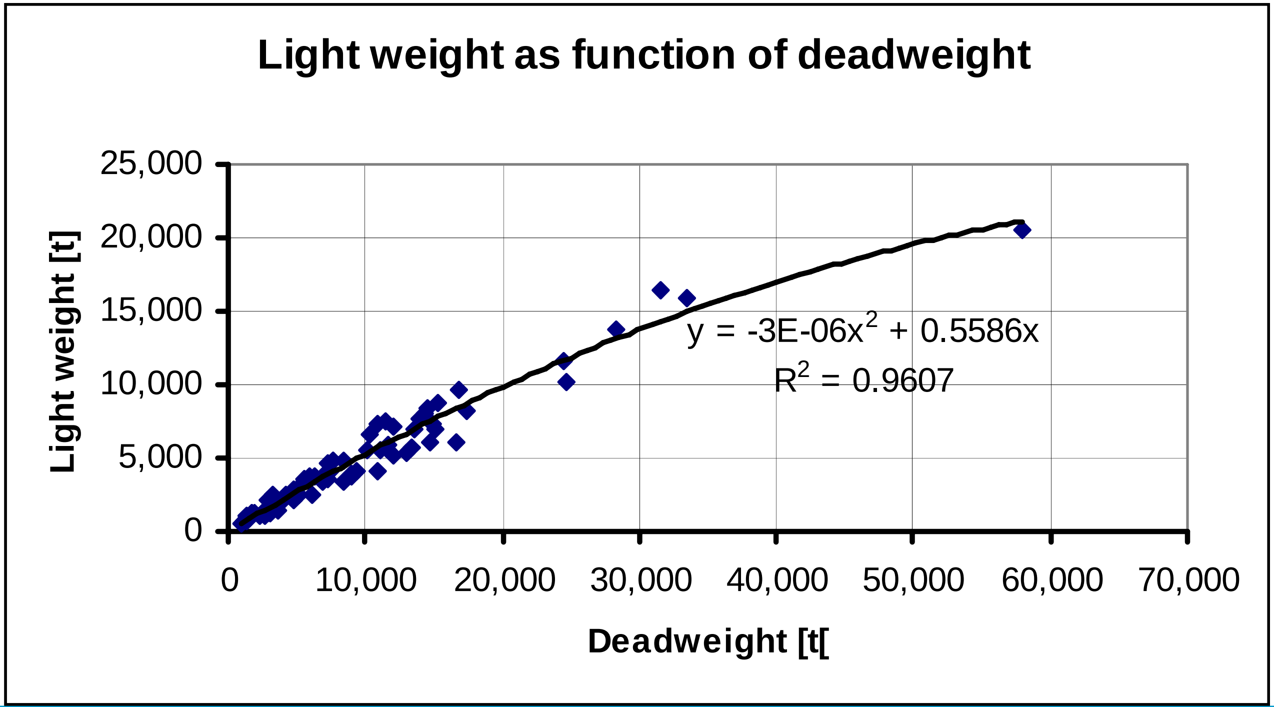
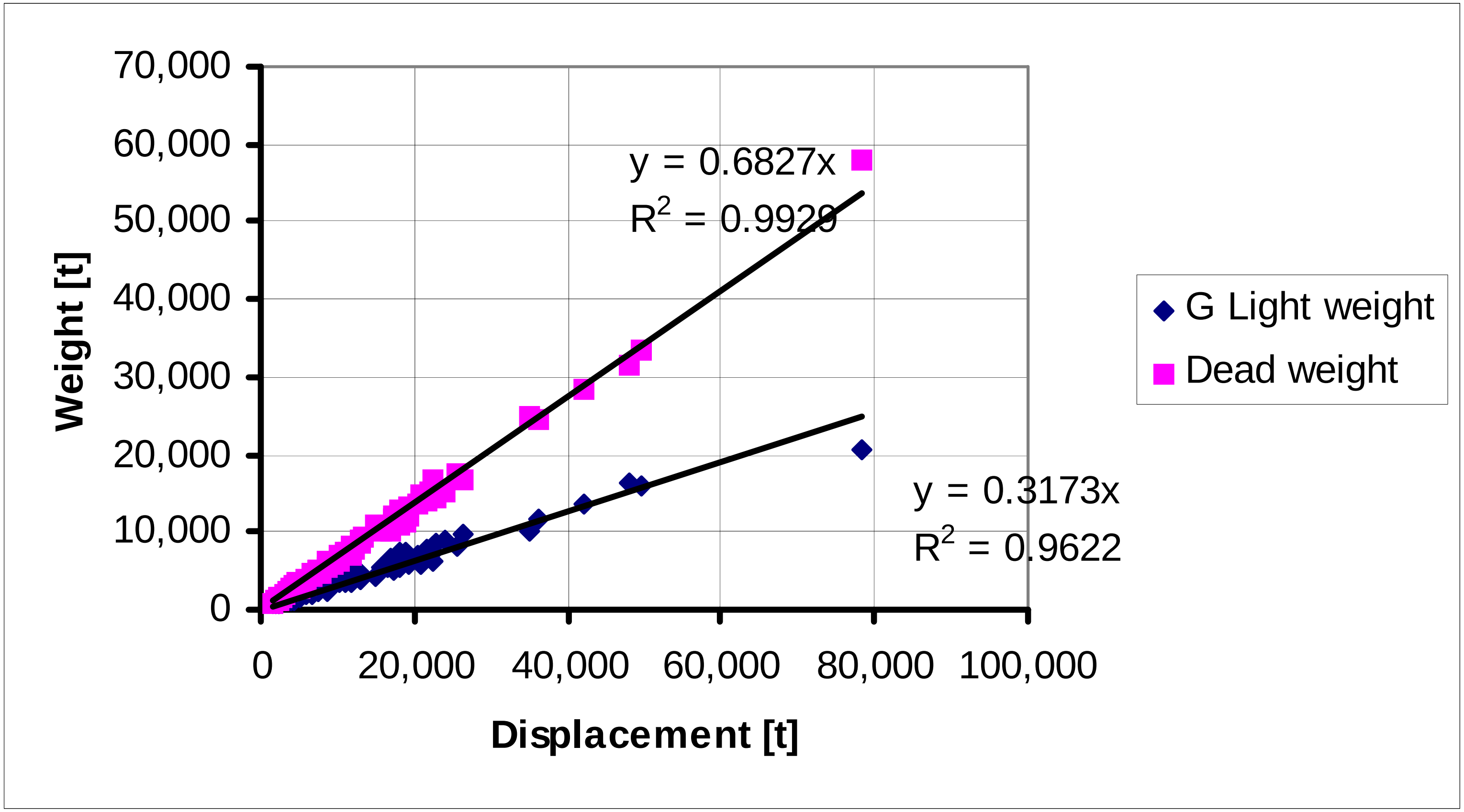
Deadweight & lightweight

Crew and their possessions, consumer goods, spare parts, and ballast water and payload.

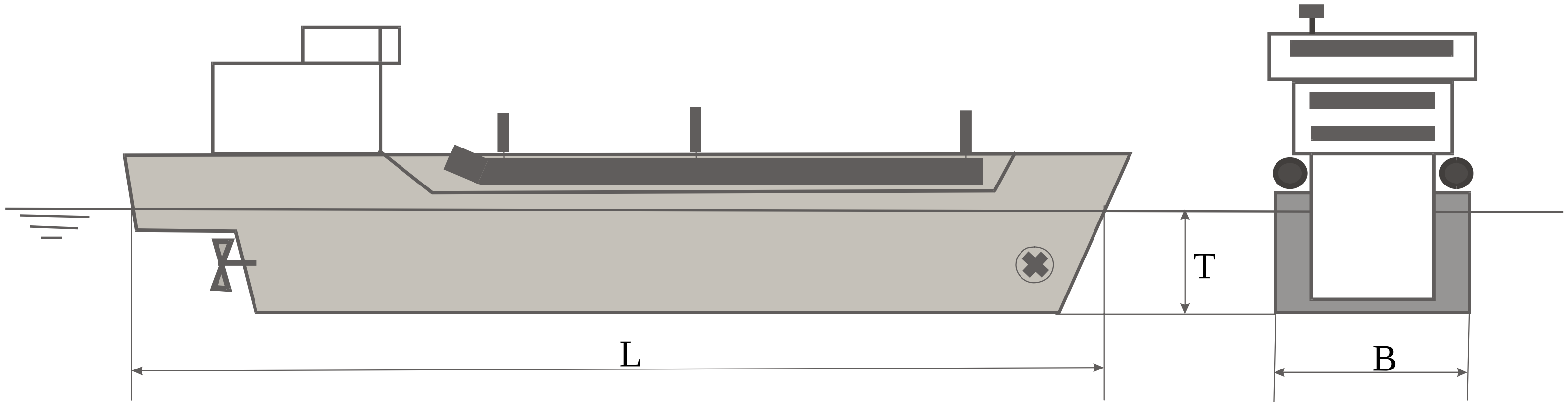
Deadweight=1.05 x payload



Displacement



Block coefficient



$$C_b = \frac{\nabla}{LBT}$$

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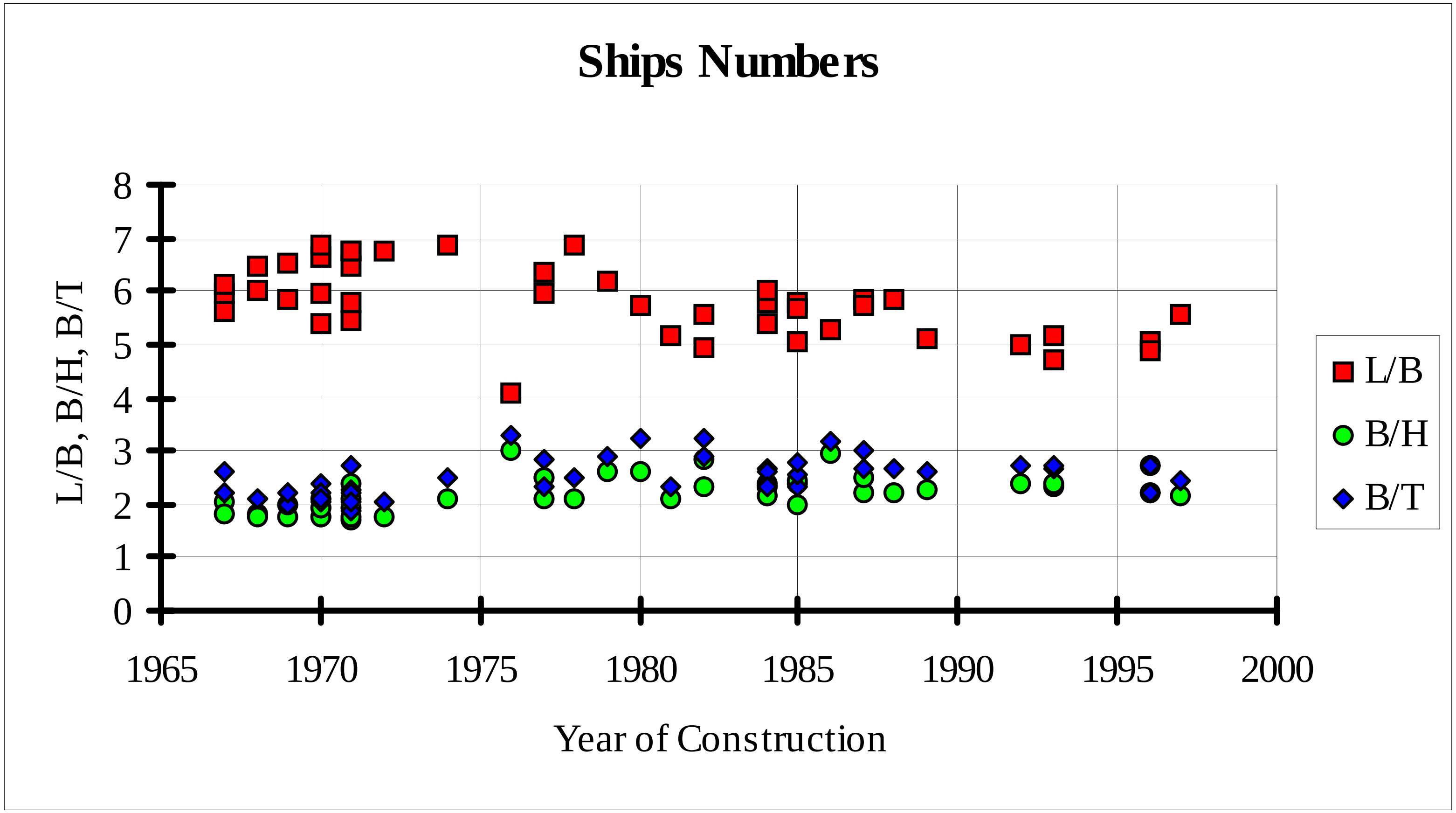
Ship Numbers



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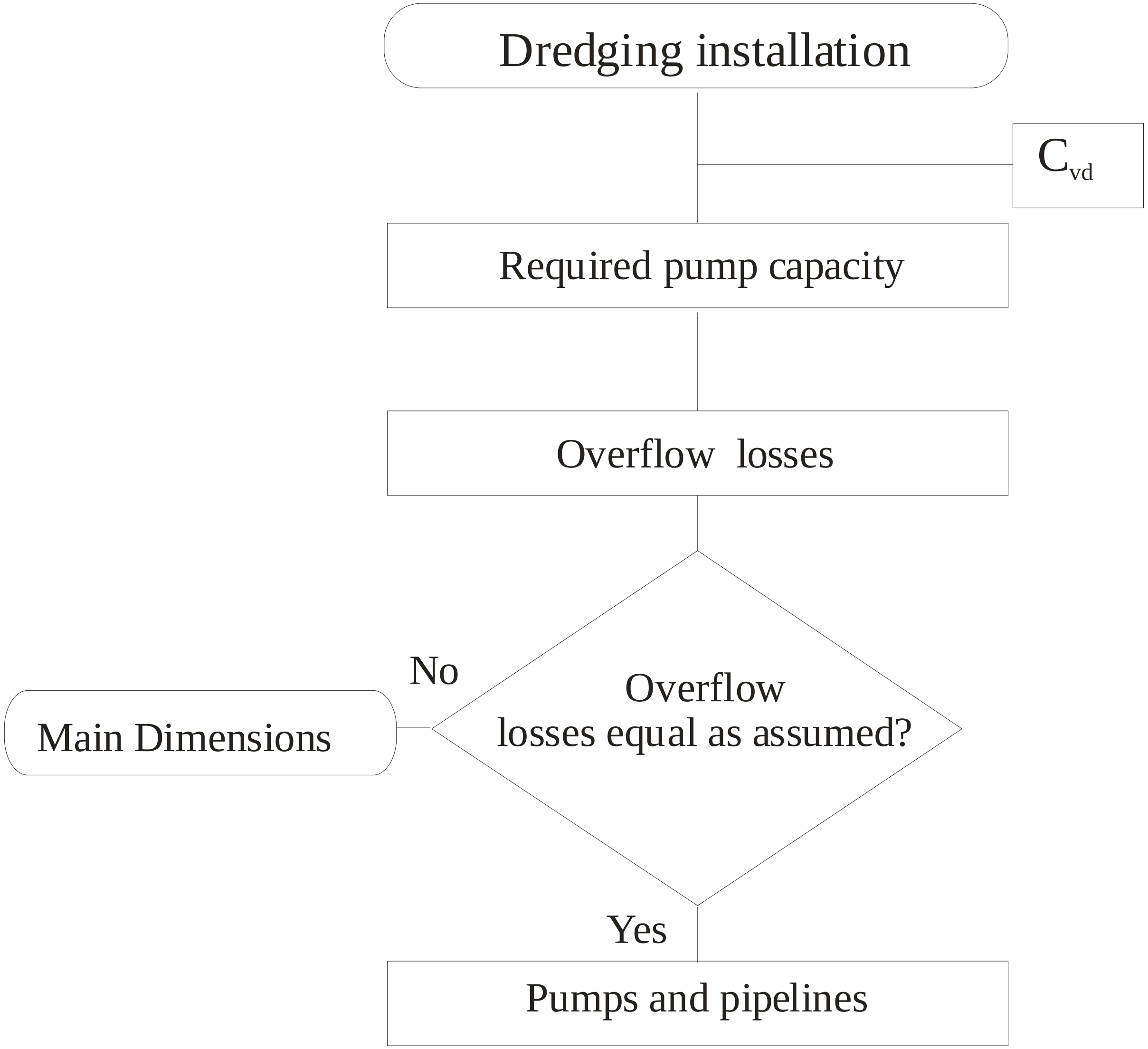
Dredging installation
C_{vd}
Required pump capacity
Overflow losses
No
Main Dimensions
Overflow
losses equal as assumed?
Yes
Pumps and pipelines

Pump capacities

- $10000\ m^3$ in 90 min=$1.85\ m^3/s$ including pores or $1.85 \times 0.6 = 1.11\ m^3/s$ excluding pores
- Assume $C_{vd}=0.2 \rightarrow$ capacity $Q=1.11/0.25=5.55\ m^3/s$ or per suction tube $2.8\ m^3/s$
- Critical velocity for course sand is 5 m/s, so pipe diameter is 0.85 m $\rightarrow$ 0.85 m

- In coarse sand and gravel there are no overflow losses to account for.

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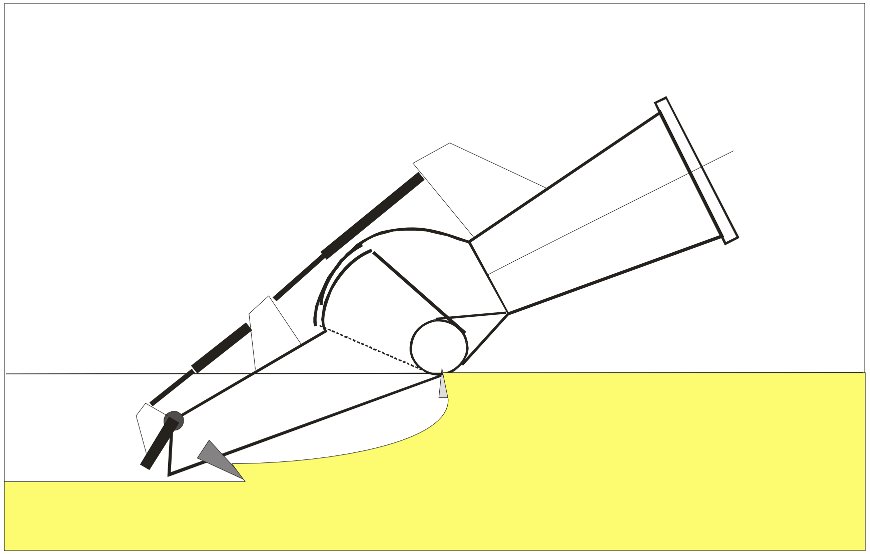
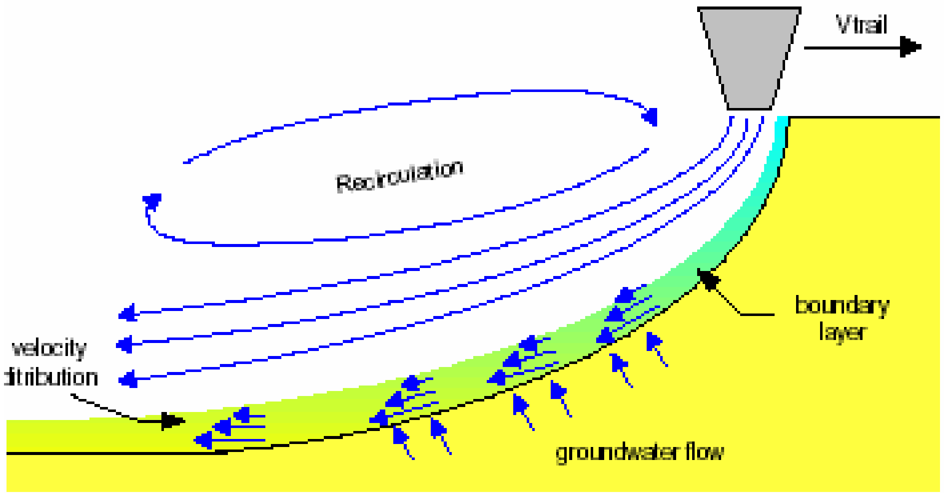
Excavation process





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Calculated the required jet pressure

- Sand mass follows from production

$$Q_{sand} = (1-n) Q_{dredged}$$

$$M_{sand} = Q_{sand} \rho_{sand} = (1-n) Q_{dredged} \rho_{sand}$$

- Momentum follows from:

With α=0.1

$$M_{sand} = \alpha \cdot I$$

$$\alpha \cdot I = \alpha \rho_w \cdot Q_{jet} u = \alpha \rho_w \cdot Q \sqrt{\frac{2p}{\rho_w}} = \alpha \sqrt{2\rho_w} \frac{P_{power}}{\sqrt{p_{pressure}}}$$

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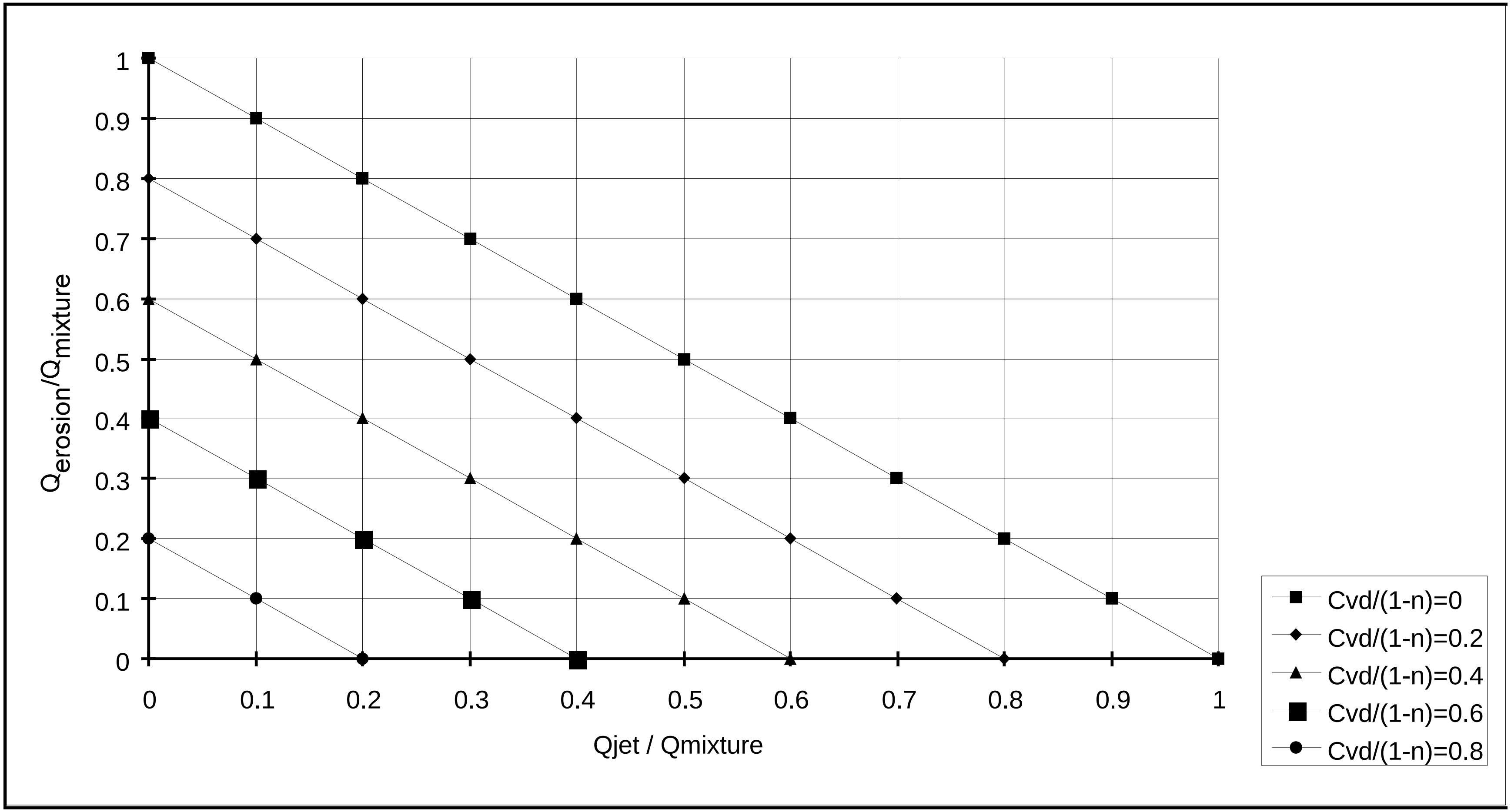
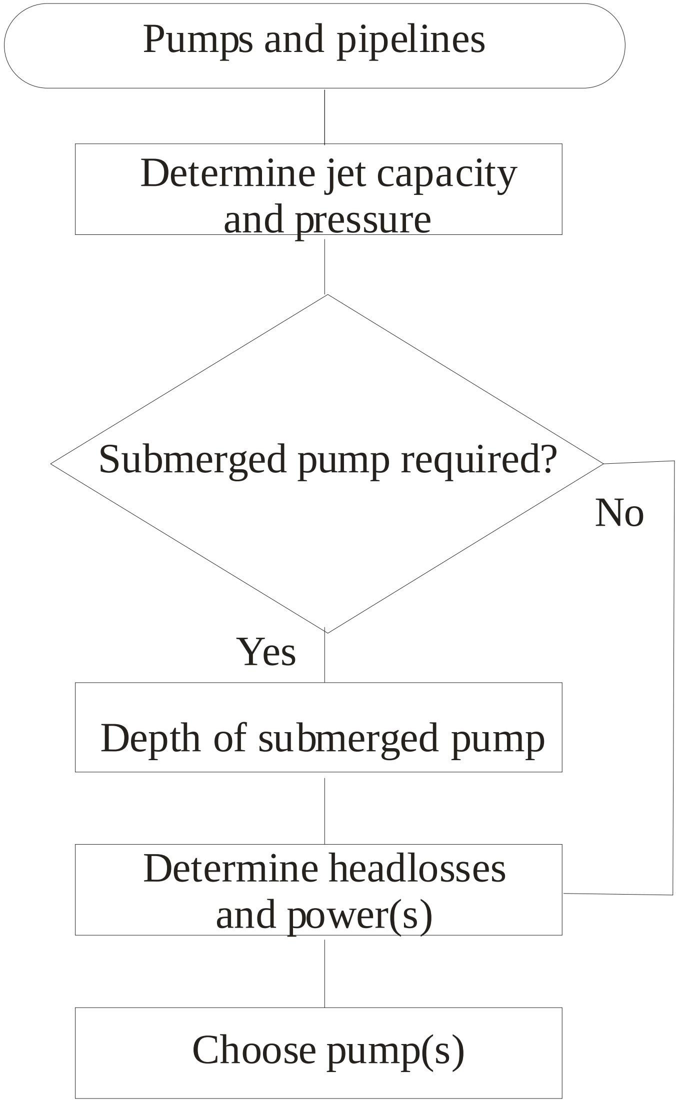
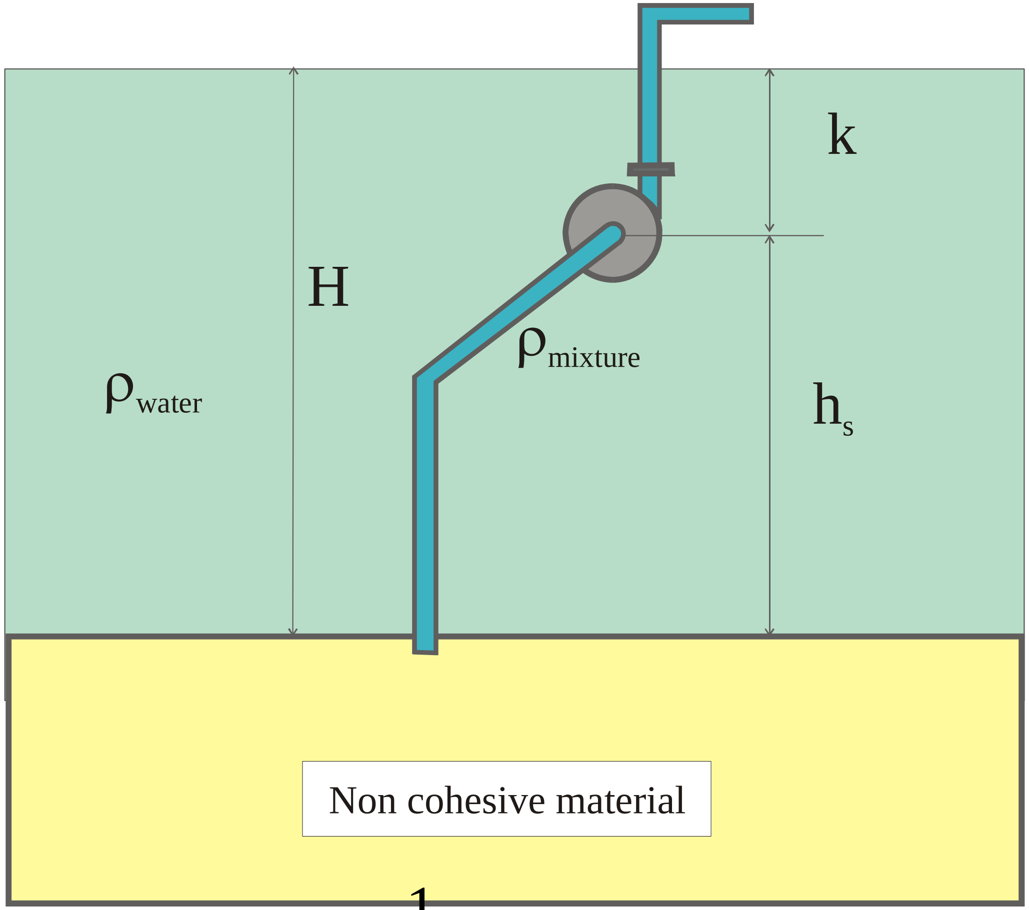
Relation between Q_{mix}, Q_{jet} and $Q_{erosion}$




Pumps and pipelines
Determine jet capacity and pressure
Submerged pump required?
No
Yes
Depth of submerged pump
Determine headlosses and power(s)
Choose pump(s)

Submerged pump required?



$$\rho_{water} gH + Vac = \rho_{mixture} gh_z + \xi \frac{1}{2} \rho_{mixture} v^2 = \rho_{mixture} g(H-k) + \xi \frac{1}{2} \rho_{mixture} v^2$$

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Hydraulic transport

- From seabed into the hopper
- From hopper to the shore
  - Mostly empirical relations (Matousek)

- For gravel dredgers this is mostly be mechanically

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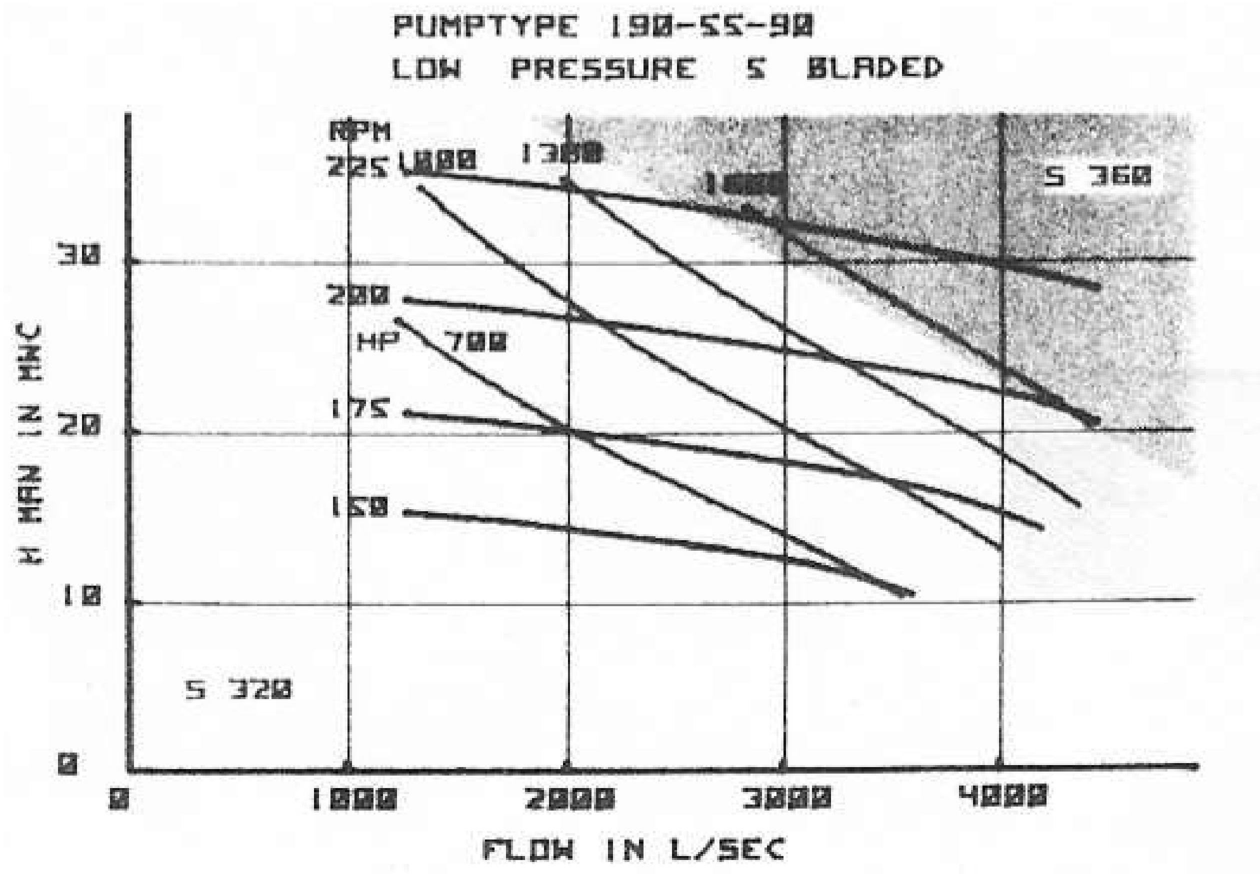
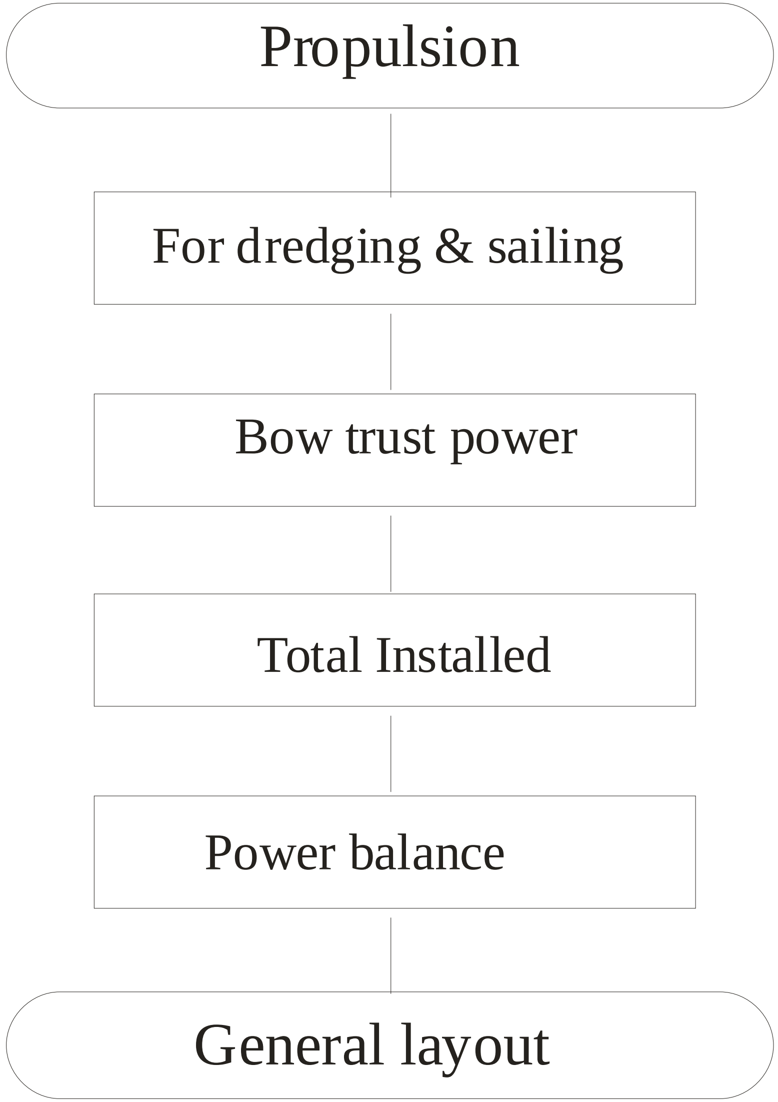
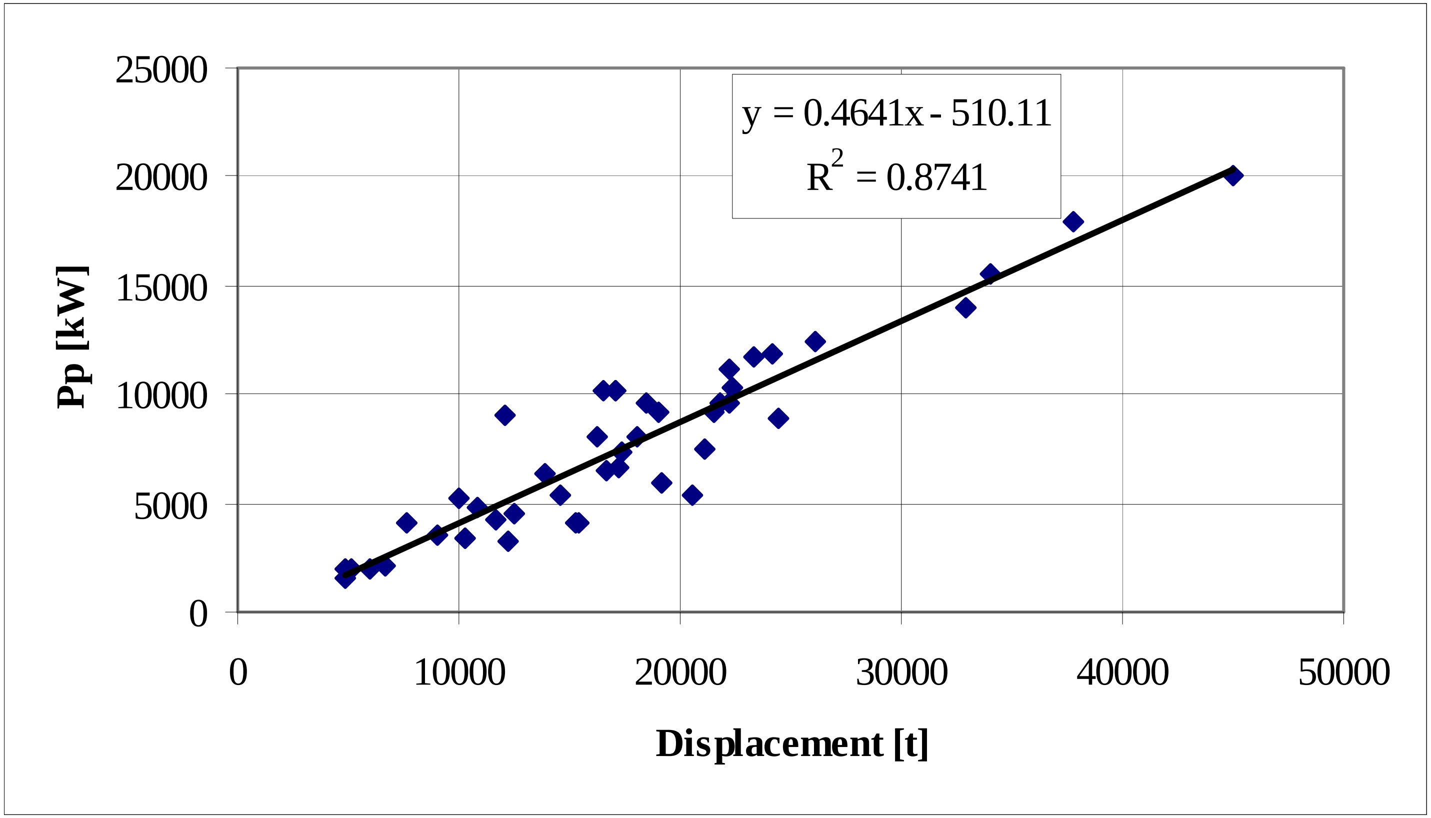
Pump characteristics

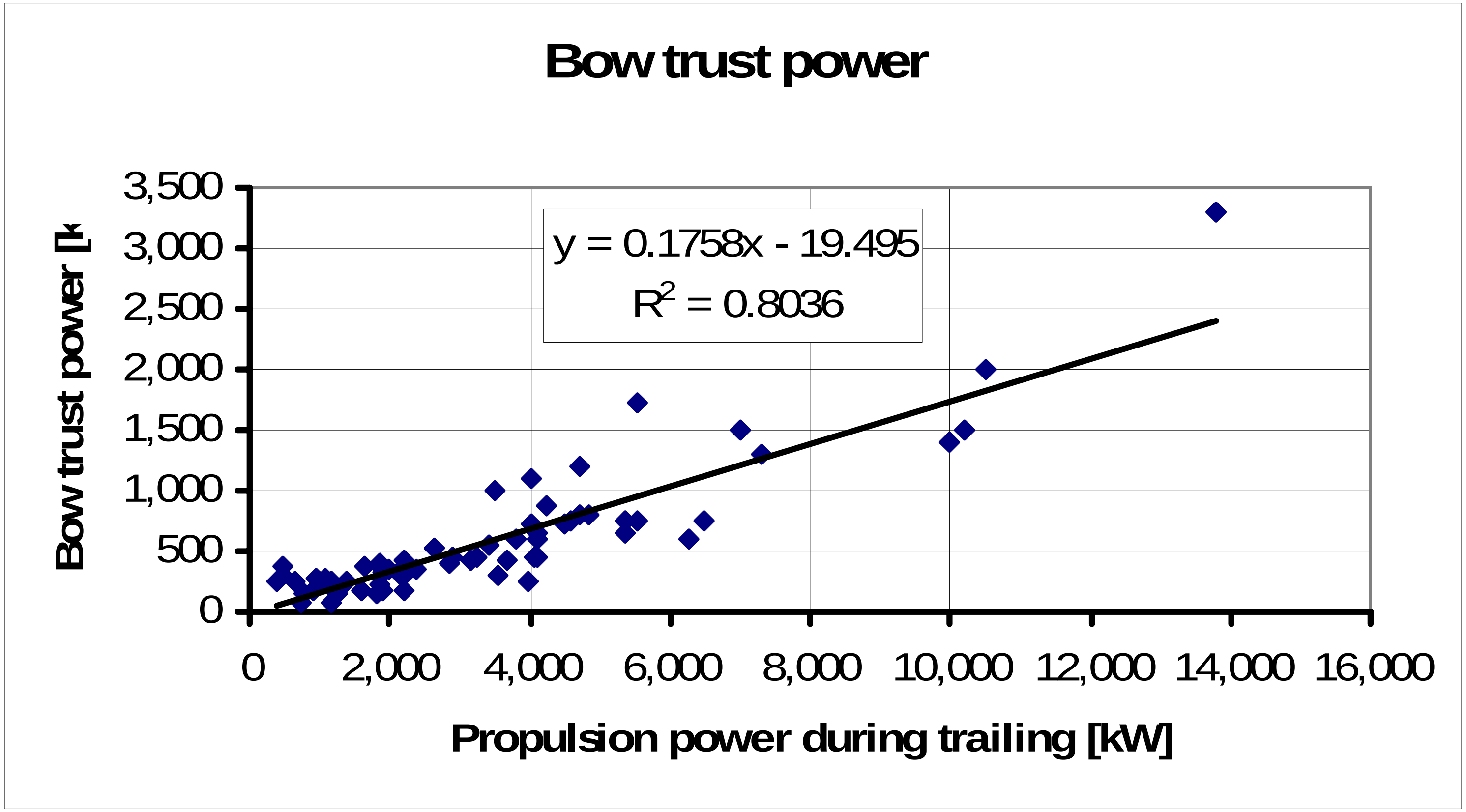



Propulsion
For dredging & sailing
Bow trust power
Total Installed
Power balance
General layout

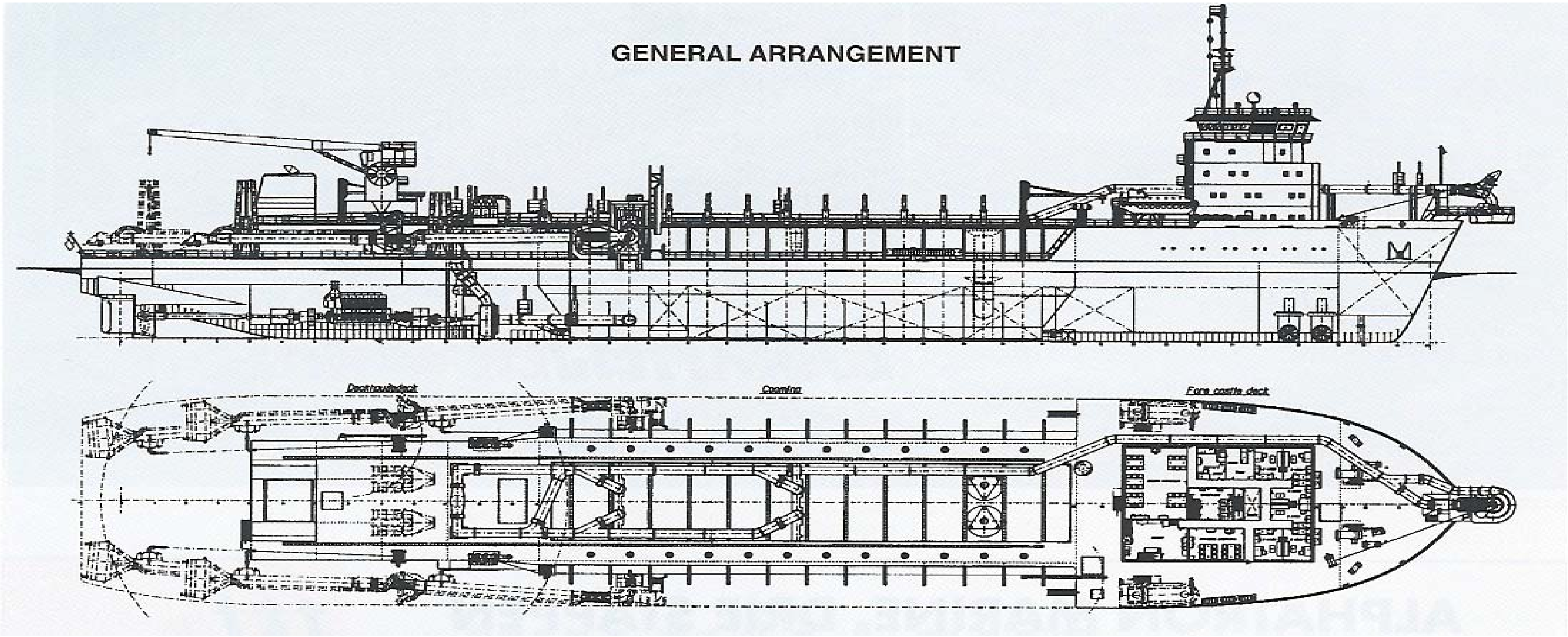
Propulsion power



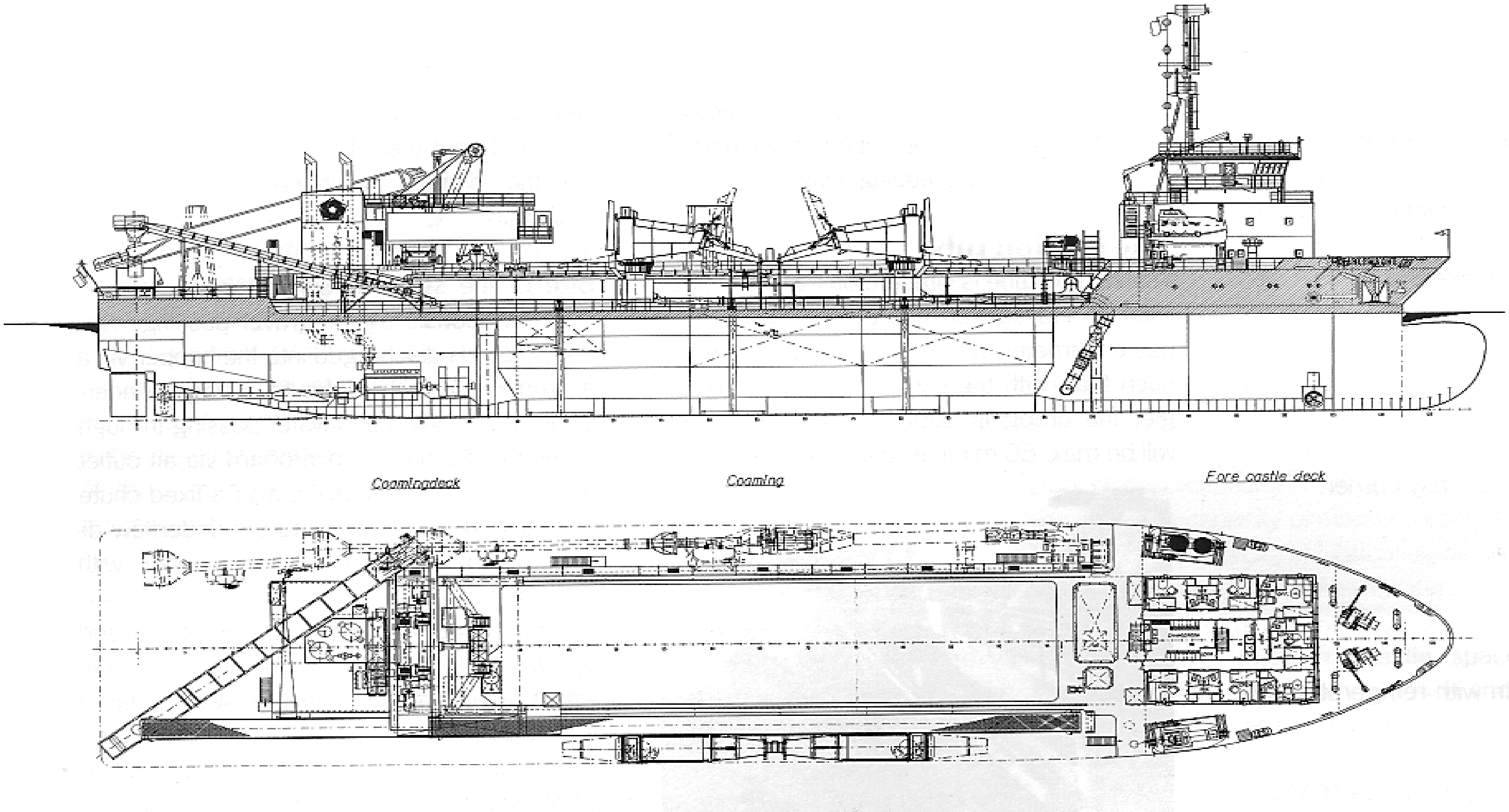
Bow trust power



General Arrangement



General Arrangement of gravel dredger



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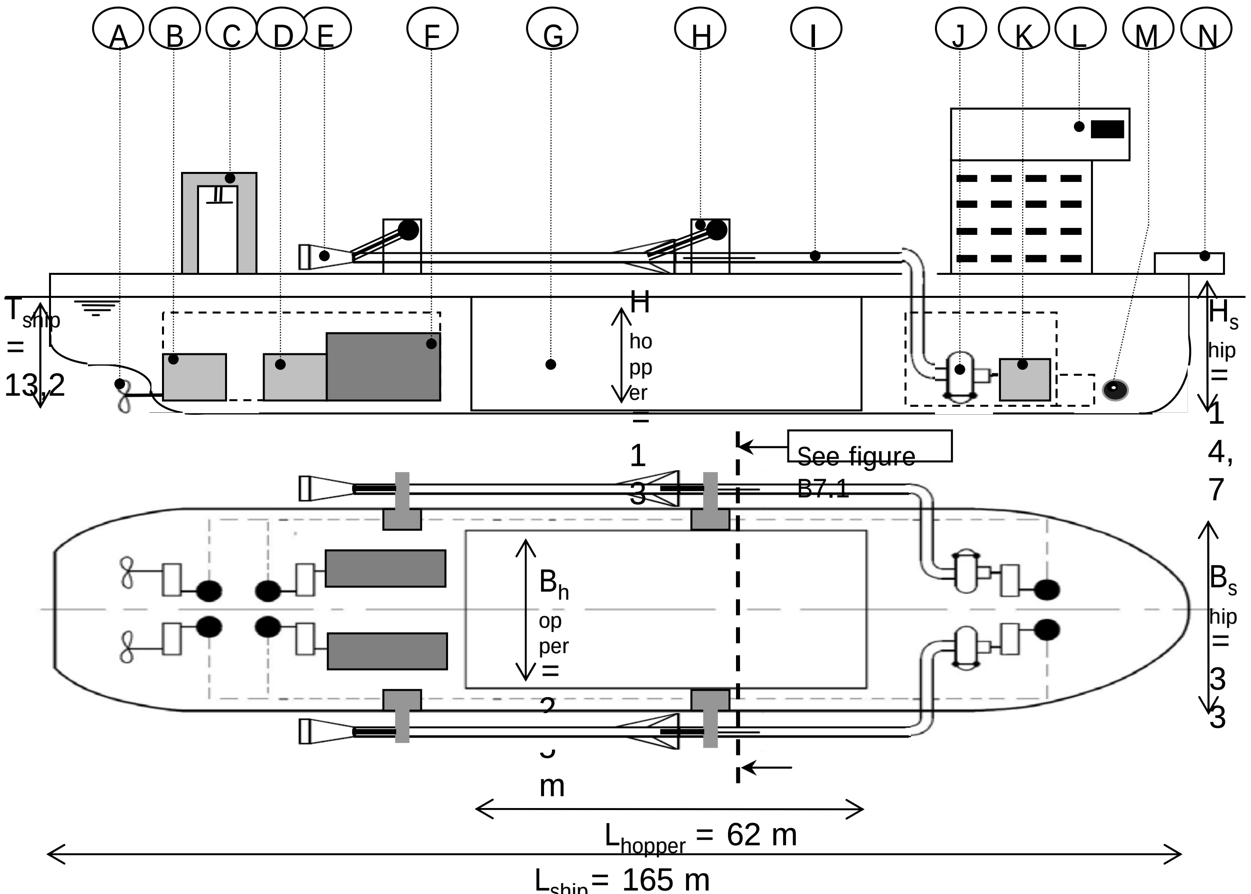
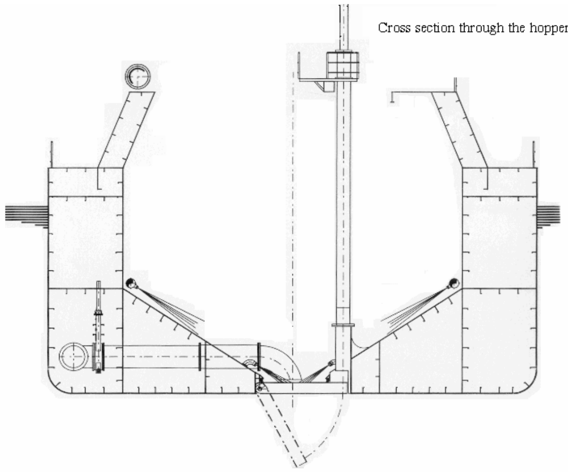
Simple general arrangment





The Cutter Suction Dredger

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Example 2

Design a cutter dredger that can dredge dredge yearly 5 Mm^3 rock with a unconfined compressive strength of 5 MPa. The tensile strength is 1 Mpa

The dredgers have to work 168 hrs a week.

Yearly overhaul 4 weeks

Christmas leave 1 week

General delays 10%

Dredging delays 20

SPE~qu

Required cut production

Available hours (52-5)x168=7896

Non dredging hours:0.3x7896=2369

Dredging hours 7896-2369=5527

Estimated spillage 25%

Required hourly output: 1.25x5000000/5527=±1130 m^3.

$Q_{dredged}$=1130/3600=0.314 m^3/s

Time losses due to stepping, spud changes 15%

Q_{cut}=0.31/0.85=0.37 m^3/s

SPE=5MJ/m^3.

Required mean cutter power 0.37x5=1.85 MW

Cutter head productions c.q. Spillage

- The rotational speed of the cutter head causes spillage.

- The productivity c.q. spillage depends on the ratio:

- For sand the productivity is: $P_r \approx 2.5 \frac{Q_{pump}}{\omega R_{cutter}^3}$

- For rock the productivity is much lower

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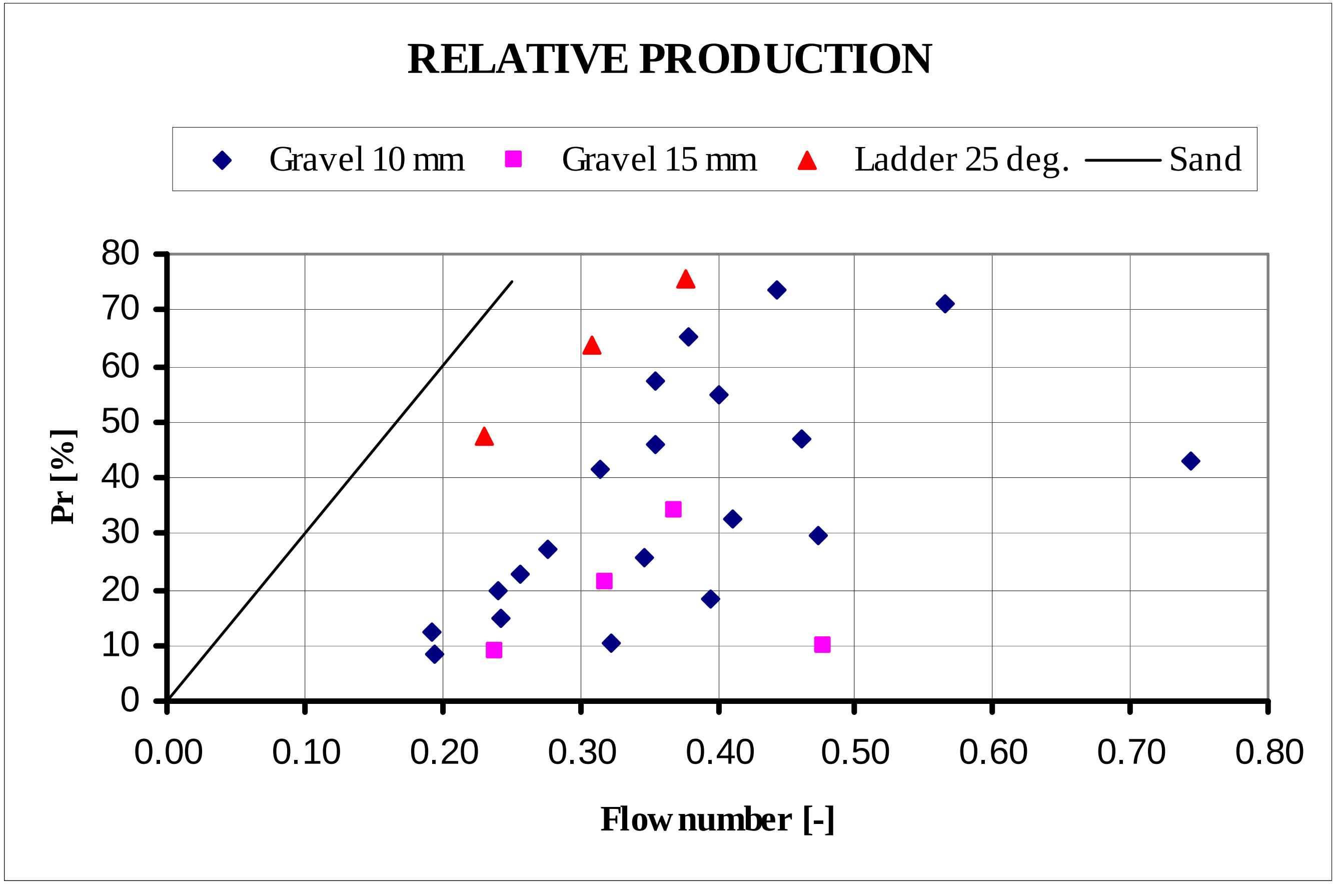
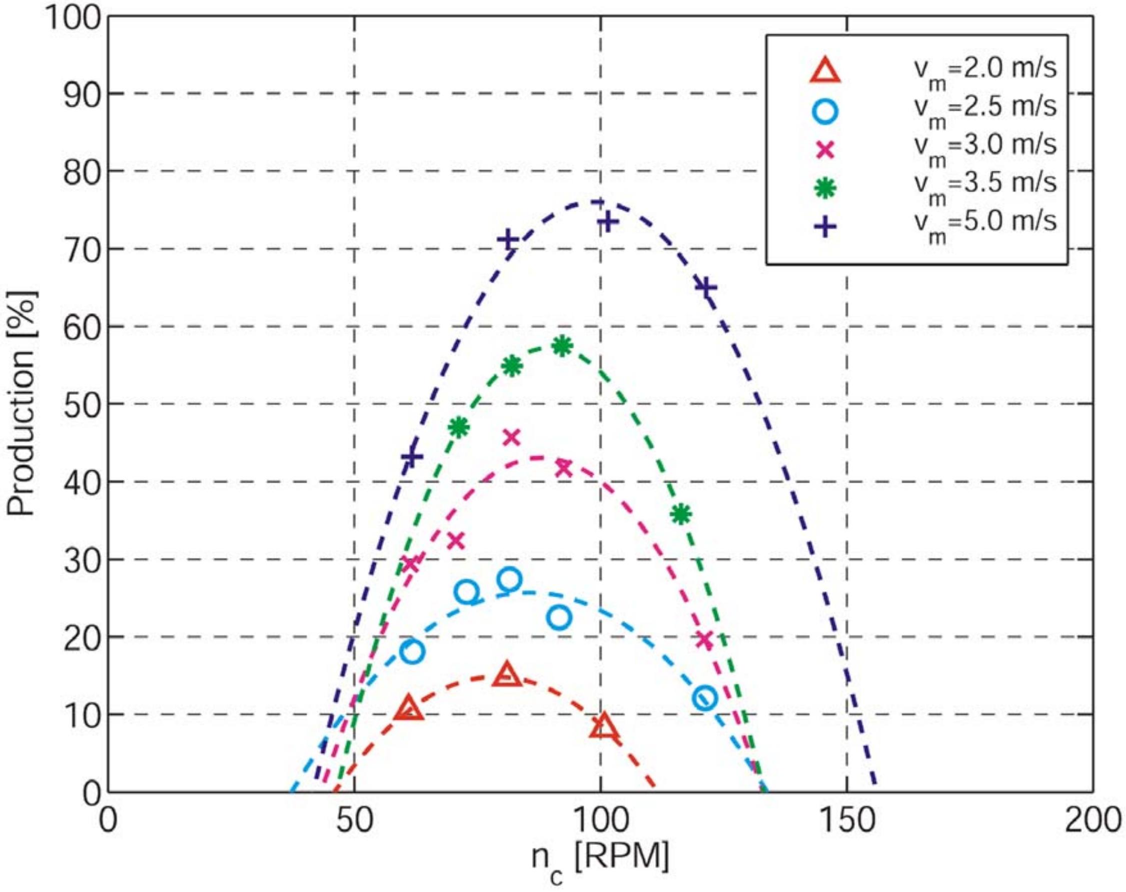
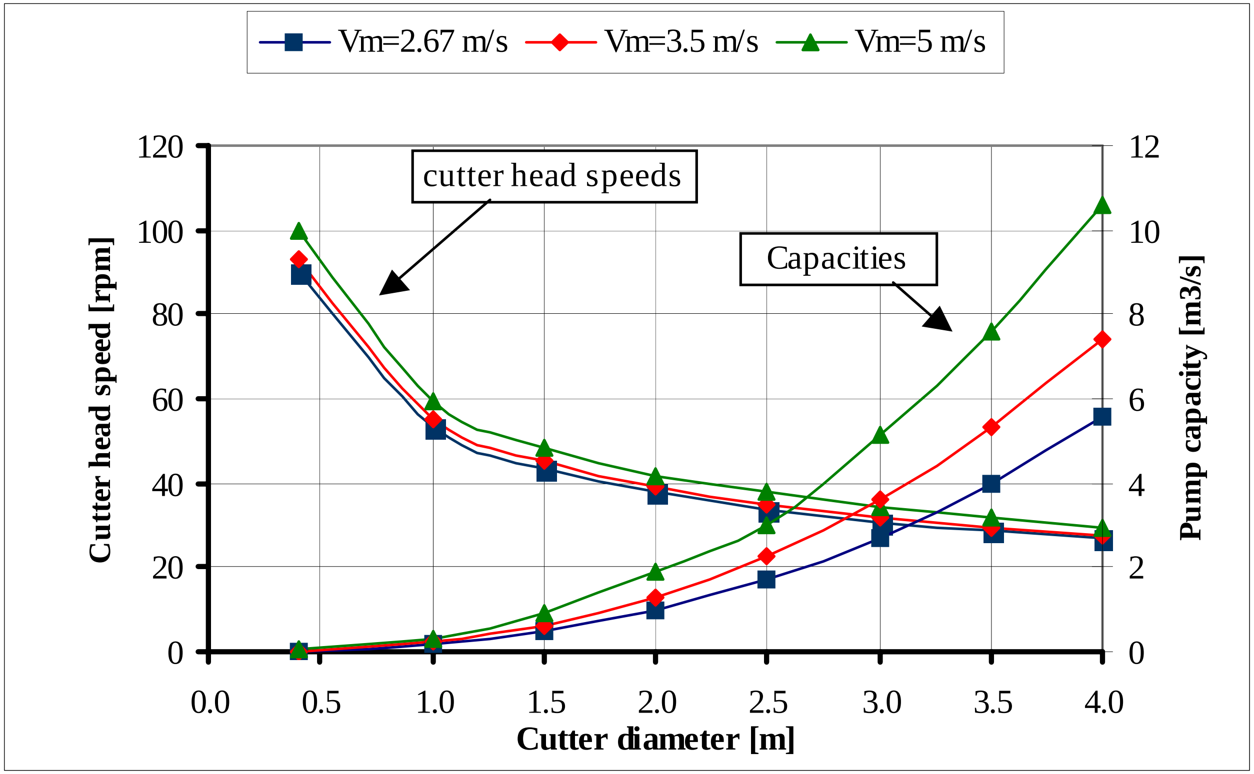
Cutter head productions c.q. Spillage



Cutter head production process in rock or gravel



Cutter head dimensions for rock with 25 % spillage



Pump capacity and concentrations

$Q_{dredged}$=0.314 m^3/s

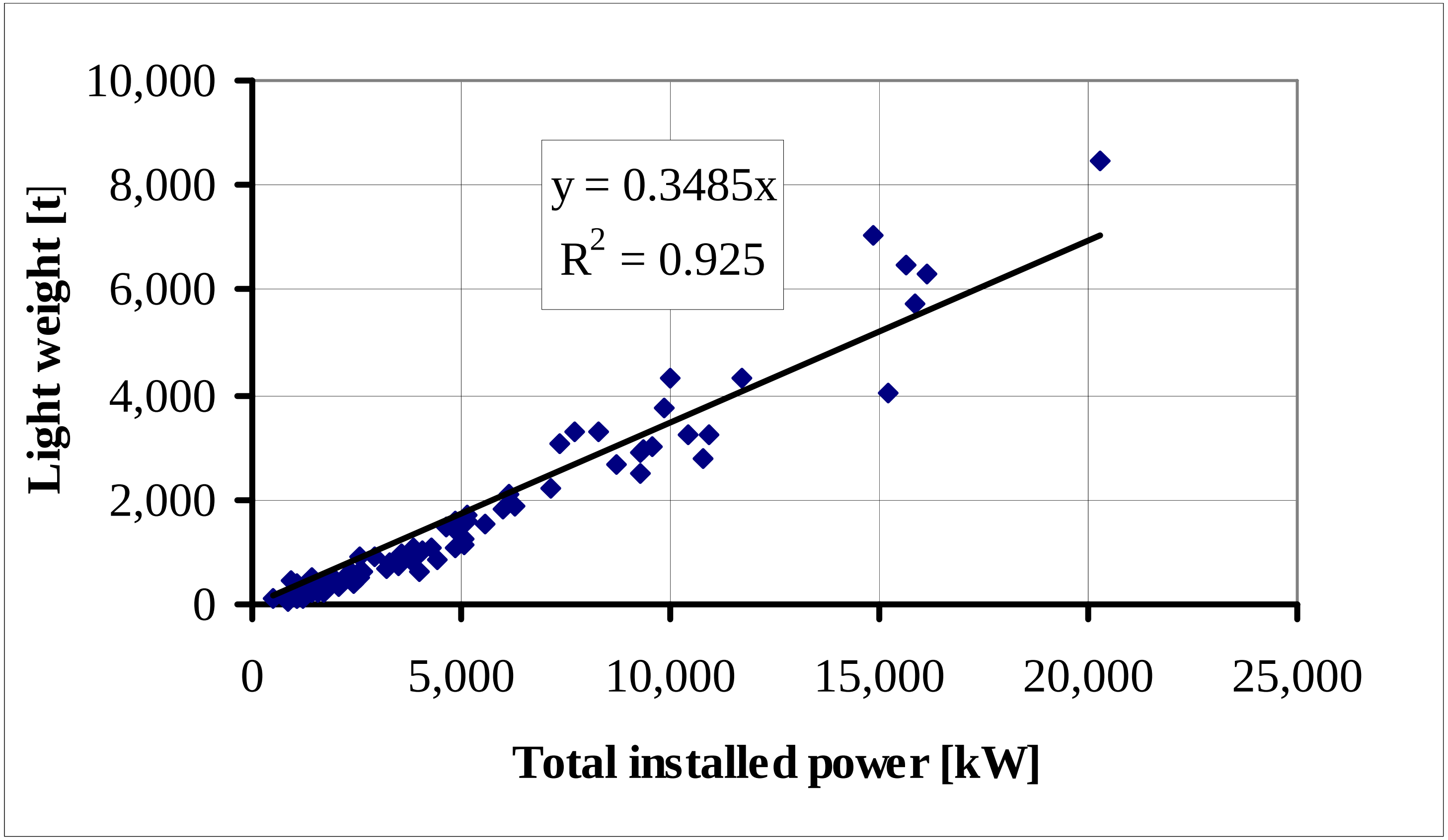
$Q_{mixture}$=3.5 m^3/s

$$C_{vd} = \frac{Q_{sand}}{Q_{mixture}} = \frac{Q_{dredged}\left(1-n\right)}{Q_{mixture}}$$

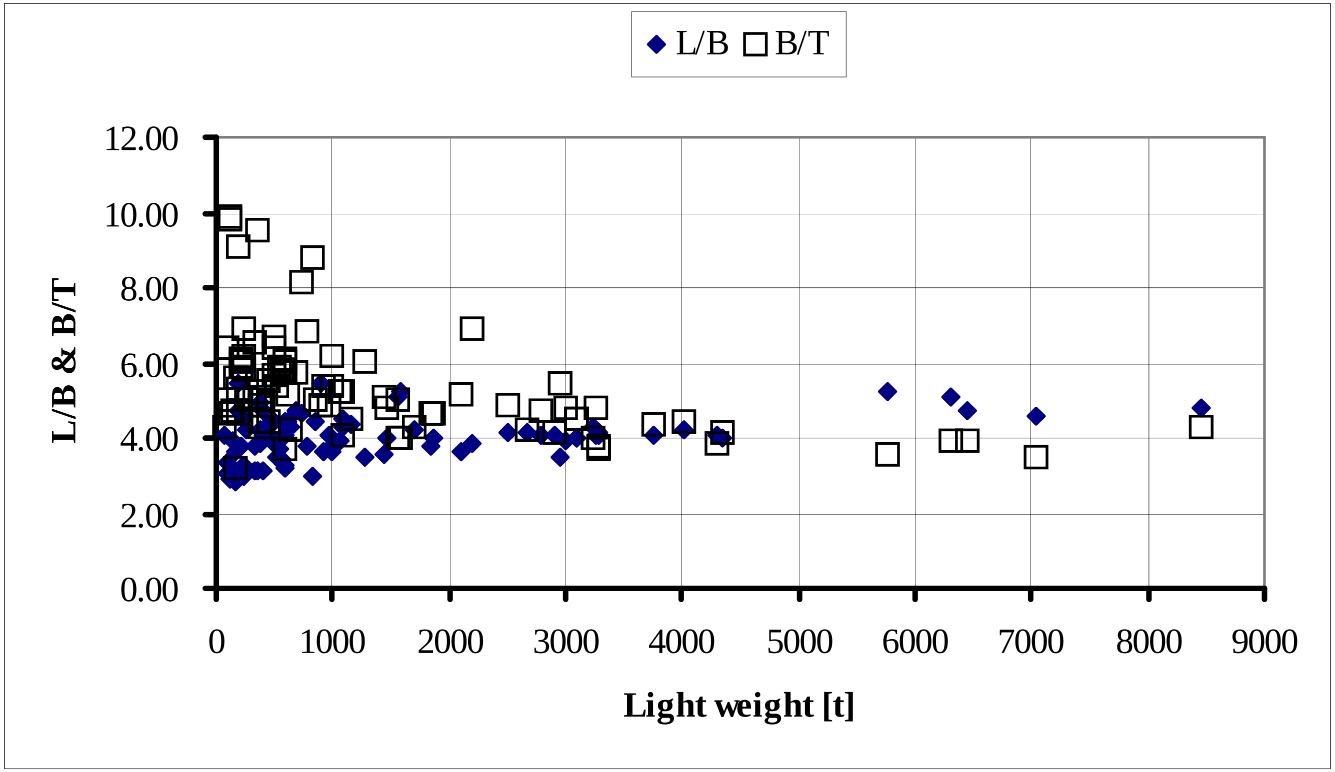
Pumping distances and installed pump power

- Knowledge of hydraulic losses can be found in the lecture notes of Matousek c.q. Talmon
- Knowledge of dredge pump can be found on our website and is downloadable.

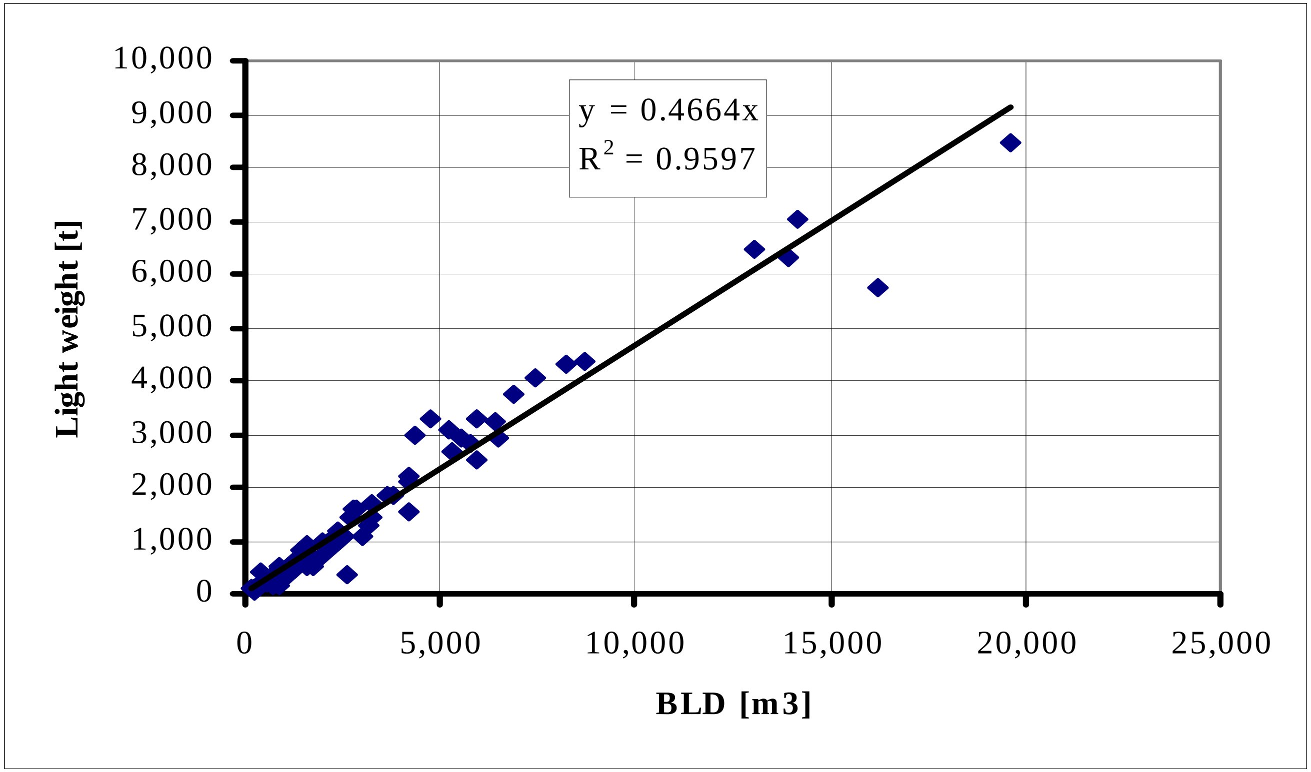
Lightweight of pontoon



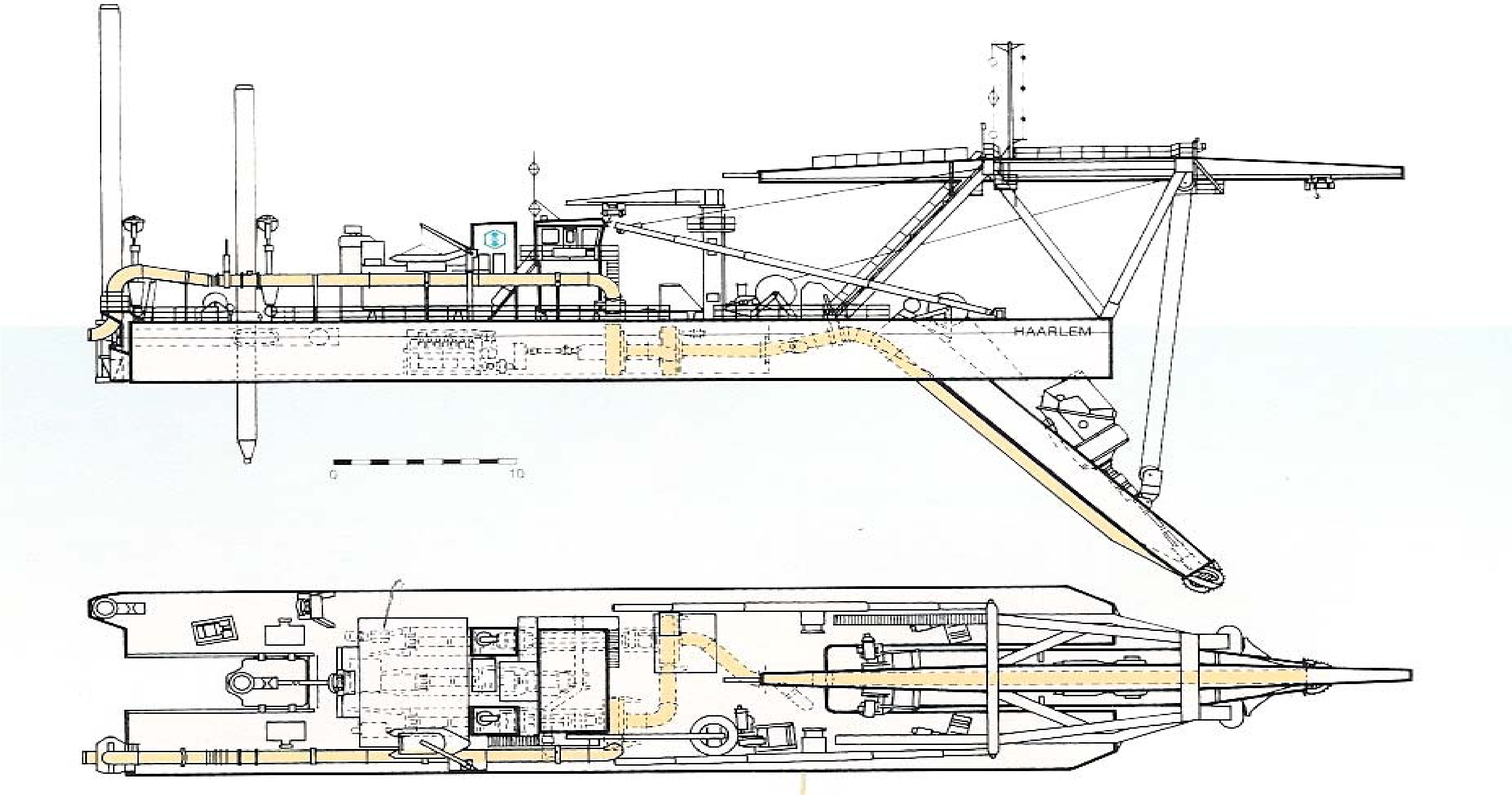
Pontoon dimensions (1/2)



Pontoon dimensions (2/2)



Simple Plan



Backhoe dredger

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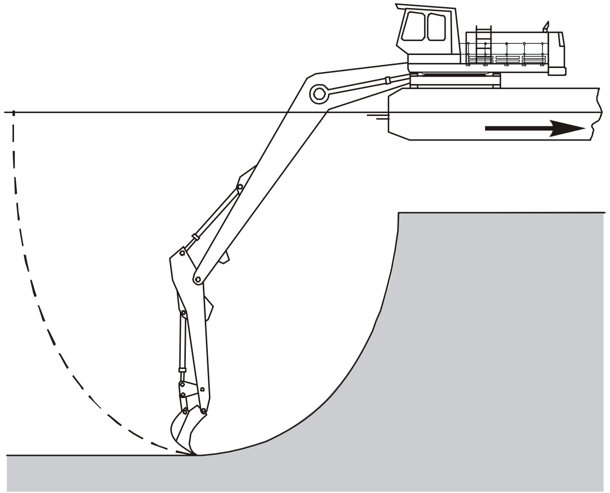
Example 3

- A backhoe dredger have to dredge 500 m³/in fine sand with a SPE of .7MJ/m³.
- Calculated the Bucket size and cylinder forces



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Fill Degree & Bulk factor

Soil type	Filling degree	Bulking factor
Soft clay	1.5	1.1
Hard clay	1.1	1.3
Sand & Gravel	1	1.05
Rock; well blasted	0.7	1.5
Rock, unblasted	0.5	1.7

Dredge Cycle

- Cycle times of the bucket depends on the dredging depth and soil type, but are in the order between 20 and 40 seconds.
- The cycle consists of:
- ● Digging
- ● Lifting and swinging
- ● Dumping
- ● Swinging and lowering
- ● Positioning.

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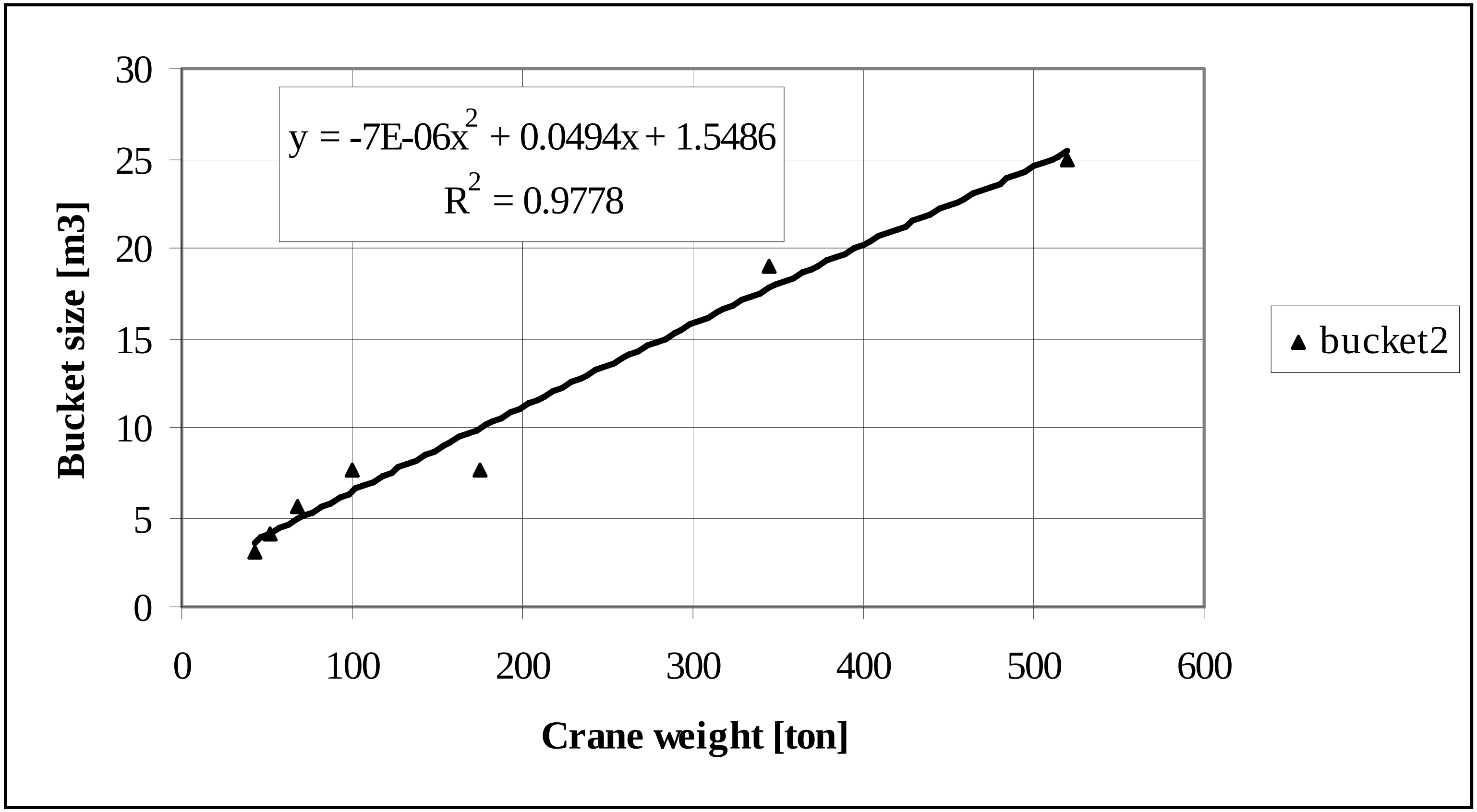
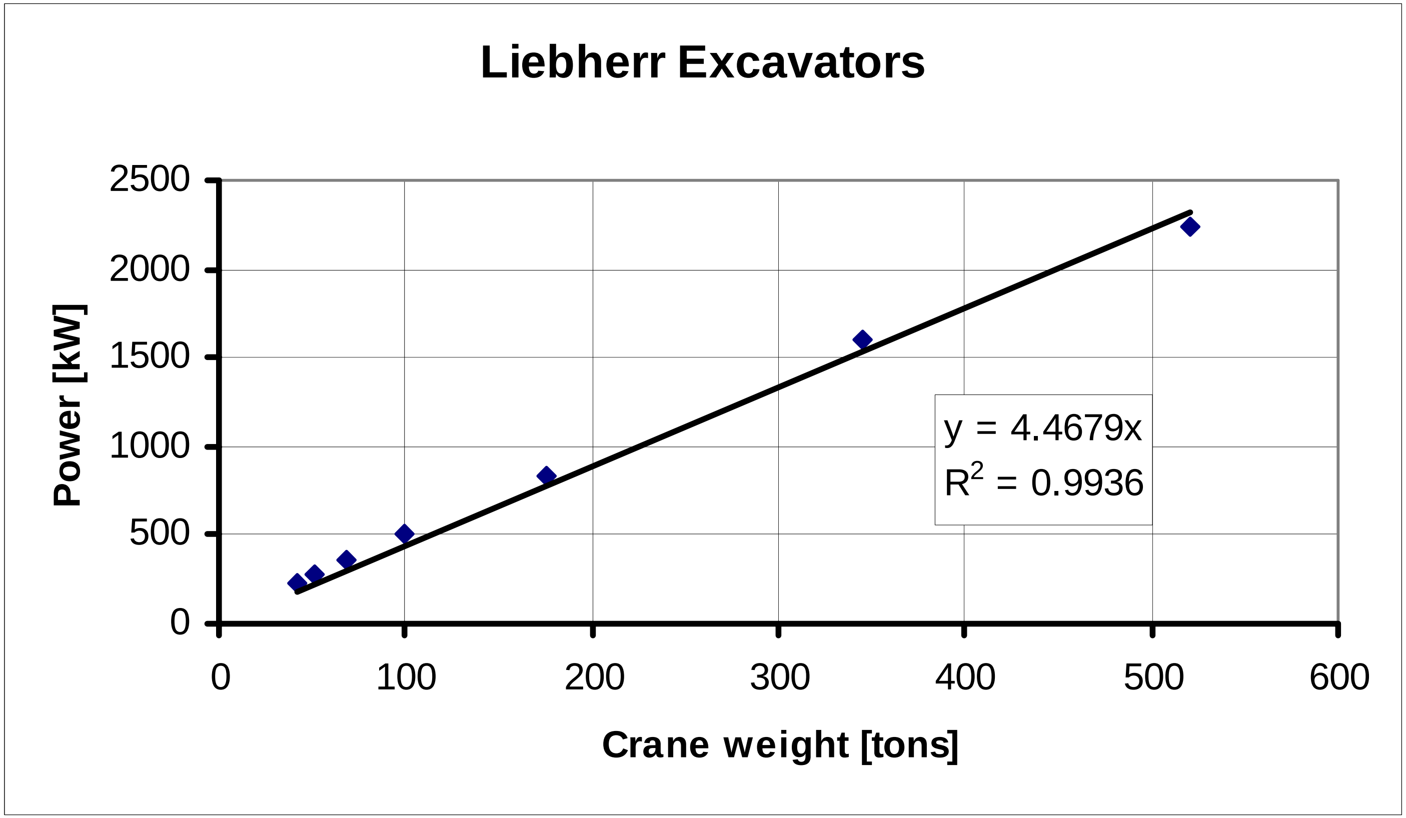
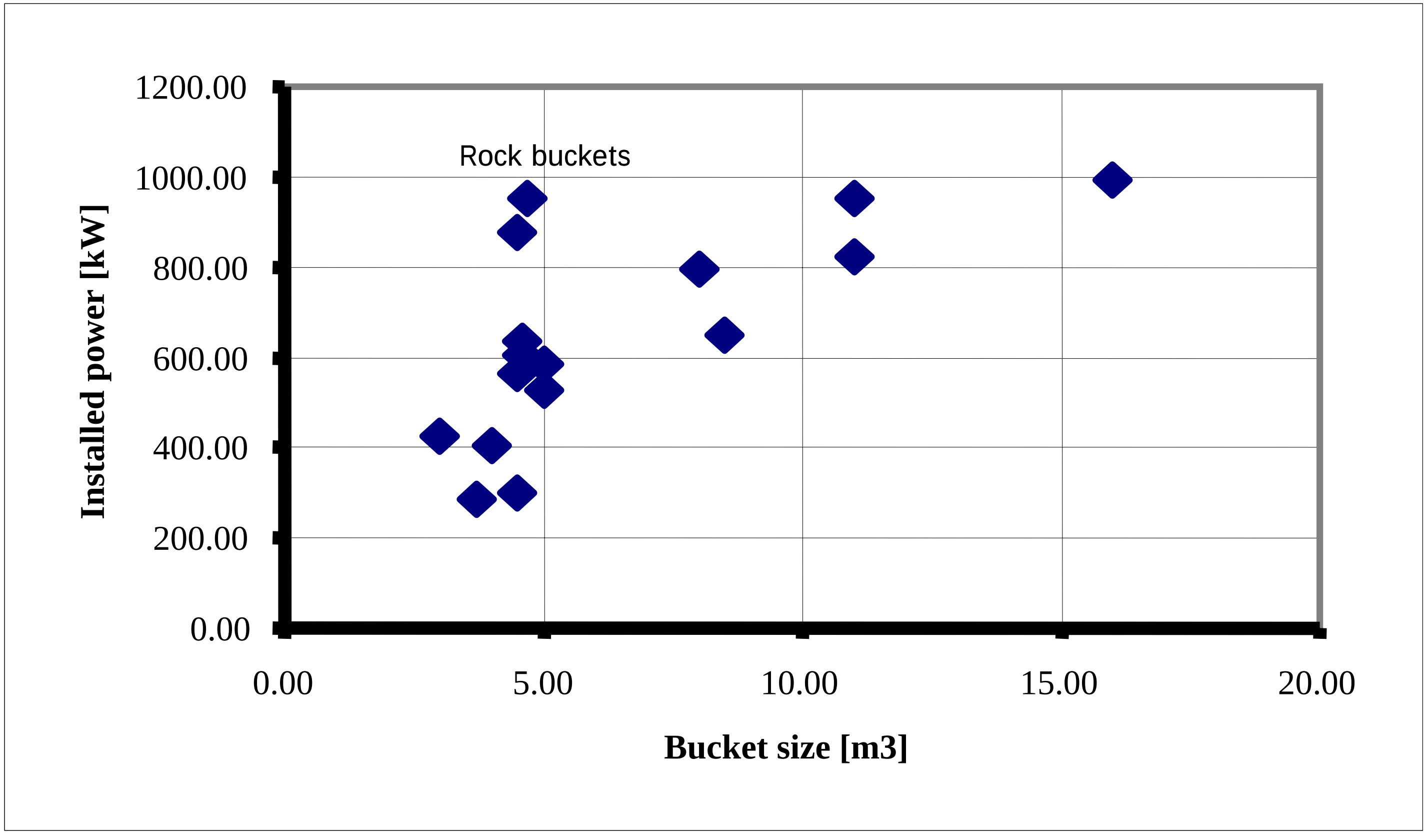
Crane weight versus bucket size for soft soil



Required power

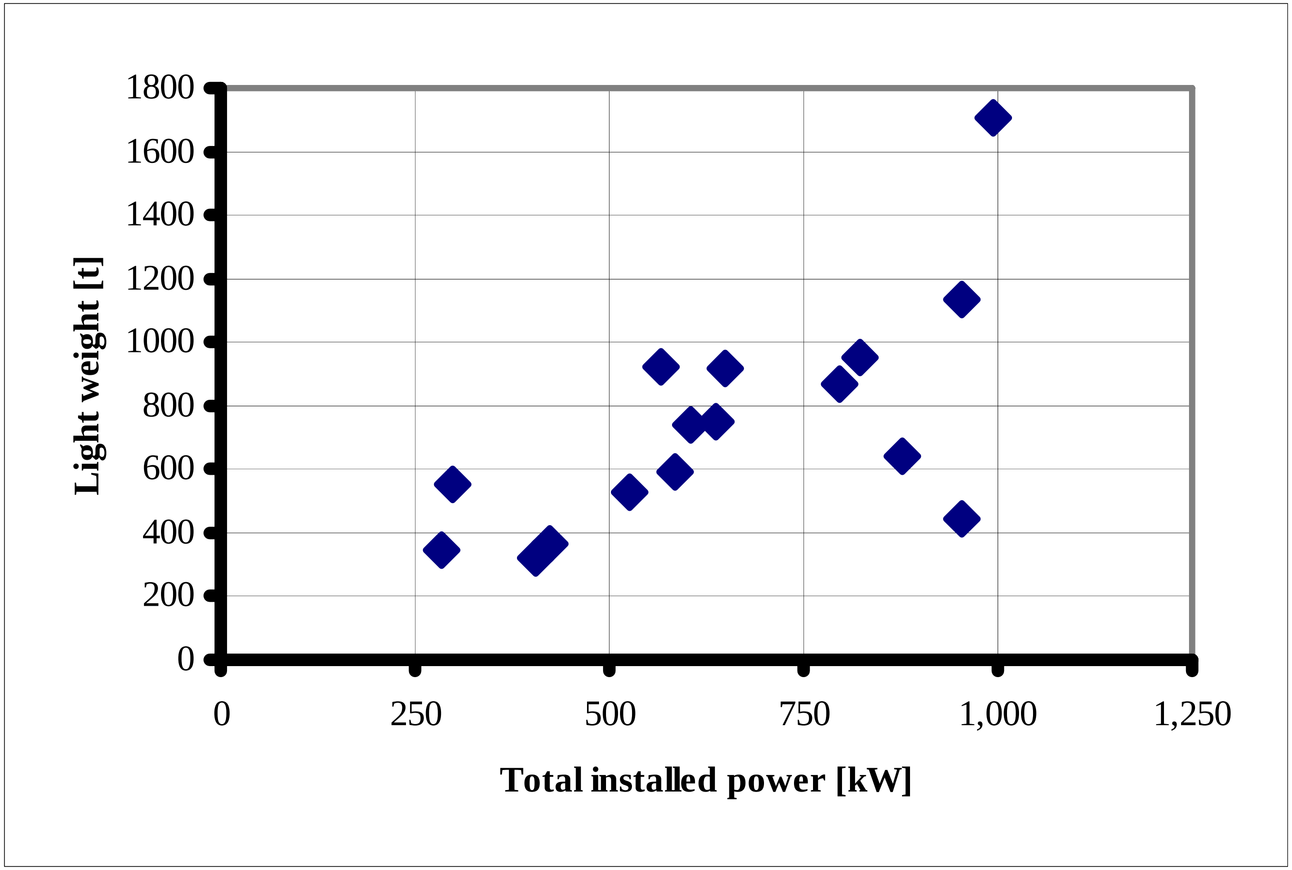


Relation for existing dredgers



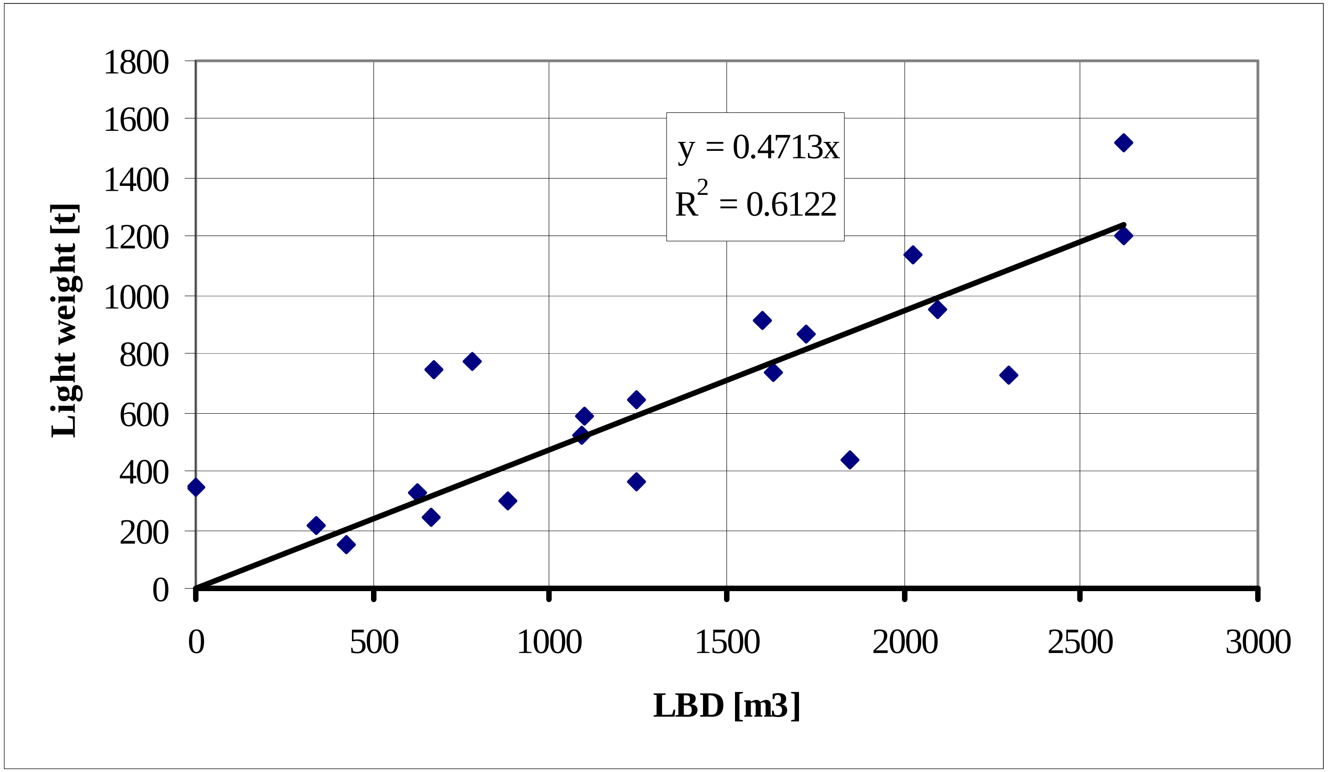
TU Delft

Light weight pontoon



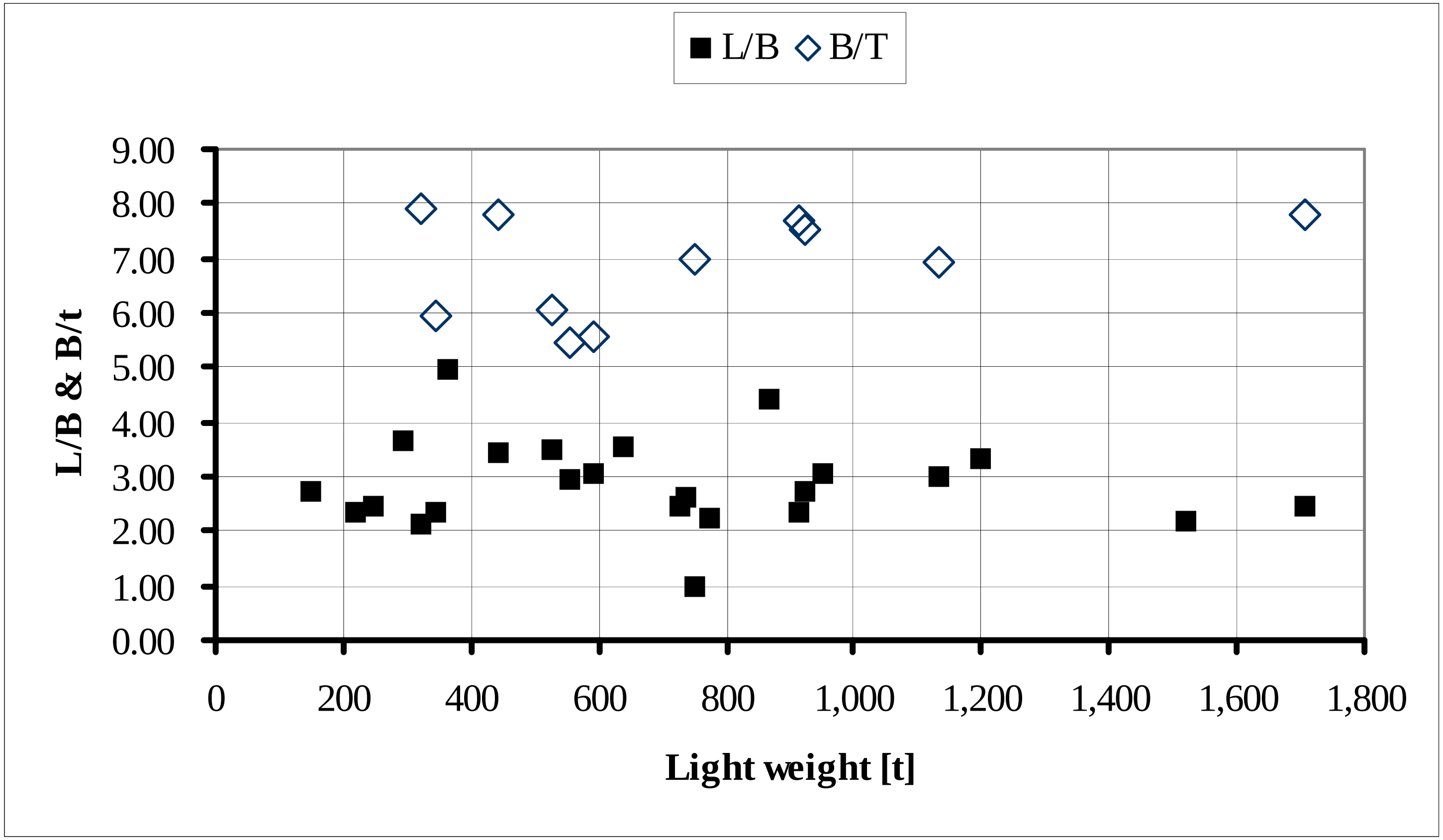
TU Delft

Pontoon volume



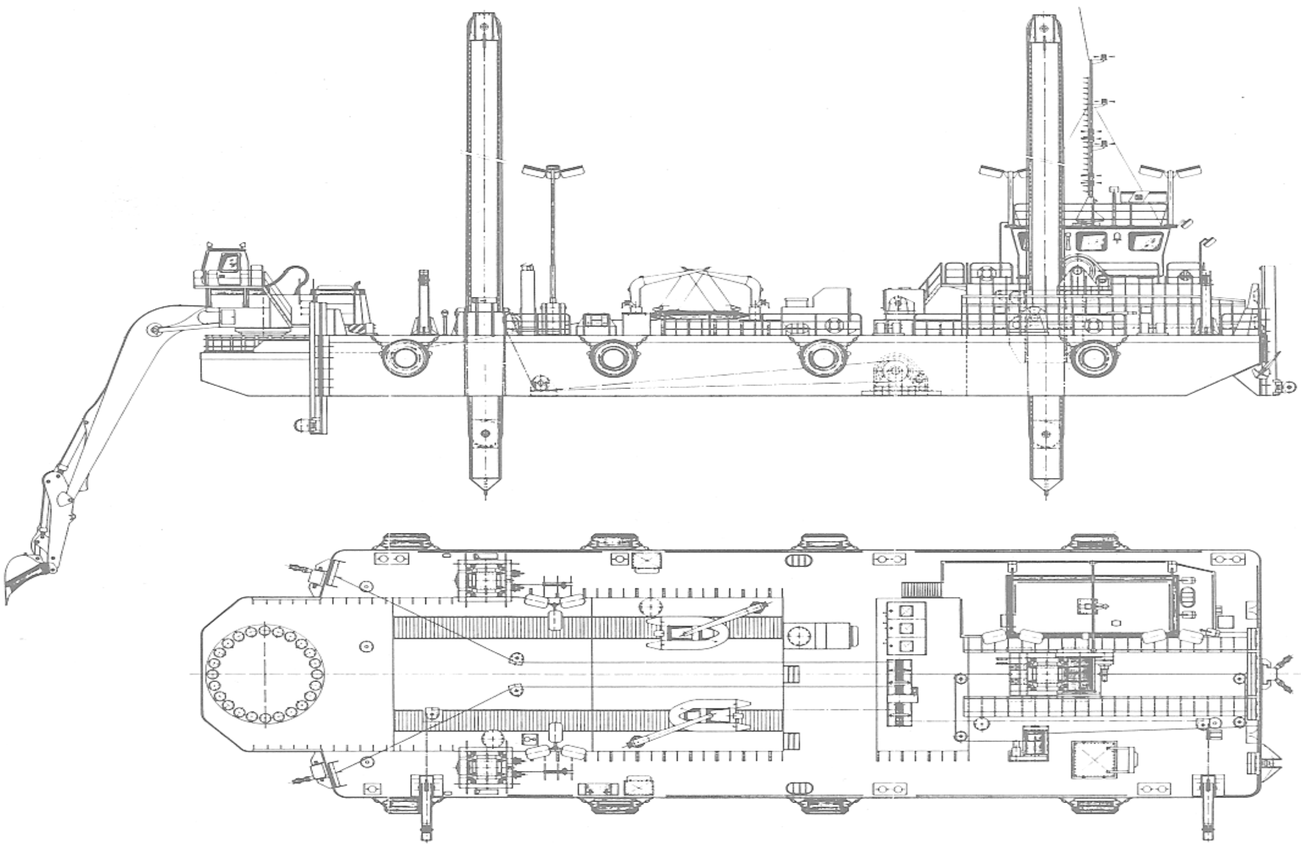
TU Delft

Ships numbers for BHD



TUDelft

Simple Plan



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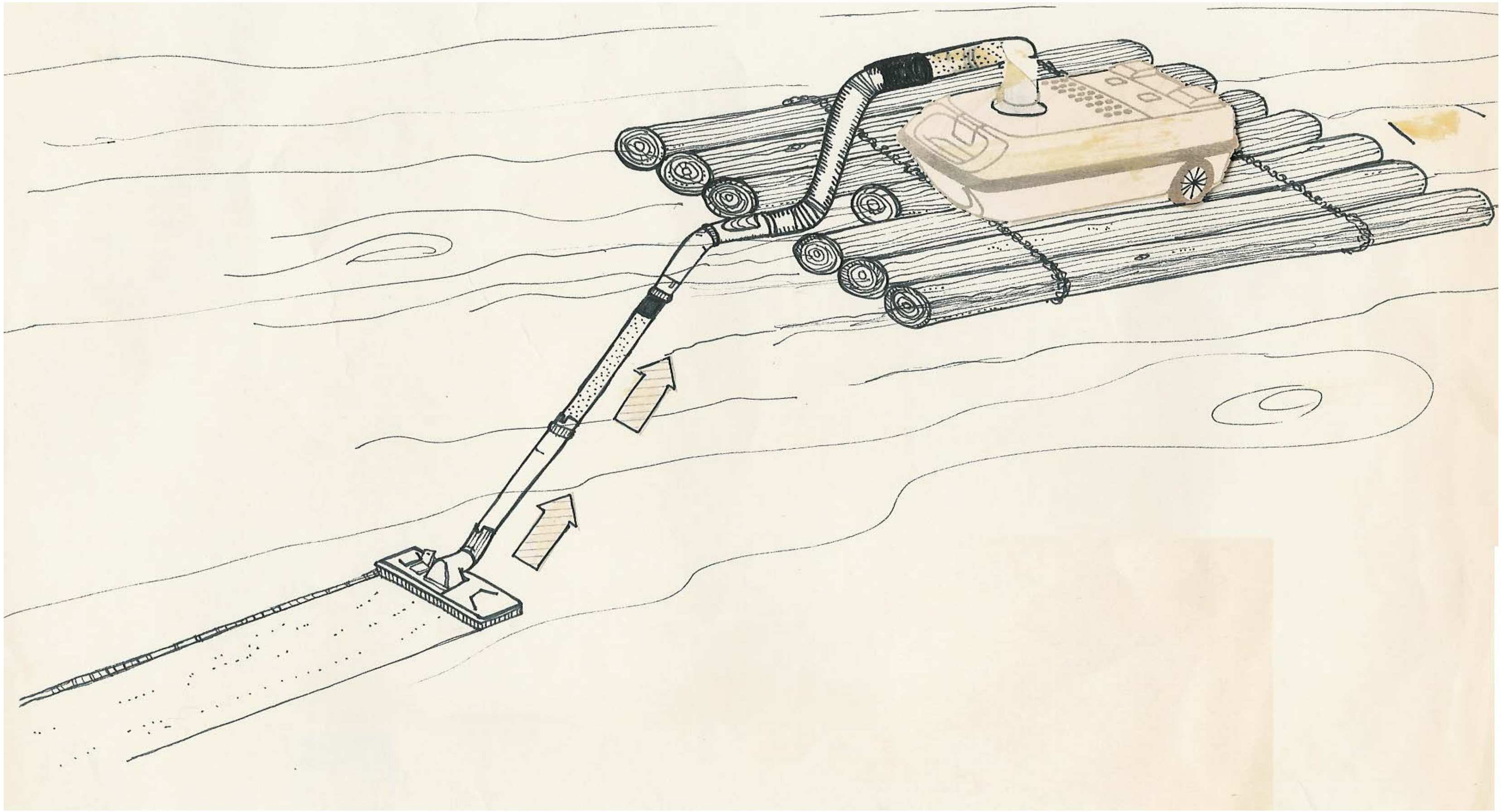
Newer ideas can be discussed



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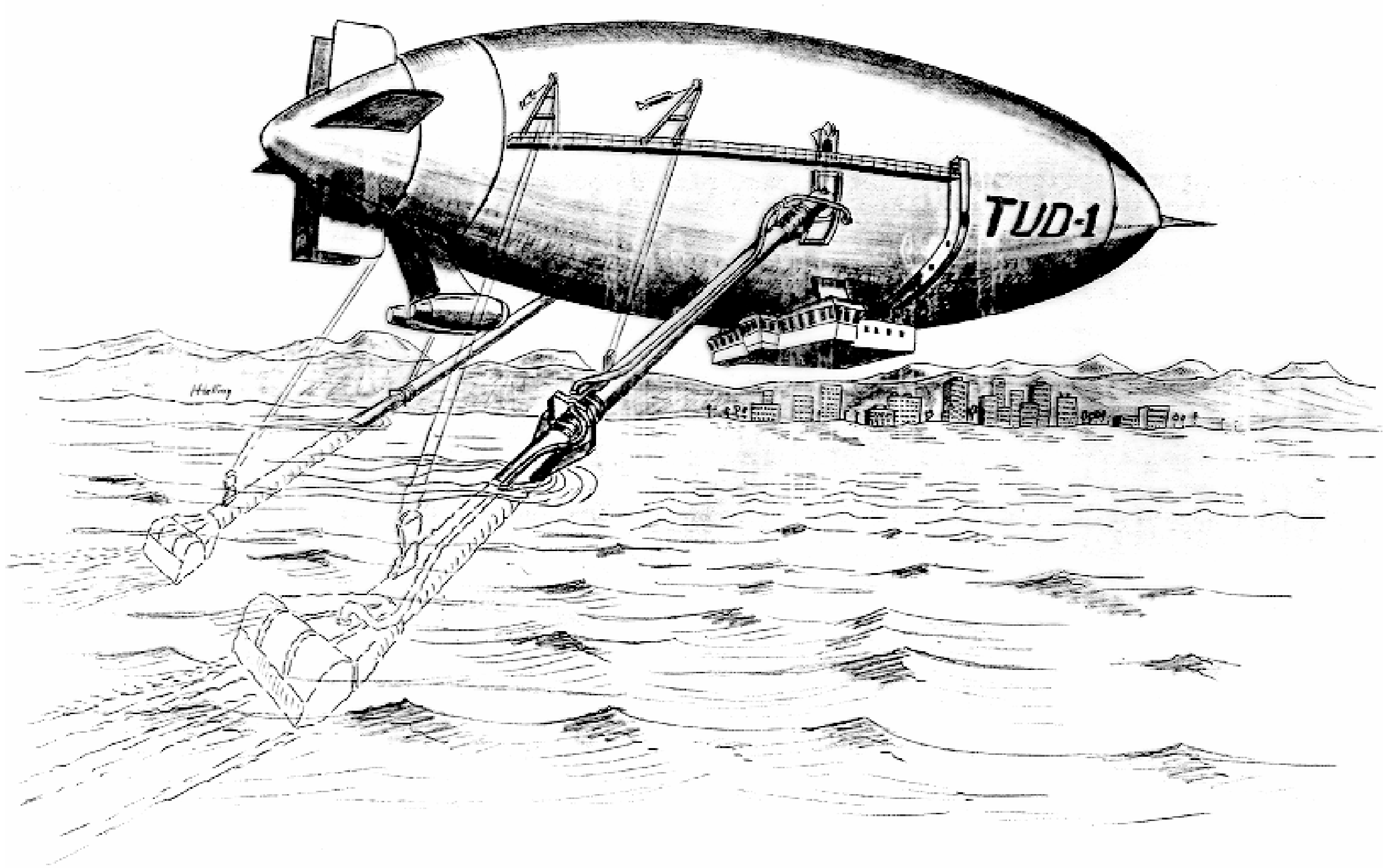
The shallow draught TSHD



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