Study on Sedimentation and Overspills from Dredging Operation using Numerical Model

by

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CERTIFICATION OF APPROVAL

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ABSTRACT

Trailing Suction Hopper Dredger (TSHD) is commonly used to dredge soft bed material. Problem arises when the fine sediment which has low settling ability is often released along the overflow of TSHD as suspended sediment. This contributes to high turbidity which could continue over a time span. The objective of this study is to measure the overspill's volume from hopper and to establish relations between inflow discharge (Q_i), hopper area (A_1=50 m x 15 m, A_2=25 m x 15 m and A_3=12.5 m x 15 m), settling velocity of sediment (i) v_s=0.0004 m/s (ii) v_s=0.0001 m/s (iii) v_s=0.000027 m/s, sediment concentration (i) C_i=10 kg/m^3 (ii) C_i=5 kg/m^3 (iii) C_i=3 kg/m^3 (iv) C_i=1 kg/m^3, and overspills (OV_o). The scope of study will cover modelling of sedimentation of fine sediment in Trailing Suction Hopper Dredger (TSHD) using MIKE 21 Hydrodynamic (HD) and Mud Transport (MT) software. The constant overspills is acquired through line discharge function and from there the trapping efficiency is calculated. All values are plotted in Graph Trapping Efficiency versus A/Q_i. The result shows a function of trapping efficiency □ A/Q_i, where the trapping efficiency will increase if inflow is decreased (inversely proportional) and efficiency will increase if hopper area is increase (directly proportional). The inflow concentration does not affect the trapping efficiency. However, low inflow concentration and low inflow discharge will lengthen the dredging loading time which is uneconomical and unproductive. The study provides good estimates on trapping efficiency for a hopper. The higher the trapping efficiency the lesser the overspills and there will be less negative impact towards the environment.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Dredging is the process of removing bed material (rock, gravel, sand or mud) out of the water and disposing of them at a various other location. This research focuses on Trailing Suction Hopper Dredger (TSHD) which is a type of hydraulic dredger. Hopper dredgers are free sailing, self-propelled vessels that load their hoppers when trailing. They can dredge all "non-rock type" soils or soft bed material.

Figure 1.1: Overspills from Trailing Suction Hopper Dredger. (Jan De Nul, 2009)

TSHD serves many purposes such as land reclamation, deepening the navigation channel, excavating construction material, removing contaminated material and many others. Trailing suction hopper dredger contains a large hopper for storage and transport of dredged materials. It implements the concept of overflow in order to increase the solid loads in the hopper and improve the efficiency of dredging operation.

Nevertheless, dredging pose dangers to environment and has caught the attentions of authority and environmental activists. It consequently cause increase in turbidity near the dredging work due to overspills and sediment dispersion. Dredging itself will cause change in topography at the dredging site and also at the relocation site. Many studies have been carried out to study the dispersion effect of overspills. However, not much study has been done to determine the overspills itself.

This study will implement MIKE 21 MT Model to model a closed area of hopper.

1.2 Problem Statement

Since TSHD is widely used to dredge soft bed, the most sensitive issue for TSHD is the suspended sediment. Unlike the excavated area which can be determined ahead and noise pollution which can be reduced by modern dredger, dispersion of suspended sediment is uncontrollable and best kept at minimum. From dredging work, there are several source of suspended sediment from water body. It could be from re-suspension of sediment cause by suction heads, overflow of dredging ships into the free water body, lost of sediment through the doors in the hull during transport, some sediment stripped from the main bulk during dumping and released of sediment into water during cleaning of suction pipes and the hopper.

Nevertheless, the **identified problem comes from overspills of sediment** from the TSHD since it is unavoidable for optimum loading of dredged material. Furthermore, the amount of overspills could be very large and it is directly influenced by the dredger operation, loading time and dredged material.

These overspills with a large volume pose significant impact to environment. The sediment released to water body could disperse in few ways, whether by dynamic plumes which descend rapidly towards seabed or by passive plumes where the fine particles may stay in the water column for several hours before settling and cover a large area. Whereby dynamic plumes could cause sedimentation where seabed is covered with layer of sediments, this could lead to burial of flora and fauna and fatality to sensitive species like coral, sea grass and mangrove which its breathing roots could be clogged by the suspended sediments. Suspended sediment from passive plumes could cause increase in turbidity. Turbidity induces backscattering and decreased light penetration which affect primary production and predators that feed on sight. Also, absorption of light could lead to reduced growth of bottom vegetations. **Therefore, reducing overspills altogether is the best way to reduce environmental impact of dredging.**

1.3 Objective

The main objectives of this study are;

i. To develop a model using MIKE software to predict overspills of hopper.
ii. To determine the overspills and trapping efficiency of a hopper
iii. To describe effects of hopper area, sediment size and inflow discharge towards trapping efficiency
iv. To describe approaches to minimize overspills

1.4 Scope of Study

The scope of study will be on dredging work of a Trailing Suction Hopper Dredger on loose grained seabed material. This study only focused on fine-grained material specifically silt of < 0.05 mm size since it has lower settling ability and pose threat as suspended sediment.

This study was conducted using MIKE 21 MT for fine sediment modelling. At the beginning stage the author focused on producing a working model. Then, various combinations of parameters were tested and analyzed. The tested varying parameters are hopper surface area, settling velocity of silt, inflow discharge of hopper and inflow sediment concentration.

CHAPTER 2

LITERATURE REVIEW

2.1 Working Principles of Trailing Suction Hopper Dredger

Figure 2.1: Drag head of a TSHD (Van Oord, 2010)

A Trailing Suction Hopper Dredger (TSHD) is a sea-going vessel equipped with suction pipes. It operates very much like a floating vacuum cleaner. The followings are descriptions of TSHD working principles by Bray, Bates and (1997). Upon arrival at the site, the suction pipes are swung outboard and the inboard end of the suction pipe are lowered at below water line and connected with the installed dredging pumps suction intake.

A TSHD could be loaded with one or two large centrifugal pumps. Attached to these suction pipes are drag heads which are trailed over the seabed with velocity ranging from one to five knots. Drag head function is to maximize the concentration of solid collected from the seabed. The erosive action of inflowing mixture helps the entrainment of solids from seabed into suction flow. The pumps suck the grain and water from seabed and transported it through the pipe work and routed directly to the hopper. The grain discharge is made via chutes in order to reduce turbulence. Significant turbulence inside the hoppers keeps the dredged mixture in suspension and this should be minimized to enhance the material to settle swiftly prior to the process of overflowing.

In the hopper, the heavy grains settle to the bottom and form a sand bed. Once the water height in hopper reaches the overflow pipes, the overflow phase will occur where excess water and lightweight grain will overspill. Overtime, the overflow losses will increase along with the increase of sand bed level. During loading process, overpills will progress until the maximum hopper capacity is reached.

2.2 Hopper as Settling Basin

During dredging process the excavated seabed sediment will be pumped through the pipe and into the hopper dredged as soil/water mixture. The mixture will basically enter the hopper as inflow discharge, Q_i and pass through sedimentation area, where most sediment will settle at the bottom as sand bed, water level and the excess water will overflow as outflow discharge, Braaksma et al. (2007) describe the loading process of hopper in Figure 2.2.

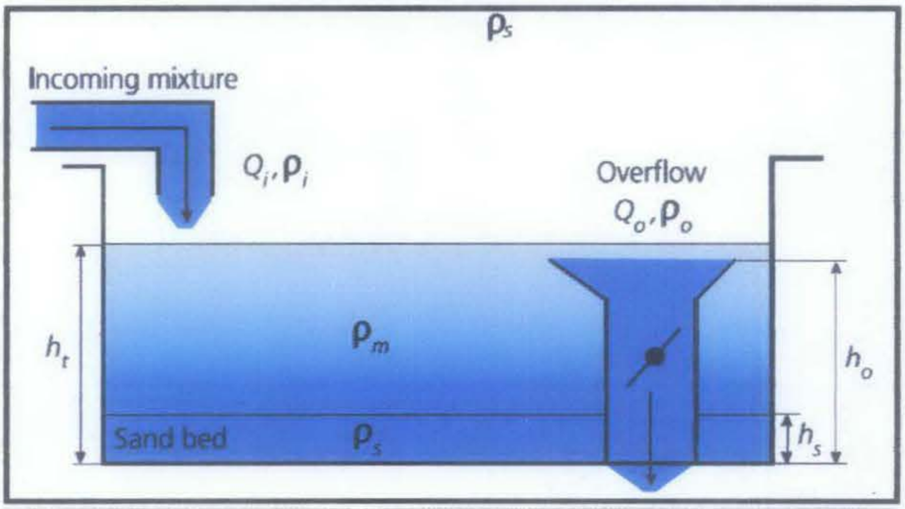

Figure 2.2: A schematic drawing of hopper dredger.

For computational modelling purpose, previous models have used black box approaches where they assume simplified velocity distribution and an ideal basin. The ideal settling basin consists of an entrance zone where the solid/fluid mixture enters the basin and where the grain distribution over the entrance cross-section, settlement zone where the grain settle on the hopper bottom and the overflow zone where the water overflow (Miedema and Van Rhee, 2007).

The Camp Model was first developed in 1946 to be used for sewage and water treatment tanks. Later, it was adopted by Miedema and Vlasblom in 1996 to be used for hopper sedimentation. Van Rhee 2DV Model also applies this ideal basin concept in modelling horizontal and vertical Reynolds Averaged Navier Stokes equation with k-e turbulence model.

Figure 2.3 shows a top view of the ideal settlement basin and Figure 2.4 shows the path of settling grain.

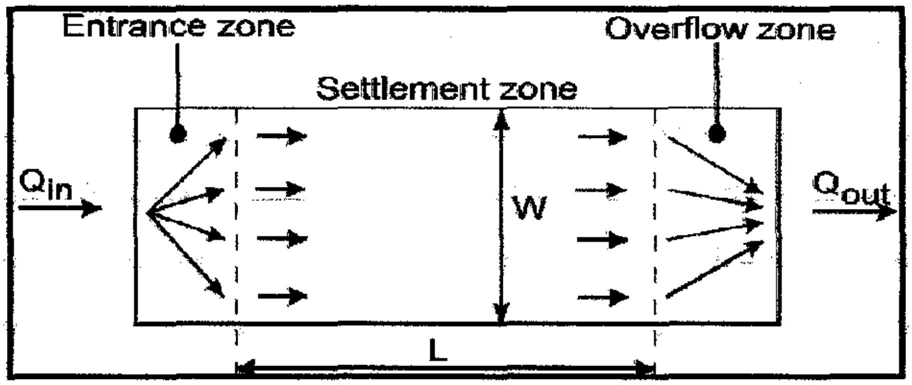

Figure 2.3: The top view of the ideal basin.

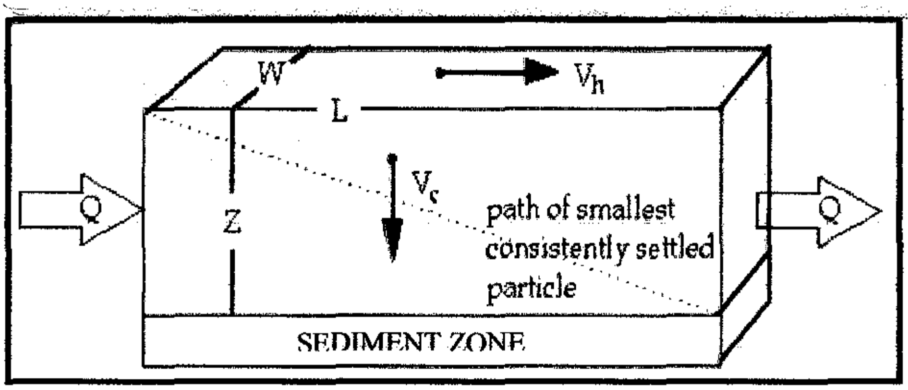

Figure 2.4: The path of settling grain. (Department of Agricultural and Biosystems Engineering, IOWA University)

2.3 Settling Velocity

Stokes Law is applied in estimating the settling velocity of sediments. The formula for Stokes Law is defined as:

$$V_s = \sqrt{\left(\frac{4g(\rho_p - \rho)d_p}{3\left(\frac{24\mu}{\rho V_s d_p}\right)\rho}\right)} = \frac{g(\rho_p - \rho)d_p^2}{18\mu} \qquad (2\text{–}1)$$

- V_s is the particles' settling velocity (m/s) (vertically downwards if $\rho_p > \rho$, upwards if $\rho_p < \rho$),
- μ is the fluid viscosity ($N \cdot s/m^2$ or $kg/(m \cdot s)$)
- d_p is the diameter of the particle (m)
- g is the gravitational acceleration (m/s^2),
- ρ_p is the mass density of the particles (kg/m^3), and
- ρ is the mass density of the fluid (kg/m^3)

Equation (2.1) is for Reynolds (Re) numbers < 0.1 and assumption that every particle is a sphere. Reynolds number is dimensionless number which measure the ratio of inertial forces to viscous forces in a given flow condition. For a water flow in a tube, Reynolds can be divided into laminar when Re < 2300, transient when 2300 < Re < 4000 and turbulent when 4000 < Re.

For Re < 0.1 and sphere sediment settling tank, Reynolds can be determined using Equation (2.2).

$$C_D = \frac{24}{R_e} = \frac{24\mu}{\rho V_s d_p} \qquad (2\text{–}2)$$

Table 2.1: Sediment Particle Diameters and Fall Velocity in Still Water.

Class Name	Diameter (mm)	Fall Velocity (cm/sec)
Very coarse sand	2.0 - 1.0	20
Coarse sand	1.0 - 0.5	12
Medium sand	0.5 - 0.25	5
Fine sand	0.25 - 0.125	2.2
Very fine sand	0.125 – 0.062	0.75
Coarse silt	0.062 – 0.031	0.16
Medium silt	0.031 – 0.0016	0.04
Fine silt	0.016 – 0.008	0.01
Very fine silt	0.008 – 0.004	0.0027
Corse clay	0.0040 – 0.0020	0.0006
Medium clay	0.0020 – 0.0010	0.00015
Fine clay	0.0010 – 0.0005	0.00004
Very fine clay	0.0005 – 0.00024	0.00001

(Source from Sediment Parameter and Calibration Guidance for HSPF by United States Environmental Protection Agency)

Table 2.1 provides fall velocity in still water; for diameters < 0.125 mm, estimated based on Stokes Law; assumed: median diameter from column 1, temperature = 24 deg C, and density = 2.65 g/cm^3. For larger particles, where Stokes Law does not apply, Rouse (1937) is used to estimate sand particles data.

The settling rate is based on gravitational force, downward and frictional resistance force, upward. Aside from very small size which contributes to low settling velocity, effects of Brownian motion and static charges n colloidal particles can cause the particles to be forever in suspension.

In basin, there is a critical settling velocity assigned to the smallest particle to be removed. Particles with settling velocity less than critical settling velocity will be removed in proportion to the ratio V_{si} /V_{sc} ratio (IOWA University, USA). The fraction removed can be calculated from;

$$Q_i = A \times V_{sc} \quad (2\text{-}3)$$

Where; A is actually area of basin (width x length). The formula shows that it is independent of depth thus this study focused on the hopper surface area instead of depth of hopper. Nonetheless, deeper depth will allow more volume of dredged material to be stored in hopper.

Furthermore, since hopper has large concentration of inflow sediment, sedimentation is likely to occur since it is formed when sediments settle and accumulate at the bottom bed. Settling can be further divided into 4 types as specified in Table 2.2.

Table 2.2: The four types of settlings.

Type	Description
Discrete (Type - I)	Individual settling, low solids concentration
Flocculant (Type - II)	Dilute suspension, particles flocculate, mass and settling rate increases with depth
Hindered (Type - III)	Intermediate concentration, mass settles as a unit, interface at top
Compression (Type - IV)	High concentration, structure formed, compression causes settling.

In conclusion, though the concept of settling basin is applied in the study, adjustment should be made where the hopper is expected to be in turbulence condition with high Reynolds number. Technically, in real dredging work, hindered settling is most likely to occur. The Equation (2.1) is for discrete settling but it gives good estimates on initial condition of sediment settling velocity in MIKE MT Model.

2.4 Sedimentation in Hopper

As observed in above Figure 2.5, the sedimentation in hopper will induce change in sand bed or bed rise. Based on Miedeme (2009) "the mixture moves down with the settling velocity causing the sediment to rise with the bed rise velocity. There is no mass added during the time step, so the sum of mixture mass and the sediment mass remain the same".

However, for our study the mass will continuously increase since the inflow is constant and sedimentation is an ongoing process. It is sufficient to understand that the sand bed level increase over time due to sedimentation. It concludes that sedimentation rate depends on settling velocity of sediment.

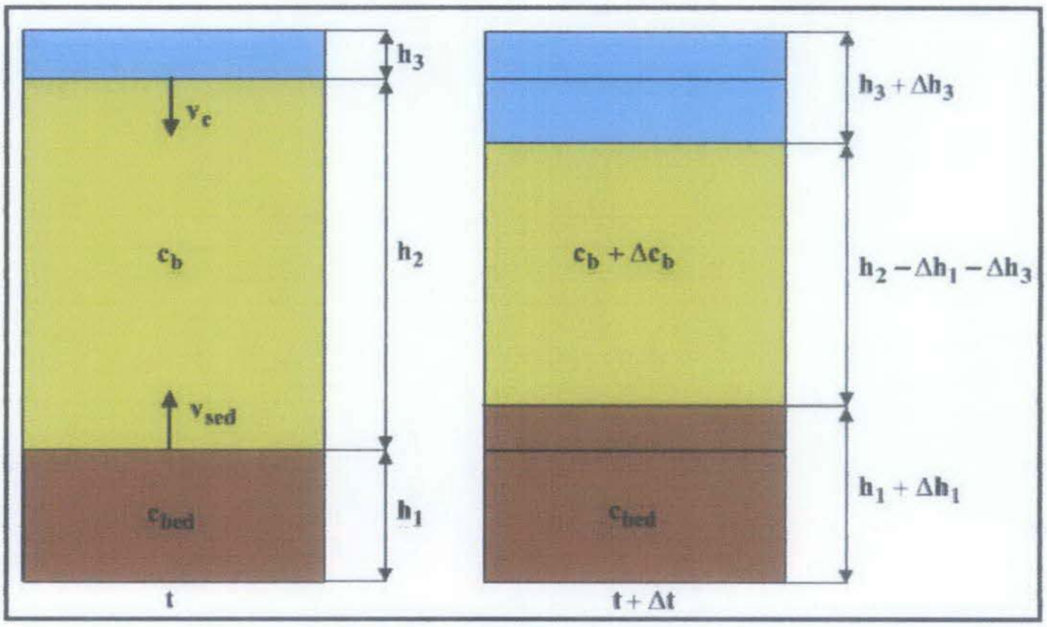

Figure 2.5: A segment of hopper at two different time step.

2.5 Overspills in Hopper

As previously discussed, during hopper loading, the excess water of dredged material or slurry in hopper will be disposed off as outflow during overflow process. The purpose is to increase the soil/water ratio in hopper by reducing water weight and increasing slurry weight and obtained a high density of settled material in hopper.

Since fine sediment has relatively low settling ability thus it is often released along with overflow, this loss of sediment due to overflow is called overflow losses or overspills. Figure 2.6 describes further on overflow losses.

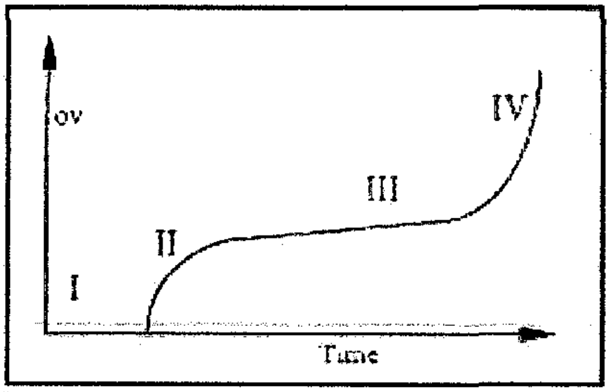

Figure 2.6: Phases in overflow loss. (P.J.T Dankers)

Phase I: In the beginning of loading process, initial height of hopper content, h_t will be below overflow height, h_o. There is no overflow occurring. Horizontal velocity is low thus the rate of sediment settling is good.

Phase II: This is a transition stage when the hopper content reach overflow pipe and begin to overflow. Horizontal velocity increase which cause decrease in settling efficiency and increase in overflow.

Phase III: The overflow pipe remains in constant position. The horizontal velocity increase and the volume of hopper mixture increase. However, the overflow is in "constant-volume" phase and contains typically low-density mixture.

Phase IV: The horizontal velocity increase and scouring will cause the extreme increase in overflow losses and volume in hopper to decrease. This phase is ended when the losses is high and no longer economical.

Technically, when it reaches Phase IV, the overflow pipe will be automatically lowered in order to maintain a constant hopper mass. However, this study will follow constant outflow point throughout the simulation (no adjustable overflow); this same method is used by Miedema and Van Rhee, 2007. The simplification of overflow field is shown in Figure 2.7.

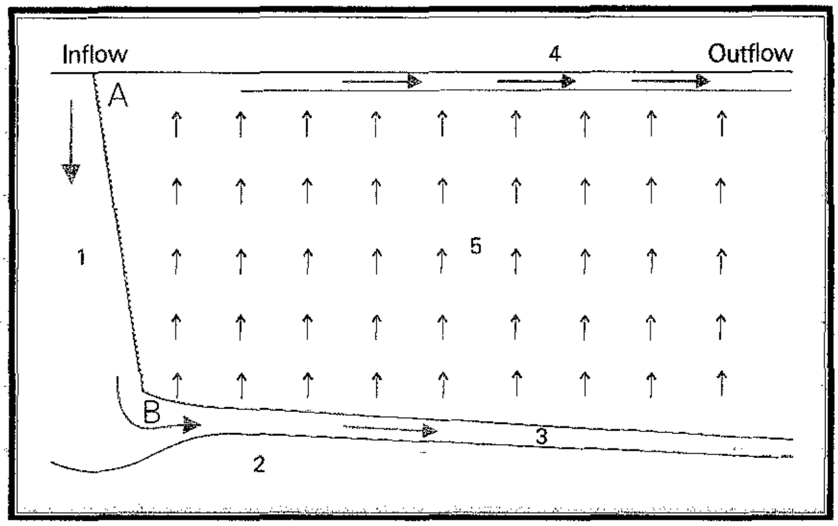

Figure 2.7: Observed flow field in the hopper. (Van Rhee, 2001b)

Unlike Figure 2.4 which shows only the grain settling path, Figure 2.7, describes the whole the flow field which consist of:

1) Inflow section
2) Stationary sand bed
3) Density flow over settled bed
4) Horizontal flow towards the overflow section
5) Suspension in remaining area

Van Rhee (2002) describes this process through a physical modelling in a laboratory flume (dimensions Length x Width x Height= 12 x 3 x 2) by using sediment median size of D_{50}= 0.105 mm. Through his observation, the inflow mixture will flow downwards and form an erosion crater and density current at the bottom. Sedimentation will result from the density current and lead to rising bed level. The unsettled grains will flow upwards into suspension. And, a horizontal flow is created at the water surface due to strong pushing force by the incoming mixture. It can be concluded that the sand size sediment will easily settle and the fine size like mud and silt will goes into suspension or unlikely to settle at all thus contribute to overspills.

In order to calculate overflow losses, a study by Ooijens (1999) has taken into account the overflow losses as a function of the grain size (D_{50}), the grain size uniformity (cu) which is the D_{60}/D_{50} ratio, the average flow, Q_{ave}, concentration in the hopper (Cv) and the height of the bed in the hopper (h_s). This formula is used when studying the sedimentation in the hopper. The relation is shown below;

$$\mathbf{OV} = f(\mathbf{C_v, Q_{ave}, h_s, D_{50}, cu}) \tag{2–4}$$

In addition, overflow losses can be determined through studying the amount of overspills. Van Rhee, 2002, states that the overflow losses can be defined whether as ratio of the outflow and inflow sand flux at the moment, or as the ratio of the total outflow and inflow volume. The overflow flux is defined as:

$$\mathbf{OV_{flux}(t)} = \frac{\mathbf{Q_o(t)\,C_o(t)}}{\mathbf{Q_i(t)C_i(t)}} \tag{2–5}$$

C_o is the outflow concentration, kg/m^3 while C_i is the inflow concentration, kg/m^3.
The cumulative overflow loss is defined as:

$$\mathbf{OV_{cum}(t)} = \frac{\sum \mathbf{Q_o(t)\,C_o(t)\,dt}}{\sum \mathbf{Q_i(t)C_i(t)\,dt}} \tag{2–6}$$

From the overflow losses, trapping efficiency of a hopper could be calculated using Equation (2.7) and Graph Trapping Efficiency versus A/Q_i could be re-plotted as in Figure 2.8 below which is uniquely for trapping in settling basin. The function of Trapping Efficiency (TR) is;

$$\mathbf{TR,\ \%} = \frac{\mathbf{(inflow\ sediment - outflow\ sediment)}}{\mathbf{inflow\ sediment}} \times \mathbf{100} \tag{2–7}$$

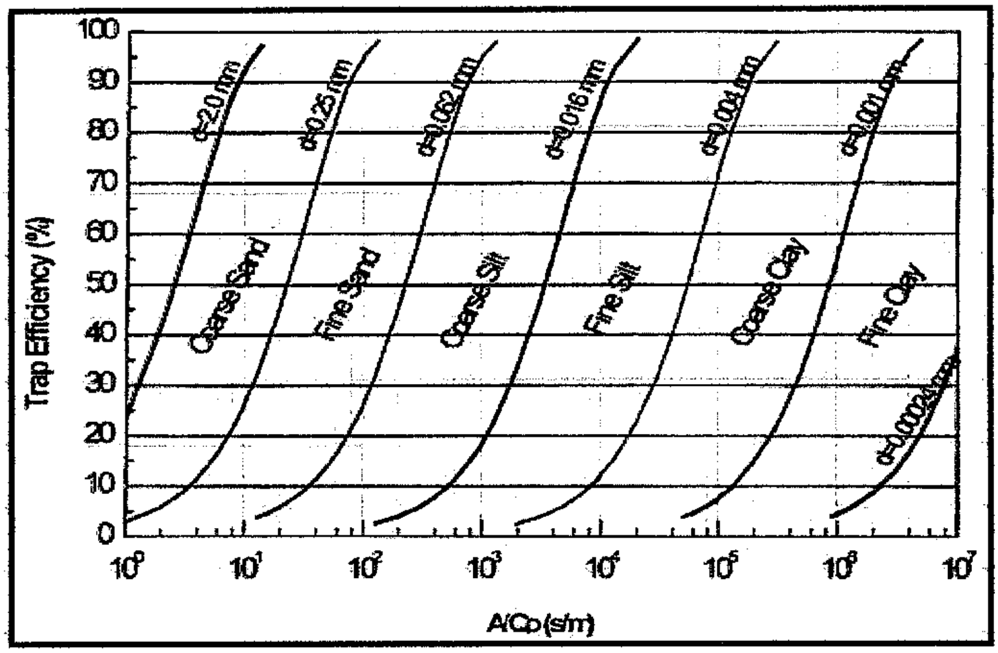

Figure 2.8: Overall Graph Trapping Efficiency vs A/Q_i. (DHI, 2009)

While the outflow losses can only be determined through simulation, the inflow sediment or inflow load can be calculated using formula;

$$\mathbf{Load_i = C_i \times Q_i \times T} \quad (2\text{–}8)$$

- $Load_i$ is total load of inflow (kg)
- C_i is inflow concentration (kg/m^3)
- T is total time of loading (s)
- Q_i is volume of inflow rate (m^3/s)

CHU (2010) mentioned that if no overflow allowed during dredging, only about 10% of normal load is carried by the TSHD and this will consequently increase the dredging cost.

2.6 Environmental Impacts of Overspills

The TSHD overspills causes release of suspended sediment in the water which will then form plumes. The plumes either mixed directly with the ambient water or act as density current. The plumes evolve through three dispersion phases which are passive plume, dynamic plume and cloud formation, refer to Appendix.

According to Dankers (2002), vegetation, fish, shellfish, algae, coral reef and other marine organisms can be negatively affected by the plumes. The dynamic plumes mostly cause burial of various species while passive plumes contribute to long term turbidity in the water phase. The most affected organisms are:

- Phytobenthos, plants that live on the sea bed.
- Phytoplankton, plants that drift or float in the water column.
- Zoobenthos, animals that live on or in the sediment. Further subdivided into Microbenthos and Macrobenthos.
- Zooplankton, animals that float in the water, mostly eating plant.
- Fish which further divided into Benthic, live close to sea bed, and Pelagic, live in water column.

According to Bray (2008), turbidity describes on how clear water is, also means the degree to which water contains particles that cause backscattering and absorption of light and extinction of light. Turbidity is a natural phenomena but a high turbidity may be caused by a high content of fine sediment and/or organic particles (IADC/CEDA, 2000).

Decrease in light penetration cause decrease in food production of photosynthesis activities by bed vegetation and phytoplankton. Also affected by limited light penetration are the predators that feed on sight. Fine sand does not absorb much light but silt and clay or coagulates of clay and organic material can absorb much light (Dankers, 2002). Furthermore, fine size particle such as medium clay; 0.002-0.001 mm and has very low settling ability; 0.00015 cm/sec (ASCE, 1975).

Indeed there are creatures like filter feeders, deposit feeders and a lot of bivalves that can either collect food from suspension, on seabed or both which can benefit from the increasing suspended sediment concentration since the organic matter has also increase (Groenewold & Dankers, 2002). But more critically, turbidity due to suspended fine sediment could continue over a time span thus heavily impacting the primary production of food and many other organisms higher in the food web.

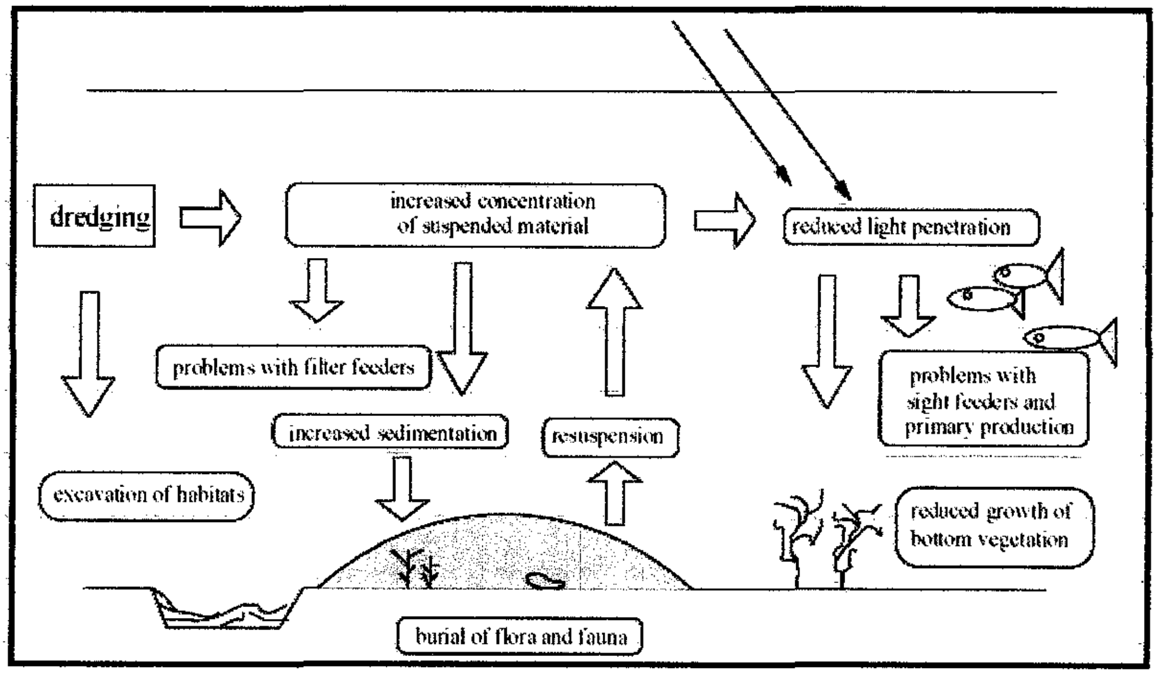

Figure 2.9: Impact of dredging on ecology. (P.J.T. Dankers, 2002)

For a major dredging work, the amount of overspills could be very large which lead to significant negative impact on environment. For a case study on effects of hopper dredging and sediment dispersion at Chesapeake Bay, United States, Nichols et al (1990) explain that:

"The upper plume dispersed over 5.7 km^2 extending 5,200 meters form the discharge point. Redeposited sediment accumulated on channel flanks covering an area of 6.4 km^2 and reached a thickness of 19 cm. Altogether, dredging redistributed into the environment an estimated 100,000 tons of sediment or 12 percent of the total material removed. Near-field concentrations of suspended sediment, less than 300 m from the dredge, reach 840 to 7,200 mg/L or 50 to 400 times the normal background level. Far-field concentrations (>300 m) are enriched 5 to 8 times background concentrations and persist 34 to 50 percent of the time during a dredging cycle (1.5 to 2.0 h)."

CHAPTER 3

METHODOLOGY

3.1 The Project Flow

MIKE 21 is a modelling of 2D free-surface flows. It widely used for simulating the hydraulic condition at seas, lakes, estuaries, coastal areas. For this study, the hydrodynamic module (HD), where its main function is to provide hydrodynamic basis of computation, is coupled with sediment transport module (MT), which describes erosion, transport and deposition of silt mud and clay particles. It is basically an innovation to use MIKE 21 MT for modelling a small area and high concentrated hopper and its overspills.

At the initial phase, this project emphasis on data gathering. This is because many studies have been made to study the effect of overspills dispersion yet hopper sedimentation and overspill itself is very rare. A real dreding data of TSHD for small hopper with 2316 m^3 is used. From the literature review, the identified varying parameters that affecting overspills are inflow rate, hopper area, sediment concentration, settling velocity of sediment. The bathymetry or hopper layout is designed and the model is setup based on the data collected for Hydrodynamic Model (HD) and Mud Transport Model (MT). A total of three different layouts with constant depth of 6.18 m but varying in hopper area.

A stable HD model is crucial to ensure the accurate flow of water from inlet point towards overflow point. After the HD is stable, we established the MT model. The MT is more difficult to set up since instability occurs due to the high concentration of sediment. Overflow losses is measured by assigning line discharge right before the overflow point during its steady state which is Phase 3.

Then the simulation is run again by changing one of the parameters. The overall results and plots can be viewed in the Chapter 4. The overall project flow can be summarized as Figure 3.1.

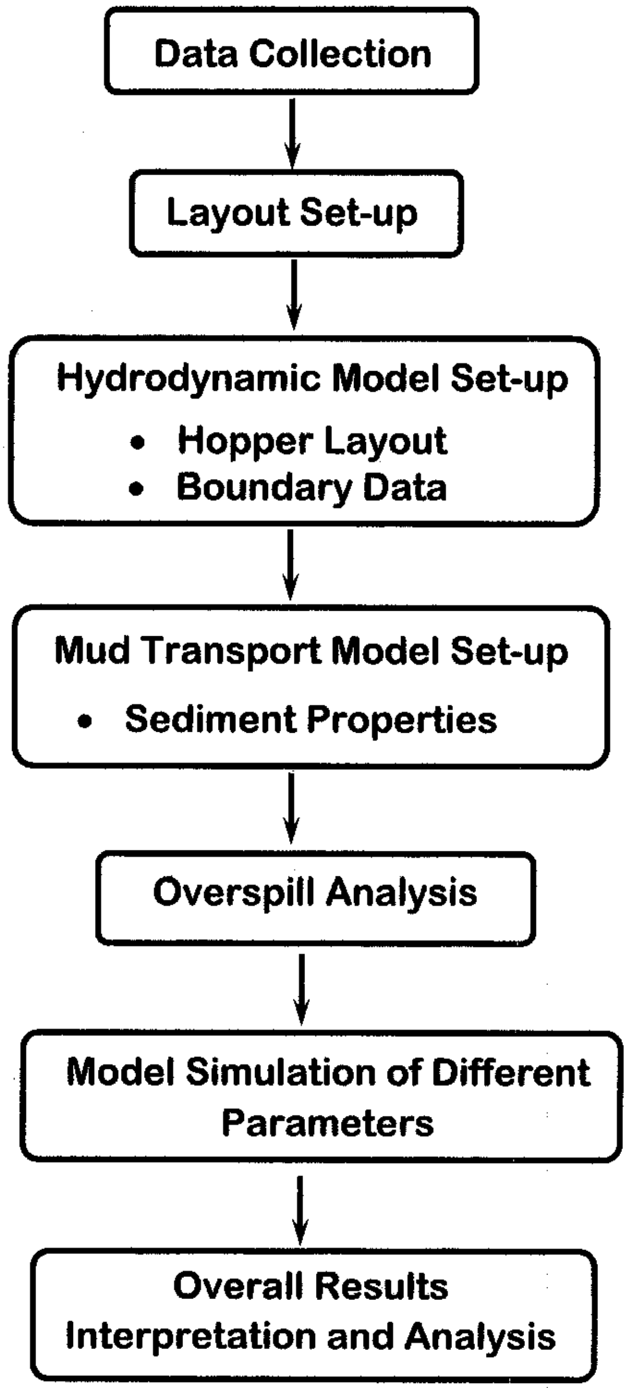

Figure 3.1: General project flow for the study.

3.1.1 Layout Set-up

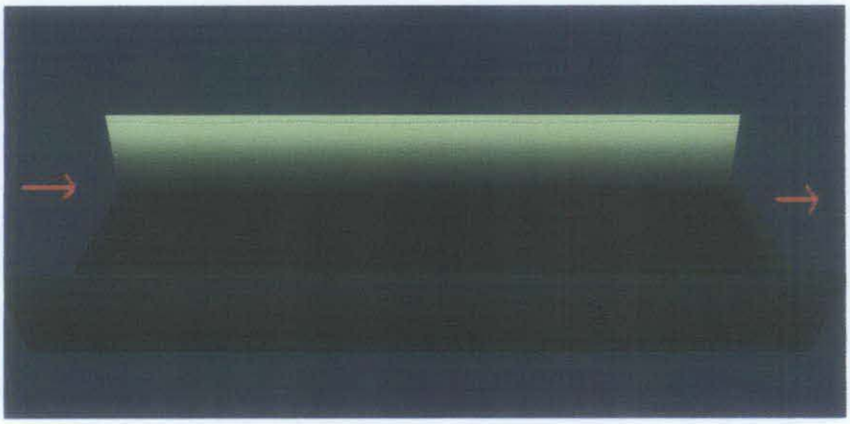

Figure 3.2: 3D view of hopper layout.

MIKE 21 uses the hopper layout as bathymetry. The model layout is based on settling basin which take after The Camp Model where the flow in through entrance zone and passing through the settlement zone and overflow over a weir at overflow zone. The flow is allowed in one direction as shown using the red arrow. The hopper is constructed using MIKE Grid Editor application by using 0.5 meter grid spacing horizontally and vertically. The hopper walls are shown in red with +5 m elevation, the hopper bottom is at -6.18 m elevation and the weir at -0.5 m elevation.

Since the water level is more or less constant at 0.00 m elevation throughout the simulation, the hopper will have water depth of 6.18 m and 0.5 m thickness of water layer above overflow level. Though the wall is specified as +5 m, it only to serve the purpose of true land where water will not reach there.

Based on the real data of small hopper 2316 m^3 volume, the derived A_2 hopper dimension is 25 m x 15 m x 6.18 m (=2316 m^3). To study the effects of hopper area towards overspills, the area is doubled and halved in order to study the effect. Since depth is independent of trapping efficiency, constant depth of 6.18 m is applied to all three hoppers.

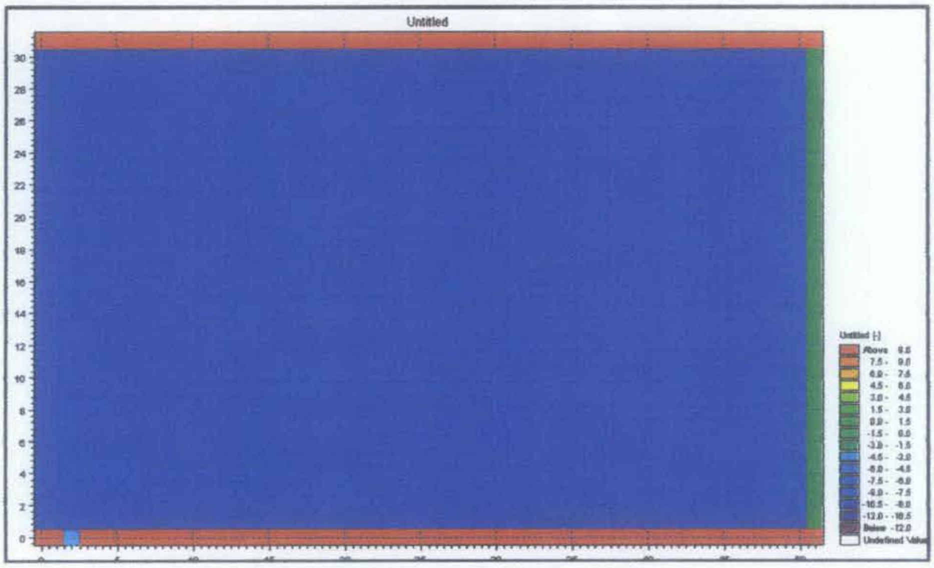

Figure 3.3: Plan view of hopper layout in Grid Editor.

3.1.2 Hydrodynamic Model Set-up

MIKE 21 usually used to model large area thus a hopper area is considered too small and instable. In setting up HD Model, the aim is to stabilize the flow of water where it will consistently flow from entrance towards overflow zone and have consistent water depth. Some measures taken are;

- Implementing a starting volume of water when the loading process starts, 0.00m elevation.
- Setting the boundary at entrance as flux discharge (m^3/s) based on Q_i specified.
- Setting the boundary at overflow zone as constant level of 0.00 m throughout the simulation.
- Use a very small time step of 0.1 s.
- All courant no is set as 1.55804 < 2 (the smaller the number the more stable the simulation.
- Implementing the CVS system where no adjustable overflow throughout loading process

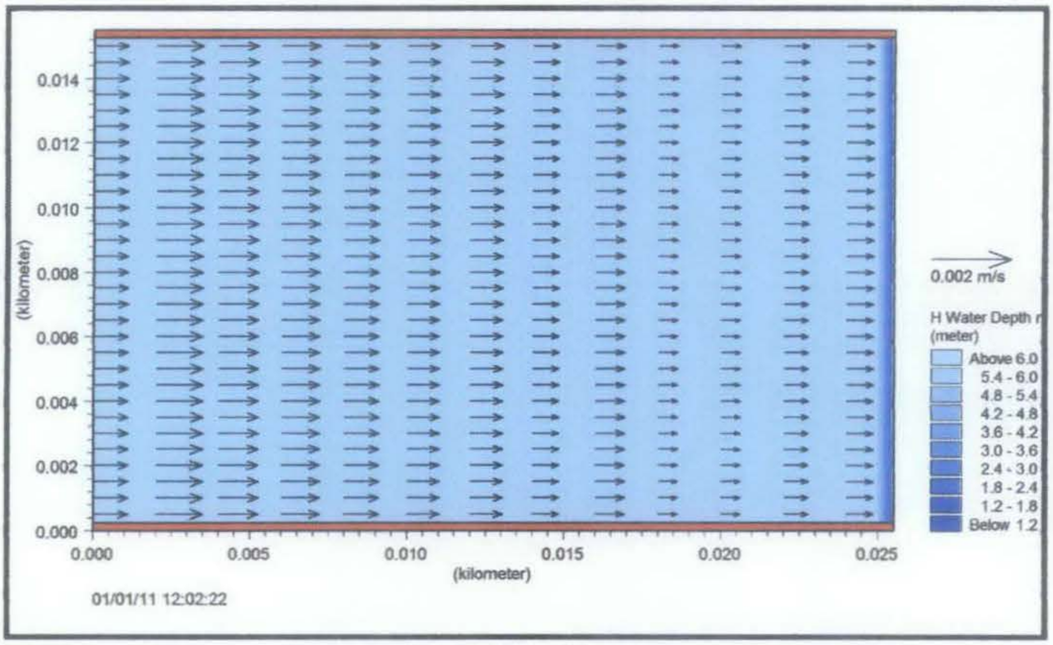

Figure 3.4: Water depth and flow direction in hopper during HD simulation.

Other specifications are;

- A Manning number of 31 $m^{1/3}/s$ is chosen base on the normal bed resistance value which range from 20 to 40 $m^{1/3}/s$ (MIKE 21, 2009).
- No wind or wave force since it is an enclosed area.
- Time step varies with each simulation; the aim is to reach the steady Phase 3 of overflow.
- Eddy Viscosity using Smagorinsky Formula with 0.5 constant.
- Drying depth and flooding depth is omitted since there is no tidal effect and the water depth is constant.

3.1.3 Mud Transport Model Set-up

For MIKE MT model, the first step is to assign values for key parametrs as shown in Table 3.1.

Table 3.1: Parameters for Mud Transport Model (MT)

Parameters	**Values**
Initial Concentration	0 mg/L
Dispersion in x-direction	Proportionality factor 1 to the current.
Dispersion in y-direction	Proportionality factor 1 to the current
Critical shear stress for deposition	0.09 N/m^2
Critical shear stress for erosion	0.10 N/m^2
Erosion coefficient	0.000004 kg/ m^2/s
Power of erosion	4
Density of bed material	400 kg/m^3
Bed Roughness	0.01 m

The second step is to assign the boundary concentration based on inflow concentration of dredger. Based on assumption that all sand will settle, focus is given to fine sediment therefore only one fraction of sediment is allocated. For that one fraction, the associated settling velocity is assigned at entrance boundary.

Third step is to specify the line discharge. The line discharge facility is used to calculate the transport of a substance through a user specified cross section of the model area (MIKE 21, 2009). Using this function, intantaneous load and cumulative load can be generated. For load in, the line discharge is set parallel and 2 grids after entrance zone. For load out, the line discharge is set parallel and 2 grids before reaching the overflow zone. Figure 3.5 shows the extracted overspills from line discharge function.

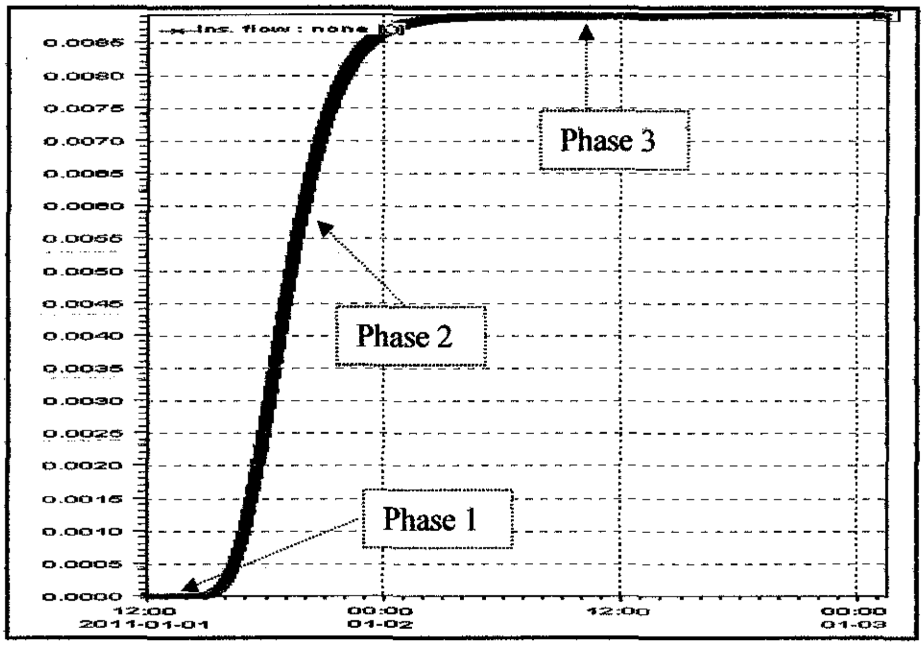

Figure 3.5: Overspills, kg versus time, s.

Once the MT model has finished running, the instantaneous load in is checked to ensure that the Phase 3 was reached. If it has yet to reach Phase 3, the simulation period is increased and the simulation is rerun. This step is repeated as many times necessary.

3.1.4 Varying Parameters

In order to plot the Trapping Efficiency versus A/Q_i data, about 100 simulations are required which will further distinguished into 12 sets. Below is the list of all varying parameters implemented in this study;

a) Hopper Surface Area, A

i. A_1= 50 m x 15 m

ii. A_2= 25 m x 15 m

iii. A_3= 12.5 m x 15 m

b) Inflow Concentration, C_i

i. C_1=10 kg/m^3
ii. C_2= 5 kg/m^3
iii. C_3= 3 kg/m^3
iv. C_4= 1 kg/m^3

MIKE MT model is set-up for modelling coastal areas and sea. It cannot handle the overwhelming concentration of typical TSHD's design density of 1000 kg/m^3. The model become unstable and will blow-up. Therefore, lesser concentrations of inflow are proposed based on knowledge that concentration does not affect the trapping efficiency.

c) Settling Velocity, v_s

i. Medium silt, 0.024 mm diameter = 0.0004 m/s
ii. Fine silt, 0.012 mm diameter = 0.0001 m/s
iii. Very fine silt, 0.006 mm diameter = 0.000027 m/s

d) Inflow rate, Q_i

The inflow is adjusted based on the author judgment in order to achieve higher or lower A/Q_i ratio.

Table 3.2: Allocation of the varying parameters.

	Hopper Area, A (m^2)	Sediment Concentration, C_i (kg/m^3)	Settling velocity, v_s (m/s)
Set 1	A_1=50 m x 15 m	10	0.000400
Set 2	A_2=25 m x 15 m	10	0.000400
Set 3	A_3=12.5 m x 15 m	10	0.000400
Set 4	A_1=50 m x 15 m	10	0.000100
Set 5	A_2=25 m x 1 5m	10	0.000100
Set 6	A_3=12.5 m x 15 m	10	0.000100
Set 7	A_1=50 m x 15 m	10	0.000027
Set 8	A_2=25 m x 15 m	10	0.000027
Set 9	A_3=12.5 m x 15 m	10	0.000027
Set 10	A_1=50 m x 15 m	5	0.000100
Set 11	A_2=25 m x 15 m	1	0.000400
Set 12	A_3=12.5 m x 15 m	3	0.000027

3.2 Literature Review

The principal of dredging and the sedimentation of hopper are analyzed in the literature review in Chapter 2. Varying parameters which affecting the overspills and key parameters for model set-up are also determined through literature review.

3.3 Key Milestone

This project has completed its scope of where the simulations have run for three different layouts A_1, A_2 and A_3. There are three sizes of silt type fine sediments used in this study. The simulations are performed in sets where in every set, the inflow discharges are varied. Proceeding on, the inflow concentration is manipulated. Total of 12 sets different dredging conditions were performed with about a hundred simulations in total, details is given in Table 3.2. All results are provided in the Appendix section.

- Set 1-9; varying the settling velocity and hopper area
- Set 10-12; varying the sediment inflow concentration

3.4 Tools

Since the work is computational modelling based, the necessary tools is in the form of hardware and software. The tools are listed in Table 3.3 below.

Table 3.3: Tools for FYP Project

Hardware	• Installation DVD for MIKE software developed by DHI Water & Environment. • Dongle to allow simulations to run, without this the MIKE will run only in demo mode. • External hardisk of 500 GB capacity, this allow sufficient storage for all simulations set up and results file (size of one dfs2 result file could reach up to 10 GB)
Software	• MIKE 21 is a 2D flow model for the coastal water and seas • MIKE 21 MT to model the dynamic of fine sediment during hydraulic processes. • MIKE Zero for preparing the input files and also for plotting and analyzing the results. • MIKE Tools for extraction of the result. • MIKE 21 HD and MT Modules to enable analysis of simulations results.

CHAPTER 4

RESULTS AND DISCUSSION

Throughout this project, we prove that MIKE MT is able to perform a simulation of sedimentation and overspills. Though the main concern is the low inflow concentration in MIKE MT compared to real dredging concentration. In real dredging work, the hopper design density could reach to more than 1000 kg/m^3. But through the simulation results, it shows that concentration is not a function which affecting the trapping efficiency of certain hopper. Therefore it is acceptable to adjust the inflow concentration in our simulation set-up.

Focus will be given on MIKE MT results since the flow in basin is basically one-way and the validity of MIKE HD has been confirmed before proceeding with MIKE MT simulation. Analysis will be done on different phases of overflow, sedimentation in hopper and the overspills itself. This is to understand and produce a relationship between overspills and affecting parameters; hopper area, inflow discharge and settling velocity for particular sediment.

4.1 Sedimentation in Hopper

The scope is to model the sedimentation and overspills behaviour of different silt sediments in hopper. In the literature review, it said that sand will mostly settle while most fine sediment will unlikely to settle. Nevertheless, it is probable that some of the silt able to settle and cause sedimentation in hopper, some silt will remain in suspension and the rest is removed through overspills.

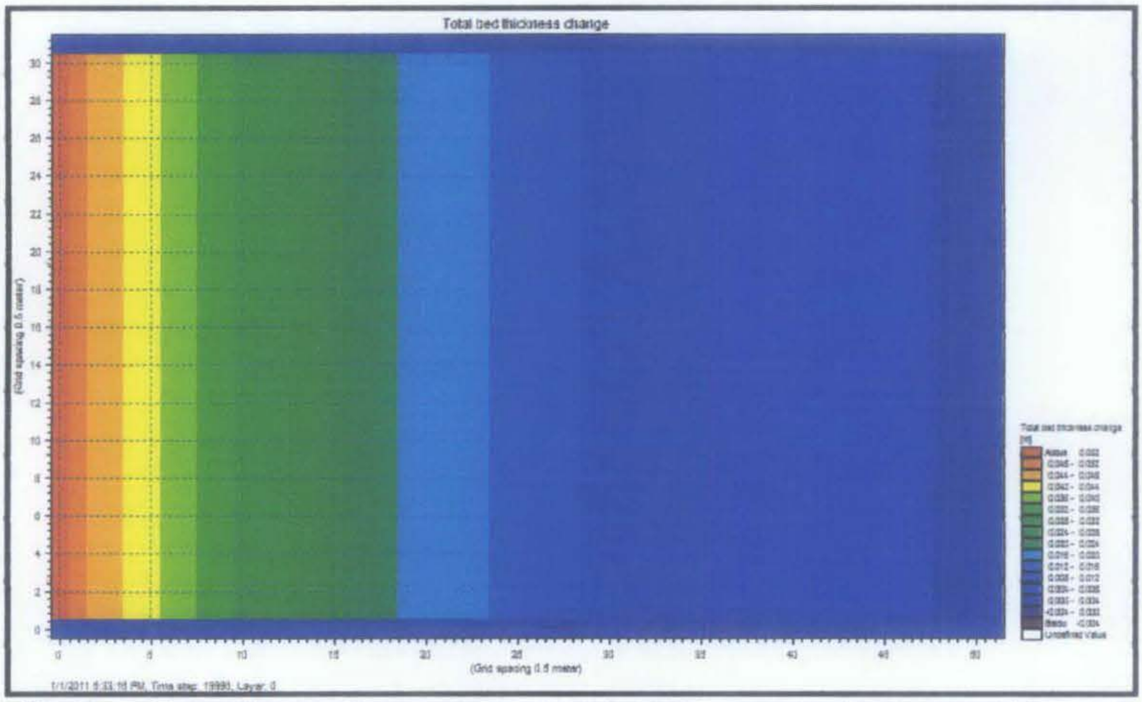

Figure 4.1: Total bed thickness change (m) in hopper.

Figure 4.1 shows as example of MT results indicating the total bed thickness change is for one of the case (v_s =0.0004 m/s, A_2 =25 m x 15 m, Q_i =0.2 m^3/s and C_i =1 kg/m^3) shows that sedimentation for silt did occur in the hopper. The maximum thickness of sedimentation is 0.513 m. From the legend, the result can be interpreted as having the highest sedimentation near the inlet and gradually reduce towards the overflow area. This model yields 84.8% of trapping efficiency.

For model set-up v_s=0.0004m/s, A=25 m x 15 m, Q_i =2.0 m^3/s and C_i=1 kg/m^3 with trapping efficiency of 13.8%, the maximum sedimentation thickness is 0.012 m. It directly shows that the higher the trapping efficiency will contribute to better sedimentation. The decrease in inflow discharge helps in improving sedimentation inside the hopper.

4.2 Phases of Overflow Losses

As discussed in literature review, there are in total four phases of overflow. However, in real dredging practice, it is uneconomical to proceed to Phase 4 since scouring will start in this phase once the sediment level is so high and that the velocity above the bed is very high. Scouring will reduce the total load inside the hopper. Dredging will usually stop at the end of Phase 3, therefore the simulations are run until it reach Phase 3.

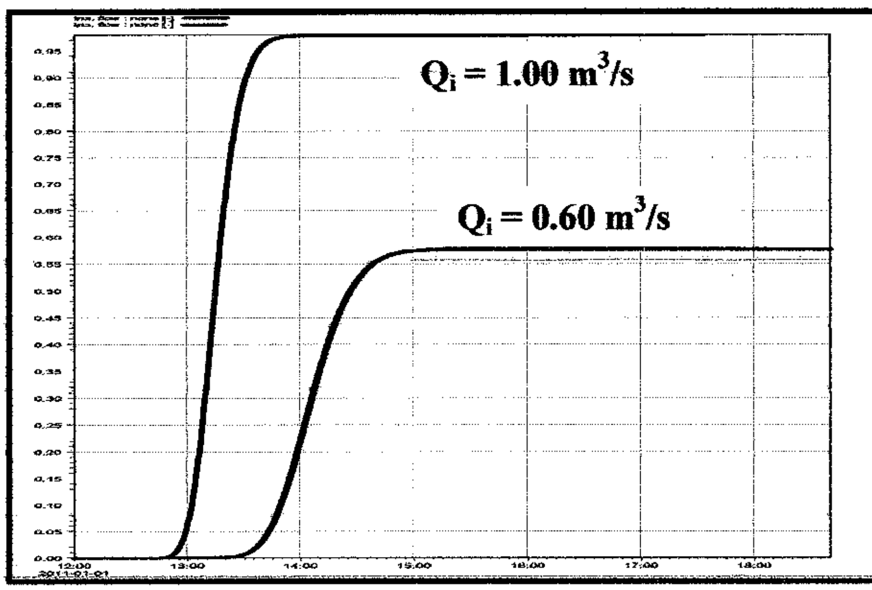

Figure 4.2 : Comparison of Overspill, kg versus time, s between $Q_i = 1.00\ m^3/s$ and $Q_i = 0.60\ m^3/s$.

Both models use same parameters of v_s =0.000027 m/s, A_3 =50 m x 15 m and C_i=10 kg/m^3. Trapping Efficiency is calculated for each phase as shown in Table . The value is measured at the middle of each phase.

Table 4.1 : Trapping Efficiency, % for Phase 1, 2 and 3.

Phase	Q_i=0.60 m^3/s	Q_i=1.00 m^3/s
1	100 %	100 %
2	46.7 %	45.5 %
3	**3.9 %**	**2.1 %**

Both results confirm that Phase 3 has the lowest trapping efficiency thus it will has the highest overspills volume. It is proven to be most critical to measure overspills and trapping effciency at this phase.

Analysis also shows that in Phase 3, each simulations will reach different constant overspills value. Referring to Figure 4.2, the constant overspills for Q_i =1.00 m^3/s is about 1.00 kg and 0.57 kg for Q_i =0.60 m^3/s. Adjusting the settling velocity, hopper area and inflow concentration will also change the constant overspills value. These different results of constant overpills are tabulated in Appendix and labelled as instant load out.

In addition, Figure 4.2 shows time taken to reach Phase 3 is different for every simulation. Lower inflow discharge, Q_i =0.60 m^3/s takes longer time to reach a steady state while the higher discharge, Q_i=1.00 m^3/s takes shorter time. This analysis is true for whole simulation results. Therefore, inflow discharge, Q_i is indirectly proportional with duration of time to reach steady Phase 3.

For cumulative overspills, technically, the longer the time of overflow, the higher it is for total overspills. This applies for all conditions of dredging. For bigger hopper area, the longer it needs to reach the loading capacity which resulted in bigger total overspills. Therefore, in order to provide a common ground, the trapping efficiency is analyzed when all hoppers are in Phase 3 of constant overflow using instantaneous outflow discharge.

4.3 Trapping Efficiency

The 12 sets which consist of about 100 simulations were analyzed and summary of the finding is tabulated in Table A-1 to Table A-12 in Appendices section. For ease of discussion, Set 9 results are shown in Table 4.2. The "% Retain" is the trapping efficiency of each simulation. For verification, the calculated "load in" is compared with the simulated "load in". All 12 sets are plotted in Trapping Efficiency versus A/Q as shown in Figure 4.3, 4.4, 4.5 and 4.6.

Table 4.2: Results of Set 9 (A= 12.5 m x 15 m, v_s=0.000027 m/s, C_i= 10 kg/m^3)

Q, m^3/s	Total time, s	A/Q_i	Calculated load in, kg	Simulated load in, kg	Simulated load out, kg	Instant load in, kg	Instant load out, kg	% Retain
0.200	30000	937.50	60000	59840.8	47356.1	0.200	0.1922870	3.86
0.100	200000	1875.00	200000	197025	174746	0.100	0.0900989	9.90
0.080	100000	2343.75	80000	78921.8	60195.6	0.080	0.0688670	13.92
0.040	150000	4687.50	60000	58992.1	36667.8	0.040	0.0297128	25.72
0.020	180000	9375.00	36000	35355.4	14125.4	0.020	0.0110882	44.56
0.010	300000	18750.00	30000	29396.5	6221.05	0.010	0.0031392	68.61
0.005	800000	37500.00	40000	40028	3074.52	0.005	0.0005394	89.21
0.003	800000	62500.00	24000	25872.4	445.474	0.003	0.0000812	97.29
0.001	900000	187500.00	9000	8803.64	0.372939	0.001	0.0000001	99.99

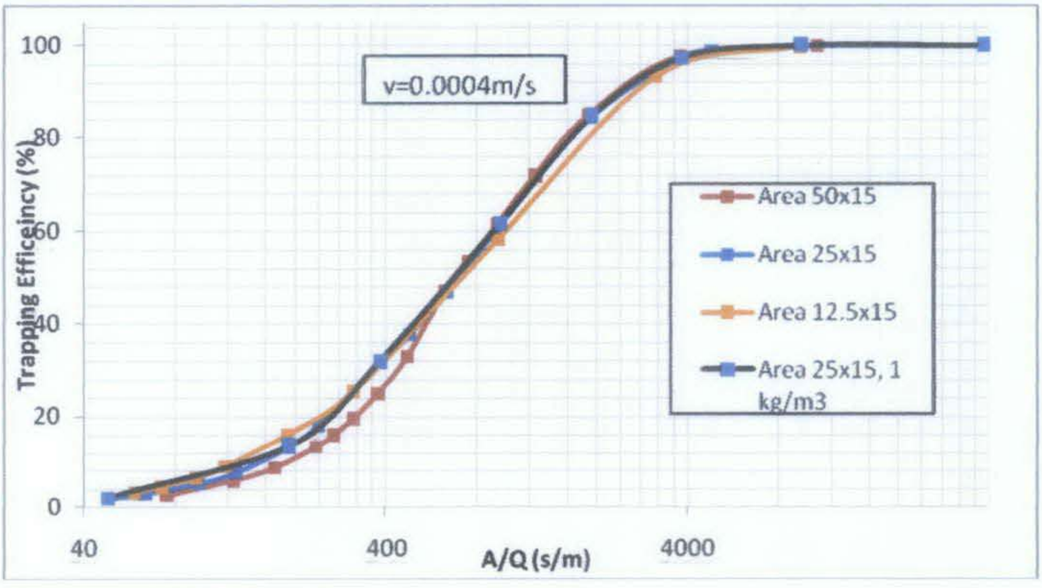

Figure 4.3: Trapping Efficiency vs A/Q_i for 0.00040 m/s settling velocity.

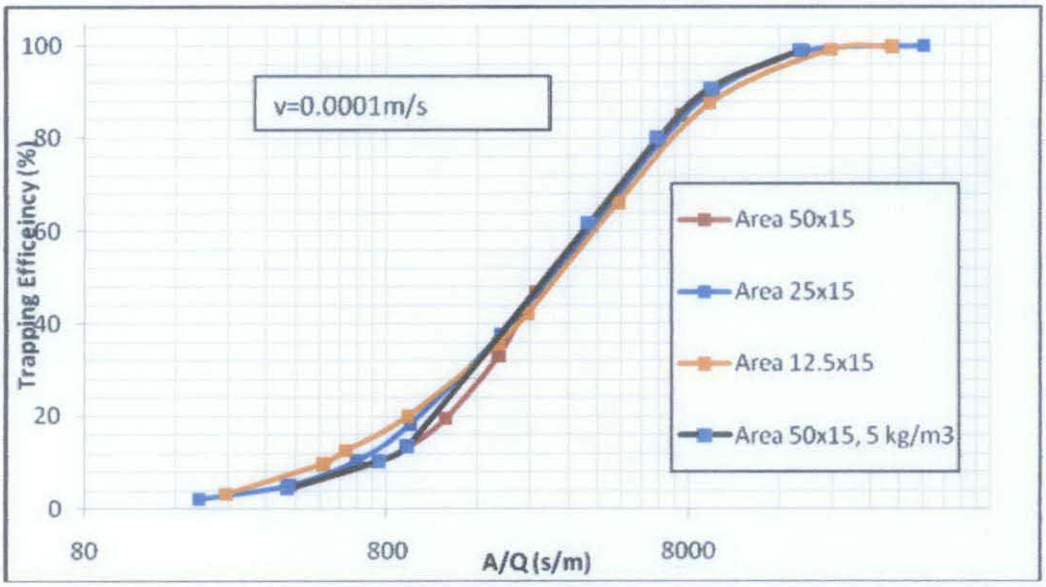

Figure 4.4: Trapping Efficiency vs A/Q_i for 0.00010 m/s settling velocity.

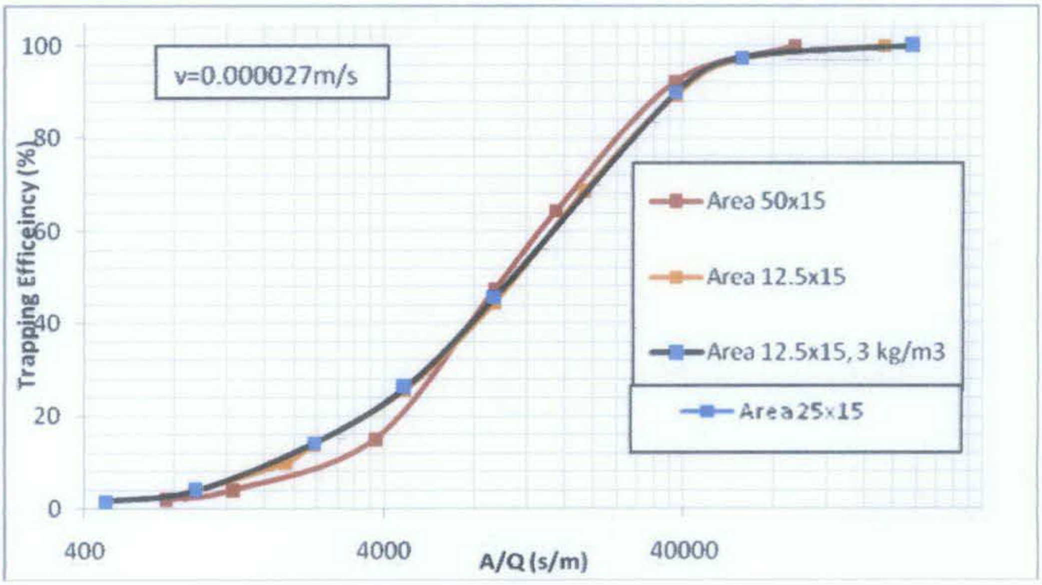

Figure 4.5: Trapping Efficiency vs A/Q_i for 0.000027 m/s settling velocity.

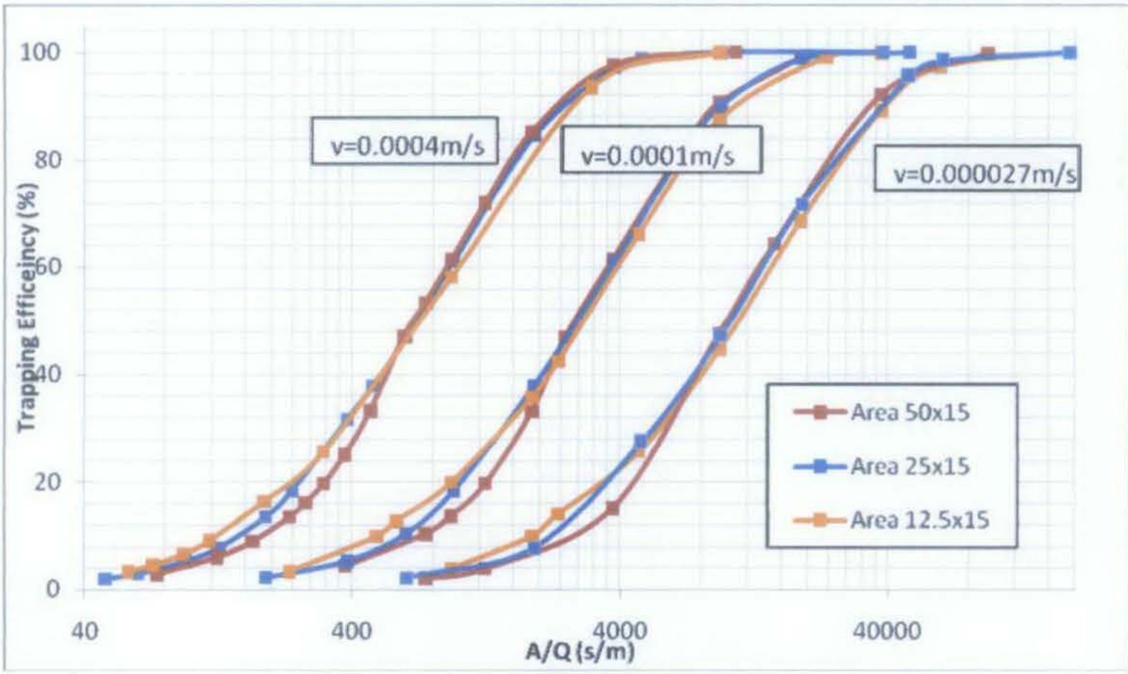

Figure 4.6: Overall Trapping Efficiency vs A/Q_i.

From the graphs, it can be observed that same size sediments will produce similar lines of trapping efficiency vs A/Q_i ratio. This means we can manipulate either the hopper area or inflow discharge in order to achieve the desired trapping efficiency for particular sediment.

As we decrease the sediment size, it requires higher A/Q_i ratio in order to settle. From Table 4.2, higher A/Q_i takes longer time to reach steady phase thus essentially increases the cost of dredging operation.

Default inflow concentration of 10 kg/m^3 is used except for Set 10 (5 kg/m^3), Set 11 (1 kg/m^3) and Set 12 (3 kg/m^3). As observed in Figure 4.3, 4.5 and 4.6, those trapping lines exactly overlapped with the same hopper area of default concentration. Thus, it proves that concentration is not affecting the trapping efficiency. Though previously it stated that the change in inflow concentration will affect the constant overspills, the trapping efficiency will remain the same since trapping efficiency is calculated using;

$$\textbf{TR, \%} = \frac{\textbf{(instant load in – instant load out)}}{\textbf{instant load in}} \textbf{ x 100} \quad (4\text{–}1)$$

Table 4.3: Result of varies inflow concentration, Q_i.

Q_i, m^3/s	C_i, kg/m^3	A/Q_i	Instant load in, kg	Instant load out, kg	% Retain
8	10	47.81	8.00	7.83987	2.00
8	1	1875.00	0.80	0.78361	2.05

In fact, the reduction of constant overspills or instant load out (Phase 3) is based on same reduction 1/10 ratio of inflow concentration. This would be useful in predicting the overspills for different Co but with same conditions for other parameters. However, it takes longer time for a low concentration of inflow to reach a specified full hopper load thus it is not economical as well.

The lines show slight deviation before it reaches 40% trapping efficiency. It may because in order to achieve low A/Q ratio for big hopper area such as A_1 (50 m x 15 m), the Q_i is increased (some up to more than 8 m/s). When flow rate is high, turbulence is introduced in the hopper. The settling of silt sediment will be disturbed and the settled silt will likely be re-suspended by water current. Drag force flow will increase in and Reynolds number will increase as well. Overspills will also increase due to these conditions. In short, the water body condition for high velocity of flow is not the same as low flow velocity. Thus it cause trapping lines for (50 m x 15 m) hopper area to deviates and has lesser trapping efficiency than the other two hoppers.

The relationship can be summarized as below;

$$\textbf{Trapping Efficiency} \propto A/Q_i$$

i) The trapping efficiency will increase when hopper area is increased
ii) The trapping efficiency will increase when inflow discharge is decreased
iii) The trapping efficiency will increase when the settling velocity of sediment is increased

Nevertheless, manipulating the A/Q_i ratio does not provide clear independent impacts of hopper area and inflow discharge towards trapping efficiency. Individual effects of settling velocity, hopper area and flow discharge towards settling velocity are investigated by plotting Graph Trapping Efficiency versus Q_i in Figure 4.7. The graph verifies that by reducing the inflow discharge, the trapping efficiency will directly improve and this applies for all sediment sizes and hopper areas.

It consistently shows that for all sediment sizes that the bigger area of hopper has better trapping efficiency. Figure 4.6 and Figure 4.7 both indicates better trapping efficiency for bigger size sediment with higher settling velocity.

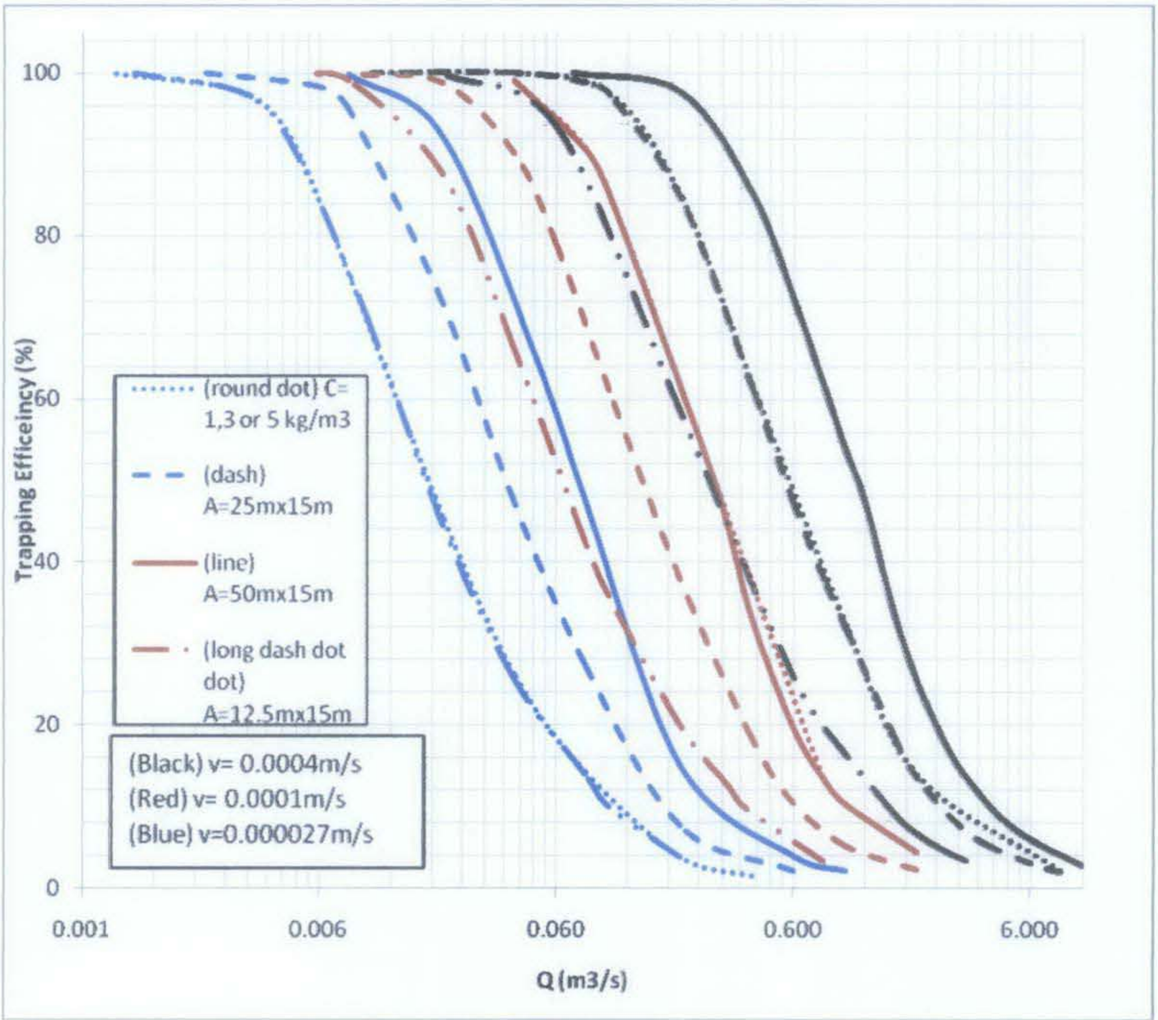

Figure 4.7: Overall Trapping Efficiency vs Q_i.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study is to simulate the sedimentation process in the hopper and to predict these overspills. It is economically and environmentally important to determine the maximum quantity of dredged sand while maintaining the optimum overspills since these two are of equal importance.

Department of Irrigation and Drainage (JPS) states in their Guidelines for Preparation of Coastal Engineering Hydraulic Study and Impact Evaluation that for transportation by barges or other dredger, where overflow is allowed, the amount of suspended sediment released at the source shall be assumed as 20 % of the fine material. In truth, as shown in the study, the overspills are affected by hopper area, inflow discharge and sediment size. By determining their hopper area and fine sediment at site beforehand, coastal practitioner could use the result of Trapping Efficiency vs Q_i to predict the percent of overspills for fine sediment for each case of dredging.

Furthermore, this study provides a platform on measures to improve environmental aspect of dredging by manipulating the use of hopper area and inflow discharge since sediment size in reality is a fixed parameter depending on their site condition. In order to enhance the trapping efficiency in dredging work, the study proposes the use of bigger hopper with larger area or reduces the inflow discharge of the suction pumps. Though by significant reduction of inflow discharge, it will prolong loading time, reduce production efficiency and increase the dredging cost. Therefore, a balance between overspills and manipulated inflow discharge is necessary for both environmental and economical optimization.

While many dredging works have used high inflow discharge to shorten loading time, increasing the sediment concentration of inflow discharge could also help in shortening the loading time. Currently, the real dredging work applies 1/10 soil over water ratio during the suction of TSHD. New technology should aim towards to increase this inflow concentration because the shorten period of loading process will definitely benefit the economy.

In short, the trapping of fine sediment become less and less effective with decreasing grain size, due to the decreasing settling velocity of sediment particle. Trapping efficiency will increase when hopper area is increased or by reducing the inflow discharge. The inflow concentration does not affecting the trapping efficiency of a hopper. An ideal case of low overspills is when the dredging use a big size of hopper, moderate pumping of inflow discharge with high density inflow of sediment and the work is performed at a site with low percentage of fine sediment.

5.2 Recommendation

Throughout this study, the function of hopper area is measured by using sum method (A = L x W). It is interesting to see the effect of W/L ratio towards overspills. For extended study, it possible to implement combination of different hopper lengths and widths for a specific area. The study can also use several level of initial water level during hopper loading and investigate the impacts towards sedimentation and loading.

5.3 Economic Benefits

For environmental protection, it is required to do Environmental Impact Assessment (EIA) for dredging work. There is a standards guideline for modelling the impact of sediment dispersion. The conventional 20% of fine sediment released could be very big which lead to negative results in dispersion. In order to proceed with the dredging work, mitigation measures such as installing double silt curtain is required. Additional costs may be applied for extreme installation situation. In actuality, this study yield more individual result of overspills for each different dredging situation, thus better management of mitigation cost.

Also, dredging operators could use the information to pre-determine the trapping efficiency, type of TSHD to be used and operation time. It will help them to plan the dredging operation and budget for the project.

Plant capital cost of individual dredger may vary depending on the method of construction and sophistication of the design and equipment. According to a book entitled 'Dredging: A handbook for Engineers' in Dredging Costs and Prices section, for 3000 tonnes hopper capacity (Small hopper for 1st model), the plant capital cost alone is approximately 20 000 000 Dutch Guilders which equal to about RM 200 million. For plant running cost, it will cover for fuel, lubricants, other consumables, crew and supervision, routine maintenance, repairs, insurance, overheads etc.

However, above rate will differ based on specific project requirement and location. Dredging works for the improvement of Batang Rajang River internal drainage system has cost about RM 50 million (Dredging Today, May 5th, 2010).

For this study, optimizing the dredged volume will give direct impact to working cycle, power usage, working hour and efficiency of operation thus can help save the fuel cost.

Result shows that higher A/Q_i ration will take longer time to reach constant overspills. By manipulating the A/Q_i ratio and reducing to meet satisfactory EIA, it is possible to reduce loading and operation time which will directly reduce the labour cost and fuel cost for the whole operation process. Assuming that this research could help in reducing the total cost by 0.2% and taking a dredging project of RM 50 million as an example:

The total project saving = 0.002 x RM 50 000 000

= RM 100 000

In conclusion, in term of economic benefit, this project could help in managing the budget for dredging process and cost for mitigation. Also, it could lead to hundred thousands of cost saving.

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APPENDICES

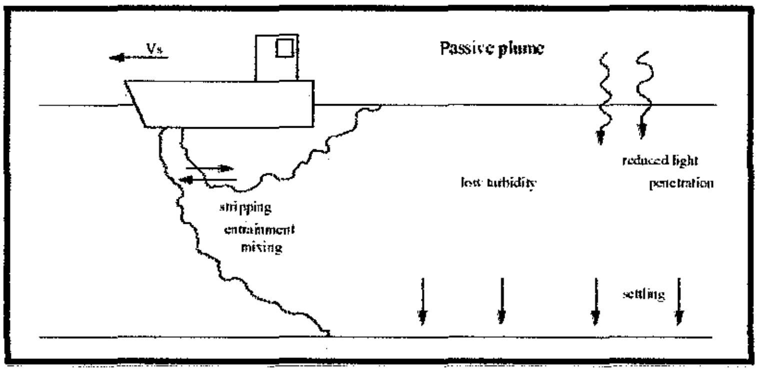

Figure A-1: Process in and around passive plumes. (P.J.T. Dankers, 2002)

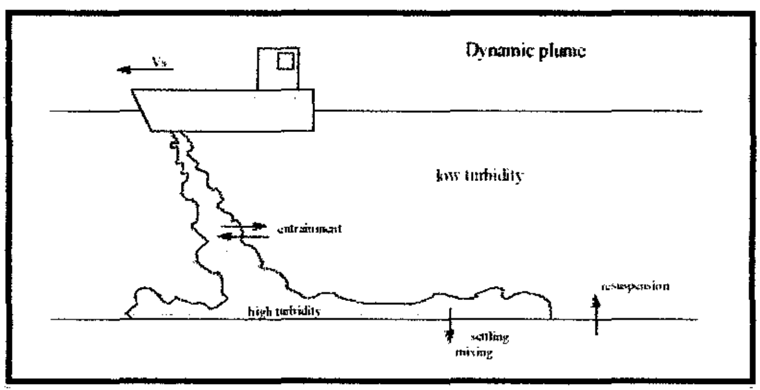

Figure A-2: Process in and around dynamic plumes. (P.J.T. Dankers, 2002)

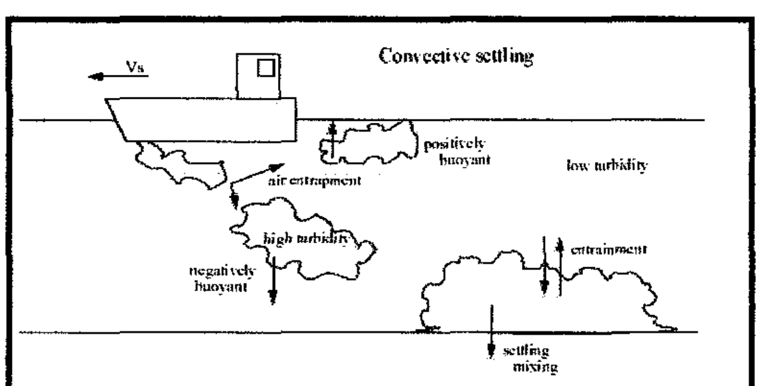

Figure A-3: Process in and around clouds of sediment. (P.J.T. Dankers, 2002)

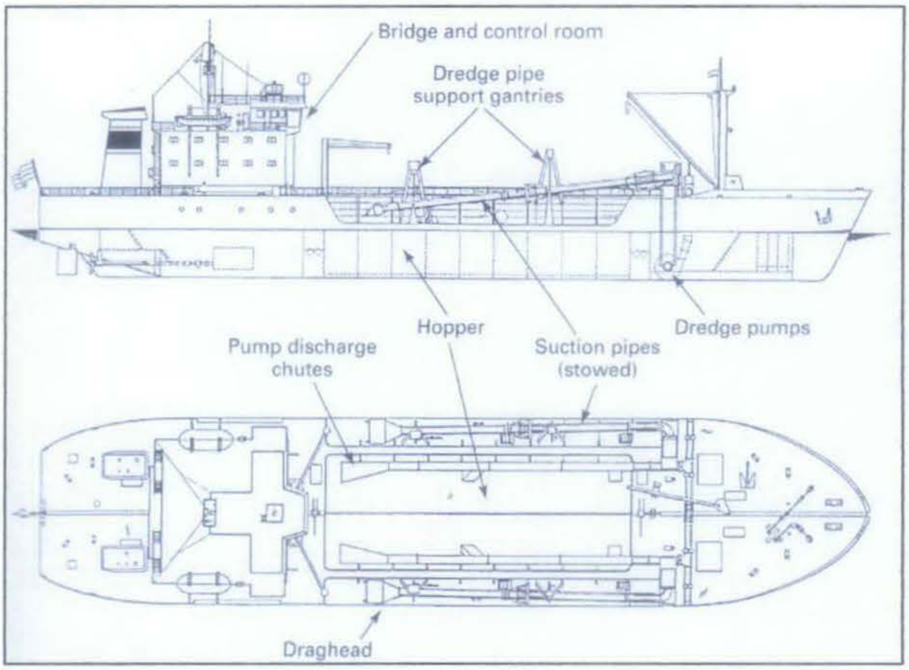

Figure A-4: Main features of trailing suction hopper dredger.

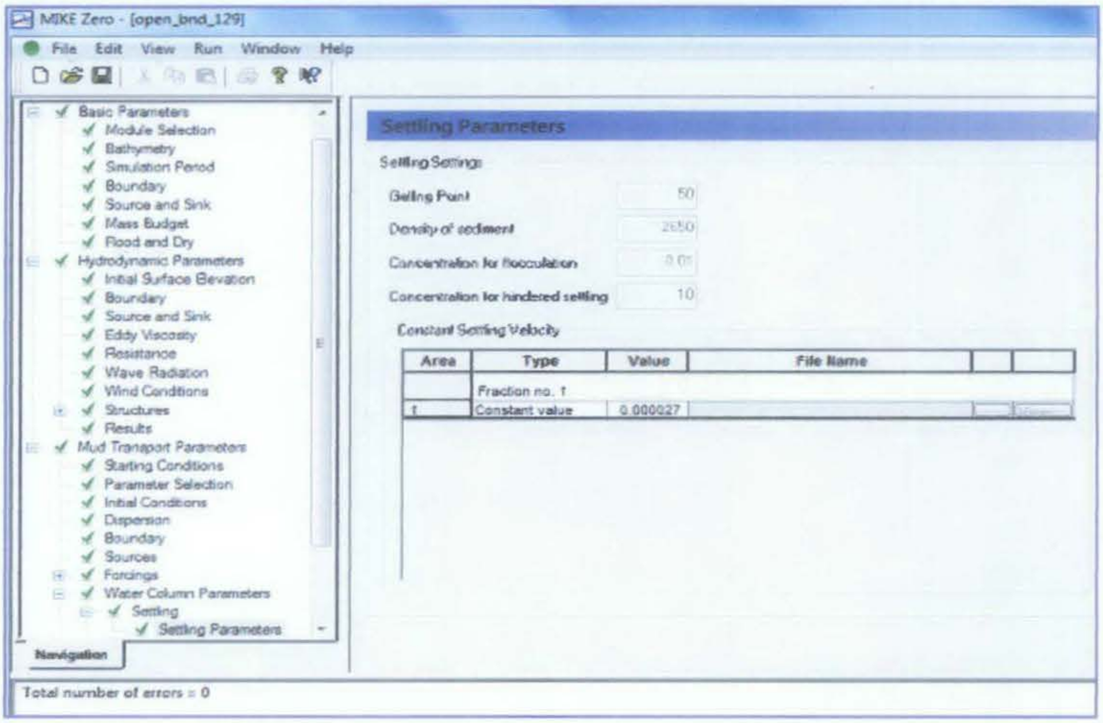

Figure A-5: MIKE MT and HD model set-up.

Table A-1: 50 m x 15 m hopper for medium silt

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00040000	10	10.0000	3000	75.00	300000	299995	247359	10.00	9.71941	2.806
0.00040000	10	6.0000	3000	125.00	180000	179997	126669	6.00	5.6451	5.915
0.00040000	10	4.4000	5000	170.45	220000	220091	159086	4.40	4.00797	8.910
0.00040000	10	3.2000	5000	234.38	160000	160079	99130.8	3.20	2.7669	13.534
0.00040000	10	2.8000	5000	267.86	140000	139928	79441.1	2.80	2.34827	16.133
0.00040000	10	2.4000	5000	312.50	120000	119946	59976.7	2.40	1.92586	19.756
0.00040000	10	2.0000	5000	375.00	100000	99999	41057.6	2.00	1.49835	25.083
0.00040000	10	1.6000	10000	468.75	160000	159976	76587.9	1.60	1.06902	33.186
0.00040000	10	1.2000	10000	625.00	120000	120111	39718.1	1.20	0.634644	47.113
0.00040000	10	1.0000	10000	750.00	100000	99999.5	25710	1.00	0.465409	53.459
0.00040000	10	0.8000	10000	937.50	80000	79988.1	13631.7	0.80	0.307732	61.534
0.00040000	10	0.6000	30000	1250.00	180000	179728	38001.4	0.60	0.168111	71.982
0.00040000	10	0.4000	50000	1875.00	200000	23394.8	200708	0.40	0.0597119	85.072
0.00040000	10	0.2000	50000	3750.00	100000	100354	1352.95	0.20	0.0046908	97.655
0.00040000	10	0.0700	90000	10714.29	63000	63235.6	1.00732	0.07	2.77211E-06	99.996

Table A-2: 25 m x 15 m hopper for medium silt.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/ Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00040000	10	8.0000	2000	47.81	160000	159996	134525	8.00	7.83987	2.002
0.00040000	10	6.0000	2000	63.75	120000	119997	94381.5	6.00	5.81986	3.002
0.00040000	10	4.0000	2000	95.63	80000	79998	3.79E+00	4.00	3.79E+00	5.194
0.00040000	10	3.0000	2000	127.50	60000	59998.5	3.45E+04	3.00	2.77E+00	7.674
0.00040000	10	2.0000	4000	191.25	80000	79999	49683.5	2.00	1.73171	13.415
0.00040000	10	1.6000	4000	239.06	64000	64024	33840.3	1.60	1.30619	18.363
0.00040000	10	1.0000	6000	382.50	60000	59999.5	2.57E+04	1.00	0.68294	31.706
0.00040000	10	0.8000	10000	478.13	80000	79988.1	35846.7	0.80	0.497026	37.872
0.00040000	10	0.6000	10000	637.50	60000	60055.5	20090.5	0.60	0.318477	46.921
0.00040000	10	0.4000	15000	956.25	60000	59915.9	14799.2	0.40	0.155227	61.193
0.00040000	10	0.2000	30000	1912.50	60000	59840.8	5992.8	0.20	0.0308578	84.571
0.00040000	10	0.1000	40000	3825.00	40000	40020.8	5.36E+02	0.10	0.00265379	97.346
0.00040000	10	0.0800	80000	4781.25	64000	63296.8	512.377	0.08	0.000914372	98.857
0.00040000	10	0.0400	200000	9562.50	80000	78523.4	14.9429	0.04	9.32E-06	99.977
0.00040000	10	0.0100	200000	38250.00	20000	19630.8	5.66E-08	0.01	6.33E-14	100.000

Table A-3: 12.5 m x 15 m hopper for medium silt.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00040000	10	3.2000	1000	58.59	32000	31995.3	20648.6	3.20	3.09367	3.323
0.00040000	10	2.6000	1500	72.12	39000	38999	27101.7	2.60	2.48274	4.510
0.00040000	10	2.0000	3000	93.75	60000	59999	1.86961	2.00	1.86961	6.520
0.00040000	10	1.6000	5000	117.19	80000	80039.7	63127.6	1.60	1.45534	9.041
0.00040000	10	1.0000	8000	187.50	80000	79999.5	58108.2	1.00	0.836456	16.354
0.00040000	10	0.6000	10000	312.50	60000	60055.5	36846.2	0.60	0.446047	25.659
0.00040000	10	0.2000	20000	937.50	40000	39918.9	12584.1	0.20	0.0835432	58.228
0.00040000	10	0.0600	40000	3125.00	24000	24016.8	1003.14	0.06	0.00392755	93.454
0.00040000	10	0.0200	70000	9375.00	14000	13871.1	6.37486	0.02	1.73138E-05	99.913

Table A-4: 50 m x 15 m hopper for fine silt.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00010000	10	2.0000	10000	375.00	200000	199999	147870	2.00	1.91256	4.372
0.00010000	10	1.0000	10000	750.00	100000	99999.5	49090.7	1.00	0.897553	10.245
0.00010000	10	0.8000	30000	937.50	240000	239363	167683	0.80	0.691463	13.567
0.00010000	10	0.6000	40000	1250.00	240000	239103	156738	0.60	0.482095	19.651
0.00010000	10	0.4000	40000	1875.00	160000	160083	76362.4	0.40	0.267433	33.142
0.00010000	10	0.3000	50000	2500.00	150000	149239	55770.7	0.30	0.159193	46.936
0.00010000	10	0.2000	50000	3750.00	100000	100354	21305.4	0.20	0.0769536	61.523
0.00010000	10	0.1000	80000	7500.00	80000	80645.8	5.43E+03	0.10	0.0149351	85.065
0.00010000	10	0.0800	100000	9375.00	80000	78921.8	3445.27	0.08	0.00748394	90.645
0.00010000	10	0.0400	180000	18750.00	72000	70710.9	289.664	0.04	0.00037984	99.050

Table A-5: 25 m x 15 m hopper for fine silt.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00010000	10	2.0000	7000	191.25	140000	139999	114662	2.00	1.95563	2.219
0.00010000	10	1.0000	8000	382.50	80000	79999.5	54350.2	1.00	0.947497	5.250
0.00010000	10	0.6000	8000	637.50	48000	48024.3	22735.8	0.60	0.537709	10.382
0.00010000	10	0.4000	12000	956.25	48000	47962.8	20783.1	0.40	0.3265	18.375
0.00010000	10	0.2000	25000	1912.50	50000	49879.8	17220.4	0.20	0.124279	37.861
0.00010000	10	0.1000	50000	3825.00	50000	50177	10930.4	0.10	0.0388736	61.126
0.00010000	10	0.0600	100000	6375.00	60000	59455.3	8124.15	0.06	0.0125648	79.059
0.00010000	10	0.0400	200000	9562.50	80000	78523.4	5795.98	0.04	0.00395015	90.125
0.00010000	10	0.0200	200000	19125.00	40000	39261.7	237.817	0.02	0.000228728	98.856
0.00010000	10	0.0080	400000	47812.50	32000	31366.6	0.605396	0.01	3.10019E-07	99.996

Table A-6: 12.5 m x 15 m hopper for fine silt.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.0001000	10	0.8000	20000	234.38	160000	159676	144265	0.80	0.773097	3.363
0.0001000	10	0.3800	20000	493.42	76000	38017.2	24738.9	0.38	0.342605	9.841
0.0001000	10	0.3200	10000	585.94	32000	32021.1	18737	0.32	0.279492	12.659
0.0001000	10	0.2000	20000	937.50	40000	39918.9	23649.6	0.20	0.160046	19.977
0.0001000	10	0.1000	30000	1875.00	30000	29920.4	12687.7	0.10	0.0642315	35.769
0.0001000	10	0.0800	40000	2343.75	32000	32028.7	12552.6	0.08	0.0460452	42.444
0.0001000	10	0.0400	60000	4687.50	24000	23835.9	4823.2	0.04	0.0135177	66.206
0.0001000	10	0.0200	200000	9375.00	40000	39261.7	3791.43	0.02	0.00247921	87.604
0.0001000	10	0.0080	1000000	23437.50	80000	78241.6	592.456	0.01	0.00006892	99.139
0.0001000	10	0.0050	1000000	37500.00	50000	47840.5	34.2299	0.01	4.29781E-06	99.914

Table A-7: 50 m x 15 m hopper for very fine silt.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00002700	10	1.0000	20000	750.00	200000	200000	151336	1.00	0.979156	2.084
0.00002700	10	0.6000	30000	1250.00	180000	179728	129619	0.60	0.576378	3.937
0.00002700	10	0.2000	60000	3750.00	120000	120667	63195.3	0.20	0.169927	15.037
0.00002700	10	0.0800	90000	9375.00	72000	71109.3	14265.5	0.08	0.0419746	47.532
0.00002700	10	0.0500	140000	15000.00	70000	70387.4	9061.37	0.05	0.0177858	64.428
0.00002700	10	0.0200	563500	37500.00	112700	19730.4	5157.68	0.02	0.00155375	92.231
0.00002700	10	0.0080	800000	93750.00	64000	62616.6	46.4156	0.01	1.45889E-05	99.818

Table A-8: 25 m x 15 m hopper for very fine silt.

Settling velocity, m/s	Sediment conc, Co kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00002700	10	0.6000	30000	637.50	180000	179728	154026	0.60	0.587267	2.122
0.00002700	10	0.2000	30000	1912.50	60000	59840.8	34395.6	0.20	0.184625	7.688
0.00002700	10	0.0800	100000	4781.25	80000	78921.8	41978.3	0.08	0.0581239	27.345
0.00002700	10	0.0400	100000	9562.50	40000	39460.9	9437.87	0.04	0.0210449	47.388
0.00002700	10	0.0200	300000	19125.00	60000	58792.9	10831.5	0.02	0.00565756	71.712
0.00002700	10	0.0080	500000	47812.50	40000	39179.1	894.628	0.01	0.000357788	95.528
0.00002700	10	0.0060	500000	63750.00	30000	29422.5	175.225	0.01	9.79E-05	98.368
0.00002700	10	0.0020	2000000	191250.00	40000	45415.3	0.375478	0.002	2.84E-08	99.999

Table A-9: 12.5 m x 15 m hopper for very fine silt.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00002700	10	0.2000	30000	937.50	60000	59840.8	47356.1	0.20	0.192287	3.857
0.00002700	10	0.1000	200000	1875.00	200000	197025	174746	0.10	0.0900989	9.901
0.00002700	10	0.0800	100000	2343.75	80000	78921.8	60195.6	0.08	0.068867	13.916
0.00002700	10	0.0400	150000	4687.50	60000	58992.1	36667.8	0.04	0.0297128	25.718
0.00002700	10	0.0200	180000	9375.00	36000	35355.4	14125.4	0.02	0.0110882	44.559
0.00002700	10	0.0100	300000	18750.00	30000	29396.5	6221.05	0.01	0.00313918	68.608
0.00002700	10	0.0050	800000	37500.00	40000	40028	3074.52	0.01	0.000539444	89.211
0.00002700	10	0.0030	800000	62500.00	24000	25872.4	445.474	0.00	8.11972E-05	97.293
0.00002700	10	0.0010	900000	187500.00	9000	8803.64	0.372939	0.00	1.07132E-07	99.989

Table A-10: 50 m x 15 m hopper for fine silt, C_i =5 kg/m^3.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00010000	5	2.0000	8000	375.00	80000	79999.5	54789.6	1.00	0.955744	4.426
0.00010000	5	1.0000	10000	750.00	50000	49999.8	24505.9	0.50	0.448295	10.341
0.00010000	5	0.8000	50000	937.50	200000	200708	152558	0.40	0.345134	13.717
0.00010000	5	0.2000	50000	3750.00	50000	50177	10571.1	0.10	0.0382158	61.784
0.00010000	5	0.1200	60000	6250.00	36000	36017.8	2839.27	0.06	0.0121302	79.783
0.00010000	5	0.0800	200000	9375.00	80000	78523.4	5433.58	0.04	0.00370233	90.744
0.00010000	5	0.0400	300000	18750.00	60000	58792.9	361.883	0.02	0.000189283	99.054
0.00010000	5	2.0000	8000	375.00	80000	79999.5	54789.6	1.00	0.955744	4.426
0.00010000	5	1.0000	10000	750.00	50000	49999.8	24505.9	0.50	0.448295	10.341

Table A-11: 25 m x 15 m hopper for medium silt, C_o =1 kg/m^3.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00040000	1	8.0000	2000	47.81	16000	15996.9	13444.2	0.80	0.783609	2.049
0.00040000	1	2.0000	6000	191.25	12000	12006.9	8400.38	0.20	0.172507	13.747
0.00040000	1	1.0000	7000	382.50	7000	7004.43	3231.52	0.10	0.0678038	32.196
0.00040000	1	0.4000	13000	956.25	5200	5203.81	1153.83	0.04	0.0153105	61.724
0.00040000	1	0.2000	20000	1912.50	4000	4003.27	286.503	0.02	0.00302939	84.853
0.00040000	1	0.1000	40000	3825.00	4000	4003.59	52.5582	0.01	0.000260338	97.397
0.00040000	1	0.0400	180000	9562.50	7200	7089.56	1.26182	0.00	9.20751E-07	99.977
0.00040000	1	0.0100	180000	38250.00	1800	1772.39	4.32E-09	0.00	6.33648E-15	100.000

Table A-12: 12.5 m x 15 m hopper for very fine silt, C_i =3 kg/m^3.

Settling velocity, m/s	Sediment conc, C_i kg/m^3	Q_i, m^3/s	Total time, s	A/Q_i	Calculated load in total, kg	Simulated load in total, kg	Simulated load out total, kg	Instant load in, kg	Instant load out, kg	% Retain
0.00002700	3	0.4000	30000	468.75	36000	35924.2	32437.3	0.12	0.11824	1.467
0.00002700	3	0.2000	30000	937.50	18000	17962.1	14230.5	0.06	0.0577196	3.801
0.00002700	3	0.0800	35000	2343.75	8400	8385.85	4493.77	0.02	0.0205831	14.237
0.00002700	3	0.0400	150000	4687.50	18000	17829.4	10918.7	0.01	0.0088467	26.278
0.00002700	3	0.0200	100000	9375.00	6000	5985.04	1623.06	0.01	0.00325916	45.681
0.00002700	3	0.0050	400000	37500.00	6000	5890.79	343.77	0.00	0.000152389	89.841
0.00002700	3	0.0030	800000	62500.00	7200	7583.9	123.797	0.00	2.33666E-05	97.404
0.00002700	3	0.0008	2000000	234375.00	4800	4096	0.0533957	0.00	4.5518E-09	99.998