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VALIDATION OF THE TASS SYSTEM FOR PREDICTING THE ENVIRONMENTAL EFFECTS OF TRAILING SUCTION HOPPER DREDGERS

ABSTRACT

TASS is a software programme that enables the user to predict the spatial development and concentration of turbidity plumes arising from dredging activities by trailer suction hopper dredgers. TASS has been developed because of a recognised need by the dredging industry to improve the quality of predictions of the effects of dredging in Environmental Impact Assessments. This article describes the TASS model and the validation of TASS predictions against validation measurements off the Dutch and German coasts.

The results show that the TASS system reproduces the observed concentrations of the overflow discharge well, as well as the observed increases in suspended sediment concentrations in the far-field. In addition the measurements highlight the fact that most of sediment released in the overflow is not seen in the far-field passive plume but descends to the bed as a dynamic plume. Evidence from the measurement campaign confirms the results of previous measurements undertaken in Hong Kong that the far-field plumes initially represent roughly 5-15% of the fine material released in the overflow discharge. Identifying how this percentage may be predicted *a priori* is an area on ongoing research.

Present efforts focus on further development and validation of the model for a variety of environmental conditions. Once thoroughly tested, the model will be made publicly available to facilitate sound predictions of dredging-induced turbidity.

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INTRODUCTION

TASS (Turbidity ASsessment Software) is a software programme that enables the user

Above: Survey vessel *Corvus*, conducting experiments in the plume of a trailing suction hopper dredger. The results were used to validate the predictions made by TASS (Turbidity Assessment Software), which measures the spatial development and concentration of turbidity plumes.

to predict the spatial development and concentration of turbidity plumes arising from dredging activities by trailer suction hopper dredgers (TSHDs). The project was initiated in the late 1990s and has been developed in collaboration between HR Wallingford and Rijkswaterstaat and Vereniging van Waterbouwers in Bagger-, Kust- en Oeverwerken (VBKO) and more recently, with Stichting Speurwerk Baggertechniek and the Dutch funded EcoShape project. The project has arisen because the often poor estimation of the effects of TSHDs can lead to unrealistically optimistic or pessimistic predictions of the effects of dredging in Environmental Impact Assessment which in turn can greatly impede the successful implementation of dredging works. This article briefly describes the model and its validation by measurements in the field. It also gives an outline of future developments and the planned release to the public in 2012.

The plumes arising from TSHDs are caused by the discharge (or "overflow") of sediment-laden water from the hopper (usually through the hull of the dredger but sometimes over the ship-sides) which can form surface or near bed plumes. Disturbance by the draghead and erosion from propeller wash also play a role (see Figure 1).



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studied at Clare College, Cambridge and received an MA in mathematics and later at Imperial College, London, where he was awarded an MSc in engineering hydrology. In 1995 he obtained a PhD at Oxford Brookes University studying the use of empirical methods to predict long term morphological changes in estuaries. He then joined HR Wallingford and has worked there till the present day. Presently he holds the position of Principal Scientist, specialising in estuary processes and dredging plume dispersion.



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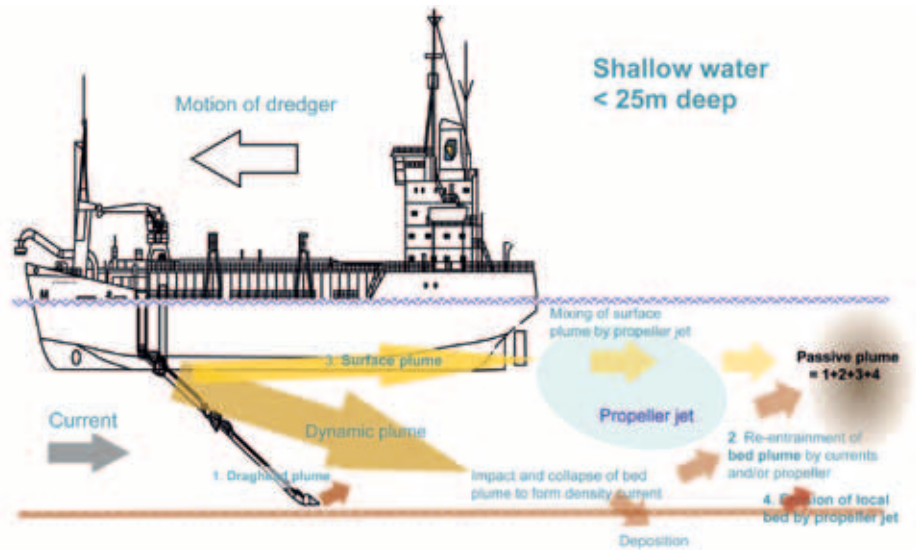


Figure 1. Mechanisms for release of sediment arising from TSHD dredging.

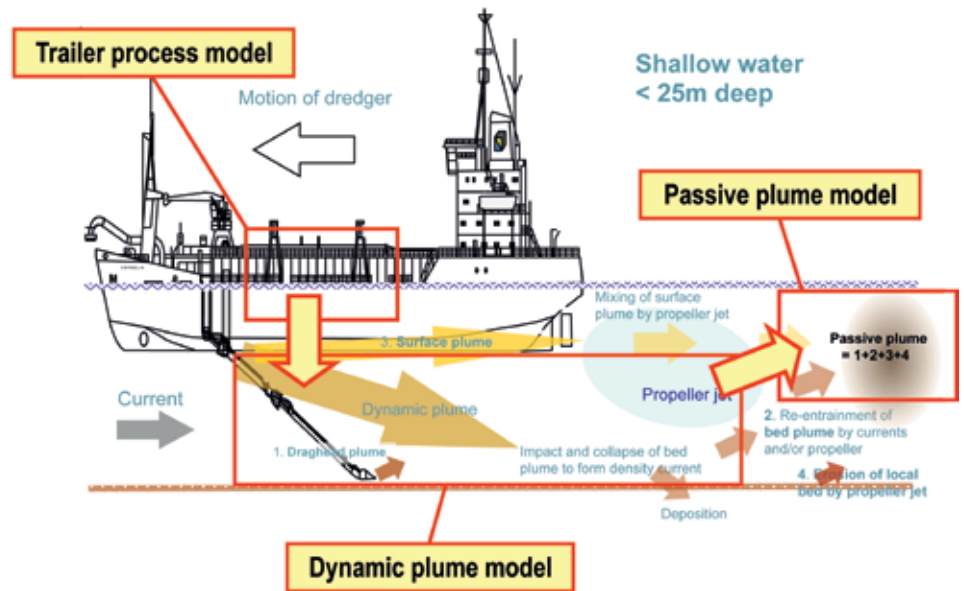


Figure 2. Structure of TASS software.

All of these sources contribute to the plume which is observed at some distance from the dredger, usually termed the "passive plume". The goal of the TASS project is to reliably predict the far-field concentrations resulting from passive plumes associated with TSHDs.

The TASS software comprises three elements: overflow, dynamic plume and passive plume modules (Figure 2). The dynamic plume module simulates the near-field mixing of the overflow plume and provides the magnitude and geometry of the source term for the passive plume module. The passive plume

module can be replaced with other detailed 2DH or 3D plume dispersion software.

For the purposes of this article *near-field* is defined as the zone near to the dredger where the dynamic plume phase occurs (see section on "Description of the TASS Dynamic Plume Module" below) and mixing of the plume is a function of complex processes. The term *far-field* is used to mean the zone outside the *near-field* zone where the plume disperses as a passive plume (see section on "Description of Passive Plume Module" below). The spatial extent of these zones

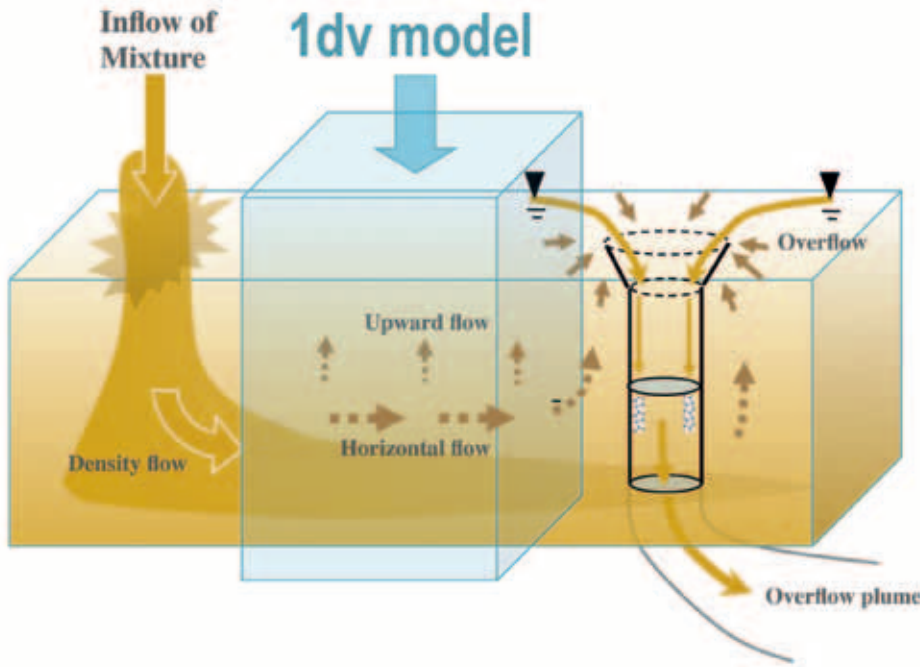


Figure 3. Conceptualisation of the hopper as presented in this study.

depends on the local hydrodynamic conditions, and additionally, in the case of the near-field zone, the nature of the overflow discharge.

DESCRIPTION OF THE TASS OVERFLOW MODULE

The TASS overflow module conceptualises the hopper (as first postulated by Vlasblom and Miedema, 1995) as being split into three zones: the input jet zone, a zone covering most of the hopper where the main effects of the input jet have receded (the zone essentially reproduced by the TASS model), and an output zone where (so called "orifice") flow occurs through all of the hopper depth into the weir (Figure 3).

The TASS model consists of a 1dv model of the hopper processes. However, while many models of hopper processes consider just the vertical advection of sediment and water, the TASS 1dv model calculates both the horizontal advection and upward movement of water and sediment (Figure 4). Inherent in this calculation is the assumption of continuity, i.e., that horizontal discharge occurs in all layers along the hopper and, because flow at the weir occurs in all directions, out of the hopper. In this way the overflow concentrations are a function of both the distribution

of concentrations in the hopper and the distribution of velocities. This effectively means that the clearer layers of water that often occur near the surface waters of the hopper do not dominate the output of sediment in the overflow.

1dv model of the hopper

Resolution in the vertical direction is represented as a series of layers of equal thickness, which will be referred to as the 1dv model (see Figure 4). This model is similar to other 1dv sediment transport models which have been used successfully by other sediment transport researchers (e.g., Winterwerp, 1999; Winterwerp and van Kesteren, 2004).

The aim of the 1dv model as used in this task is to distribute the discharge of water and the suspended sediment concentration sediment through the vertical. This means that the flux of sediment into the overflow is not merely the product of the depth-averaged (or cross-section averaged) velocity and the depth-averaged (or cross-section averaged) suspended sediment concentration, but the integral of the velocity and suspended sediment through the vertical.

The representation of the vertical structure of suspended sediment concentration improves the accuracy of the settling flux onto the bed of the hopper and better reproduces the slow increase in concentration that is commonly observed in dredging overflow as the sediment has to diffuse upwards through the model layers.

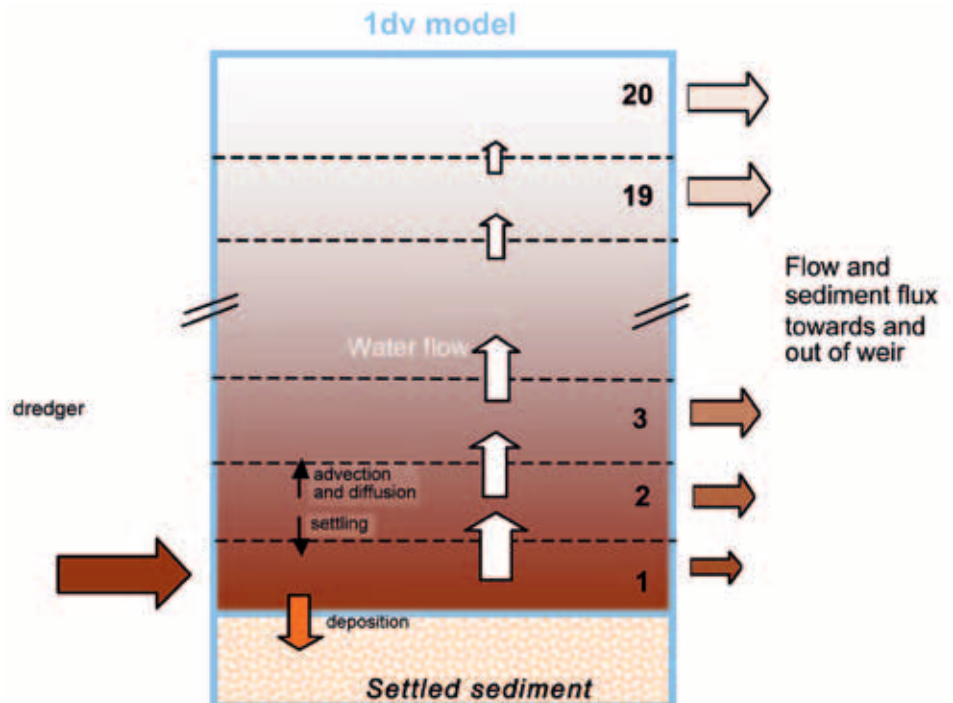


Figure 4. Schematisation used in the 1dv model.

Table I. Characteristics of the Trailer Suction Hopper Dredgers used in the field measurements.

Field survey	Cornelia	Oranje	Geopotes 15
Measurement site	Bremerhaven	Rotterdam	Den Helder
Length (m)	112.76	156.00	133.54
Maximum draught (m)	7.45	12.02	9.07
Breadth (m)	19.60	28.00	23.64
Hopper capacity (m ³)	6,388	15,961	9,962

COMPARISON OF TASS OVERFLOW MODULE RESULTS WITH MEASURED OVERFLOW DATA

The field measurements of overflow discharge were made at three locations along the North Sea coast (Bremerhaven, Germany; Rotterdam and Den Helder, the Netherlands) using different sized dredgers (see Table I) working in different sediment types (fine/medium sand through to sandy silt).

The overflow measurements principally took the form of measuring the concentration in the overflow discharge. This was done by taking bottle samples of the overflow mixture which were later analysed in the laboratory for sediment concentration. Trial measurements were also undertaken using a density profiler but these were not used for the present study.

The experiments at Bremerhaven were undertaken in 2006 on TSHD *Cornelia*. The dredging took place at several locations within the approaches and estuary and the sediment dredged can be summarised as fine sand and silty fine sand. During these experiments the practicality of pumping samples of overflow discharge from inside the orifice chamber was explored. This was considered to be in principal a success but air bubbles in the overflow mixture were found to cause problems for the pump. This led to the use of an airflow method of pumping in the subsequent overflow measurements at Rotterdam and Den Helder. An example of the measured and predicted overflow sediment concentration at Bremerhaven is shown in Figure 5.

The Rotterdam experiments were undertaken in 2007 inside the Rotterdam Harbour, and seaward in the approach channel to the

Rotterdam Harbour. They were part of a larger measurement programme, including far-field plume measurements for the first time within this research project. The measurements were made on TSHD *Oranje* (Figure 6).

The sediment dredged can be summarised as very silty fine sand, fine sand and very sandy silt. An example of the measured and predicted overflow sediment concentration at Rotterdam is shown in Figure 5.

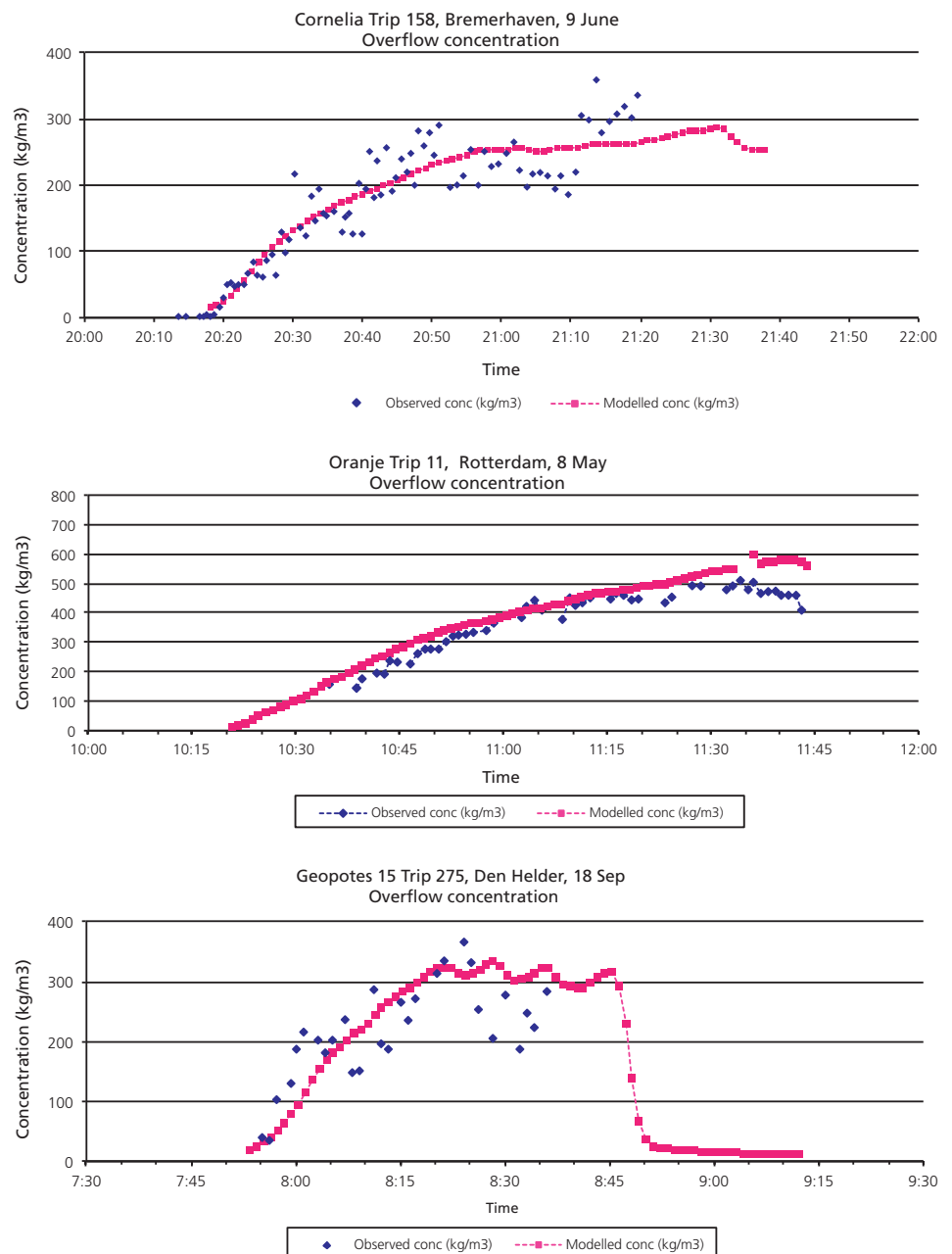


Figure 5. Observed and predicted sediment concentration in the overflow discharge Trip 158 at Bremerhaven (top); Trip 11 at Rotterdam (middle); and, Trip 275 of the Den Helder field measurements (bottom).



Figure 6. Left, the TSHD *Geopotes 15* and right, the TSHD *Oranje*.

The Den Helder dredging works were undertaken in 2007 to source sand for beach nourishments south of Den Helder. The measurements were made on TSHD *Geopotes 15* (see Figure 6). The dredging took place, approximately 12 km offshore the Dutch coastline in an area of fine and medium sand. Based on samples from the dredged area the proportion of silt in the sediment is in the range 4-8% by mass. An example of the measured and predicted overflow sediment concentration at Den Helder is shown in Figure 5.

All seventeen sets of overflow measurements were used for comparison. A selection of the model results is given in this paper together with a summary of the results as a whole. The measurements are described in more detail in Aarninkhof *et al.* (2007, 2010).

RESULTS OF THE COMPARISON OF THE TASS OVERFLOW MODULE PREDICTION WITH FIELD DATA

- Overflow measurements were carried out at three locations along the North Sea Coast.
- Bottle sampling and a density profiler were used to measure the sediment concentration in the overflow.
- Seventeen sets of overflow measurements were used for model comparison.

- Prediction of loaded mass was (on average) within 7.5%.
- Prediction of overflow concentration was (on average) within 17% of the peak concentration measured

DESCRIPTION OF THE TASS DYNAMIC PLUME MODULE

The paragraphs below describe the dynamic plume processes as well as the dynamic plume model used by TASS.

The dynamic plume processes

During TSHD operations material is disturbed and introduced into the water body via overflow as water is displaced from the hopper. The introduction of this sediment – which can have significant initial momentum – into the water column results in a body of water, denser than the surrounding water, that descends towards the seabed. This plume is referred to as the *dynamic plume*.

Under normal loading the plume ejected from the hull of the dredger creates both a dynamic plume (which descends towards the bed) and a surface plume (that is, the plume caused by all sediments not directly descending with the dynamic plume), which forms an often visible passive plume. Although the actual physical processes leading to the strength of the surface plume are not well defined, the

evidence from measurements (Whiteside *et al.*, 1995; John *et al.*, 2000, Spearman, 2003 Nick Bray, HR Wallingford, *pers.comm.* and Aarninkhof *et al.*, 2010) is that the bulk of the overflow sediment forms a dynamic plume and the surface plume represents a small proportion of the sediment released in the overflow.

Furthermore, the surface plume is known to be a function of the air content in the overflow because the surface plume is significantly reduced when air is excluded from the plume, for instance, by use of the so called “environmental” or “green” valve. The proportion of the overflow that forms a surface plume is at present a focus for study in the EcoShape Project including research into multiphase CFD modelling at Delft University of Technology (De Wit, 2010).

In the meantime the proportion is a user-defined value in the TASS model with a recommended value of 5-15% suggested based on the field measurements to date.

The dynamic plume eventually impacts with, and collapses onto, the bed to form a bed plume which may not initially mix with the overlying waters, depending on the density difference between this layer and the ambient concentrations and the magnitude of the ambient currents (and wave action).

As sediment settles out of this layer, however, and the thickness of the layer is reduced by further collapse, mixing will at some point occur and this layer may be re-entrained into the waters above to contribute to the passive plume. All of these processes are included in the dynamic plume model; a full description of the dynamic plume module is given in Spearman *et al.* (2003) and the TASS User manual (EcoShape, 2010).

Dynamic plume model

The TASS dynamic plume module reproduces the near-field mixing that occurs as the negatively buoyant jet of the overflow mixes with the surrounding waters. The initial descent of the dynamic plume is reproduced using a Lagrangian technique whereby a thin disc of the released dynamic plume is tracked as it moves downward under the forces of momentum and negative buoyancy.

The technique has been used for both dredger plume and outfall plume modelling (e.g., Koh and Chang, 1973, Brandsma and Divoky, 1976, and Lee and Cheung, 1990).

Entrainment of ambient water into the plume is modelled using the formulations of Lee and Cheung (1990) and accounts for both shear entrainment (i.e., as occurs in jets and dominates the initial stages of the dynamic descent) and forced entrainment (which dominates in the latter stages of descent and is due to the flow of ambient water into the plume) as shown in Figure 7.

The descent phase is terminated either when the plume impinges on the bed or when the vertical (downward) speed becomes less than zero (as may happen in strongly stratified conditions) or when the dynamic plume becomes sufficiently diffuse that it becomes a passive plume. Two experiments were chosen for the validation of the dynamic descent – Chu and Goldberg (1974) and Chu (1975).

In the case of these experiments, the plume was simulated by injecting dyed saline solution vertically downward/upward into a flume through a hypodermic needle/injection pipe. The results of these experiments are not shown here but are presented in Spearman *et al.*, (2003) and the TASS user manual (EcoShape, 2010).

After the plume impinges on the bed the model reproduces the collapse of the dynamic plume as a density current. For dense thin layers, on a horizontal bed, the horizontal speed of propagation of the front of the resulting density current along the bed, is related to the thickness of the density current and the gravitational acceleration modified for buoyancy (Hallworth *et al.*, 1998).

A “box-model” approach has been used to describe the shape of the density current, i.e., the density current height is assumed constant over the length of the density current. As the density current lengthens, continuity of mass implies that the thickness of the density current reduces. All of the fractions are considered to be uniformly mixed, vertically and along the length of the current. Deposition onto the bed is calculated by keeping a running total of the deposition flux for each fraction from the density current.

The validation of the bed collapse was undertaken by comparing the results of the model with the results of laboratory experiments by Hallworth *et al.*, (1998). The results of these experiments are not shown here but are described in in Spearman *et al.*, (2003) and the TASS user manual (EcoShape, 2010).

The bed collapse phase ends when the turbulence within the density current has reduced sufficiently to allow mixing with ambient waters at which point the density current can be regarded as a passive plume.

DESCRIPTION OF PASSIVE PLUME MODULE

The paragraphs below described the passive plume processes by which they disperse over time and the passive plume model used by TASS.

Description of passive plume processes

When formed, the *passive plume* of material will slowly disperse with the mixing effects of currents and waves. This effect, together with the settling of sediment particles, will reduce the concentration of the passive plume over time. There are three main mechanisms whereby this occurs:

- Turbulent diffusion, the small-scale temporal and spatial variations in current flow.
- Shear dispersion, the effect of different current velocities through the water column, which results in particles at different heights travelling in different directions and at different speeds, thus spreading the plume. This effect is generally much larger than (but is actually dependent on) turbulent diffusion.
- The settling and re-suspension of sediment particles to/from the bed.

Passive plume model

The passive plume model provided in TASS is intended to give a first order prediction of the resulting increases in suspended sediment resulting from dredging over and above background concentrations at a position some distance from the dredger. The model is not a

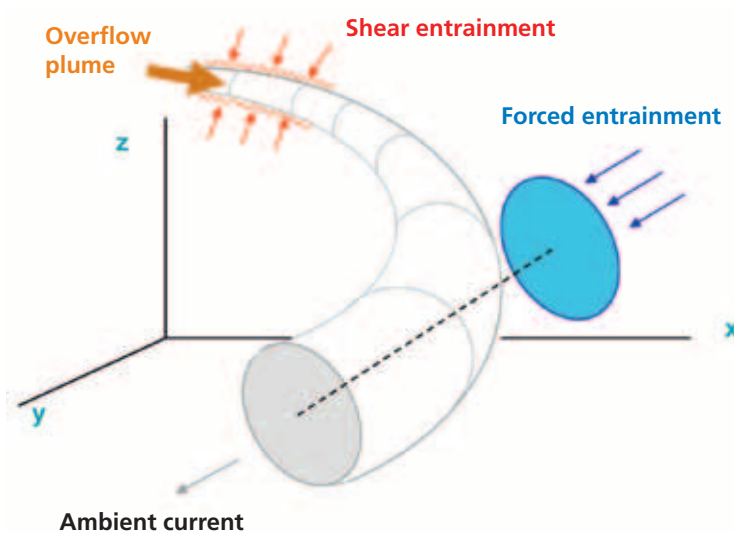


Figure 7. Entrainment processes of the dynamic plume.

detailed 3D model but predicts the depth-averaged increase in suspended sediment concentration at a point rather than the distribution of the plume in space.

In the case of the trailer suction hopper dredger, the passive plumes formed by dredging are a combination of the release of sediment directly into the water column (the “surface” plume), the sediment that diffuses out of the dynamic plume density current into the overlying waters and the sediment eroded from the bed by the propeller jet (see Figure 1). In addition there may be a small disturbance of sediment on the seabed by the draghead of the dredger but this is currently not represented in the TASS model.

The flow within the study area is assumed to be uniform and uni-directional along a single axis direction. The depth in the area of interest is also assumed to be uniform. Dispersion along and perpendicular to the direction of flow is calculated using the formulae of Elder as described in Fischer *et al.*, (1979). Under these simplifying assumptions, the solution for an instantaneous release of a slug of material into the water can be described by an analytical equation.

The method of Carslaw and Jaeger (1959) is used to solve the problem for time varying release. Further detail of the passive plume model is provided in the TASS user manual (EcoShape, 2010).

The principle objective of the TASS project is to determine the source term for dredging-induced turbidity in the far-field area from the dredger. Instead of using the simple passive plume model provided in the TASS system, the TASS overflow and dynamic plume models can also be combined (as in the HR Wallingford SEDTRAIL-3D model) with a detailed 3D passive plume model (as used in the comparisons described in below). In this way the TASS system can be used to provide initial and detailed dredging plume predictions suitable for a range of environmental assessment studies.

VALIDATION OF THE PASSIVE PLUMES PREDICTED BY THE TASS SYSTEM

In the following section, the passive plume measurements and the description of passive plume simulations will be presented as well as the effect of the dynamic plume in reducing the release of sediment into the water column and the validation of these studies against field measurements.

Measurements of the passive plume
In 2007 a field study was undertaken at Rotterdam to measure the turbidity plumes arising from overflow, draghead disturbance and from the propeller jet. This was followed later in the same year by a further field study at Den Helder where further measurements of overflow plumes were carried out (Aarninkhof *et al.*, 2010).

During the field studies in the Rotterdam waterway and offshore at Den Helder measurements of suspended sediment concentrations were made using ADCP backscatter. This methodology is based on the fact that the presence of sediment (or other particles such as bubbles or organic material) will cause reflection of the acoustic signal and the more particles present, the greater the reflection will be. The acoustic backscatter signal is therefore calibrated against water samples and, providing the results of the calibration process are satisfactory, this method can be used to record suspended sediment concentrations through depth.

As calibration can be complicated there are a number of software packages available to simplify and facilitate this process. SEDVIEW software was used for this purpose. When used to make transects the methodology can prove highly effective in providing detailed descriptions of plumes or estuary cross-sections. A combination of OBS sensors mounted on a streamer and water sampling was used to collect point measurements in order to validate the ADCP measurements.

Description of passive plume simulations

The TASS v3.2.1 overflow and dynamic plume modules described above under the “Description of the Tass Dynamic Plume Module” and “Comparison of Tass Overflow Module Results with Measured Overflow Data” were used to provide source terms within a detailed passive plume dispersion model (SEDTRAIL-3D) to predict the suspended concentrations within the passive plume at some distance from the dredger. These predictions of the passive plume concentrations were then compared against measured data (ADCP backscatter and OBS) from the Rotterdam and Den Helder field experiments (Aarninkhof *et al.*, 2010).

The flow model input used to reproduce the plume dispersion was composed of a simple “flume-type” model which was long enough to allow the motion of the plume over the course of the simulation, and wide enough to represent the lateral dispersion of the plume. The model was run to reproduce a nominal depth-averaged current speed and the current magnitudes adjusted up or down to match the

Table II. Summary of measurements used in validation.

Trip number	ADCP Frame	Distance from dredger (m)	Ambient current speed (m/s) *
<i>Rotterdam</i>			
5	07018	380	0.55'
11	08000	230	-0.54
17	09010	200	-0.73'
17	09012	320	0.7
<i>Den Helder</i>			
272	37	430	0.7
272	47	480	0.8
277	65	3080	0.3
278	80	240	Low and variable

* A positive current speed indicates that the dredger was sailing *against* the current and a negative current speed indicates that the dredger was sailing *with* the current.

current speeds reported from the field measurements. The currents produced varied in the vertical but were laterally homogeneous, which introduces a degree of error in the flow predictions, but this is not considered to compromise the purpose of the model validation or the conclusions arising from it.

The flow model used was a TELEMAC-3D finite element model, developed by LNHE, Paris. The passive plume simulations were each run to represent up to 75 minutes of plume dispersion from dredging in order to represent the dispersion of the plume over the course of the dredging “trip” represented in the simulation.

Effect of the dynamic plume in reducing the release of sediment into the water column

As discussed previously, accurate measurements of the relative magnitudes of the surface and dynamic plumes are scarce at present. The lack of knowledge in these areas means that at present it is not possible to reliably and *a priori* predict the balance of surface and dynamic plumes in a model by representing the physical processes. Having said this, relative proportions of sediment in the surface/dynamic plumes are based on measurements of dredging plumes in Hong Kong where the surface plume was estimated, on average, to amount to 15% of the overflow material discharged (*pers.comm.* Nick Bray, HR Wallingford).

Inevitably this figure is based on limited measurements but the magnitude of the measured surface plume as being substantially smaller than the dynamic plume fits well with the discussion presented above and the results of the validation exercise presented below which found that the surface plumes represented between 5% and 15% of the fine sediment in the overflow discharge.

Validation against field measurements

The passive plume was predicted for the trips and measured ADCP transects as summarised in Table II. The prediction of overflow losses were undertaken for Trips 5, 11 and 17 from the Rotterdam 2007 field experiment and for Trips 272, 277 and 278 from the Den Helder 2007 field experiment.

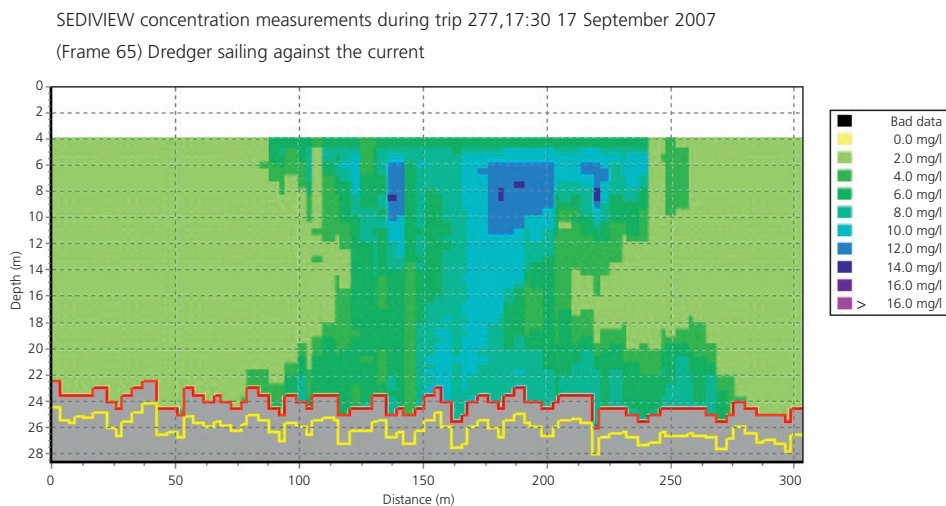
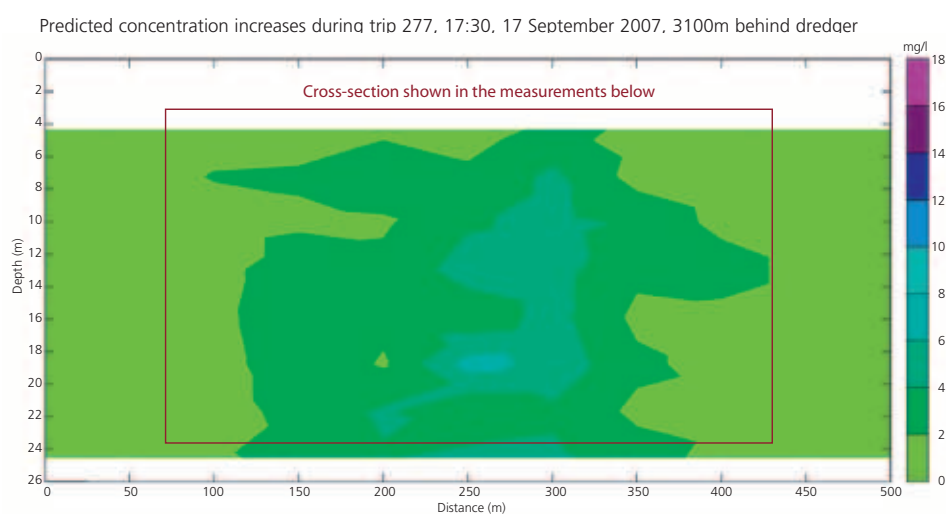


Figure 8. Predicted sediment plume predicted plume with 15% surface plume (top) and observed sediment plume (bottom) from Trip 277 of the Geopotes 15, Den Helder Field Experiment, 17 September 2007.

The validation exercise highlighted both the fact that there is a surface plume which forms a relatively small proportion of the sediment overflowed from the dredger and that there is currently no method for estimating this proportion *a priori*.

The model results were therefore calibrated by adjusting the proportion of material released into the surface plume (a user-defined parameter in the TASS model) until the model prediction broadly matched the observations.

Figure 8 shows a representative sample comparison of the prediction for Trip 277 of dredging with TSHD *Geopotes 15* at Den Helder with the measured observations. The release of fine material in the overflow is predicted by the TASS overflow model to be

around 292 kg/s at this time. The measured flux of sediment in the far-field is around 2.9 kg/s.

By considering the different frames of reference of the dredger and the measured plume and accounting for the different speeds of the dredger and the tidal currents the overflow discharge of fine sediment that would account for the measured flux can be calculated and corresponds to 11 kg/s.

The observed sediment in the water column in the far-field thus corresponds to only around 4% of the released fine material from the overflow. The model prediction gave the predicted sediment in the far-field as equivalent to 3% (in the measured part of the water column) and 4% in total.

RESULTS OF COMPARISON OF THE TASS MODEL AND DETAILED PLUME DISPERSION MODEL WITH FAR-FIELD DATA

In general small proportions of the fine sediment released are observed in the far field; this is reproduced by plume dispersion modelling using dynamic plume and passive plume modules. Modelling confirms that the surface plume accounts for 5-15% of the overflow discharge. Contributions are lower when using the environmental ("green") valve. This is similar to reports from monitoring in Hong Kong in the 1990s.

FURTHER WORK: MODEL DEVELOPMENT AND DISSEMINATION

The aim from the start of the TASS project was to make this software available to the dredging industry as well as third party users. The research on dredging-induced turbidity is currently embedded in the EcoShape I Building with Nature innovation programme, which aims at creating sustainable solutions for marine and inland water constructions. Present efforts focus on further development and validation of the model for a variety of environmental conditions, including the tropics. Once thoroughly tested, the model will be made publically available to facilitate sound predictions of dredging-induced turbidity by contractors, consultants, researchers and public authorities worldwide.

CONCLUSIONS

TASS (Turbidity ASsessment Software) is a software programme that enables the user to predict the spatial development and concentration of turbidity plumes arising from dredging activities by TSHDs. The TASS-project is currently embedded in the EcoShape I Building with Nature innovation programme.

The project has arisen from poor estimation of the effects of TSHDs, which can lead to unrealistically optimistic or pessimistic predictions of the development of turbidity plumes around dredging operations.

TASS has been validated against field data in a variety of locations and site conditions

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- along the North Sea Coast. The model has been found to reproduce both the nature of the overflow and the far-field plume correctly. The model represents a useful tool for Environmental Impact Assessment studies associated with dredging plumes from trailer suction hopper dredgers.
- EcoShape and HR Wallingford are currently cooperating to improve the robustness of TASS for use for sites around the world.
- Current efforts focus on additional measurement campaigns in tropical waters and validation of the software in the next year. It is envisaged that TASS will become available to the public in 2012.