

66. Towards improved prediction of dredging plumes: numerical and physical modelling

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INTRODUCTION

Construction and maintenance of ports and waterways involves dredging activities in many cases. Dredging projects require assessment and mitigation of a number of environmental impacts. Some of the potential impacts are related to turbidity plumes resulting from hydraulic and mechanical processes bringing sediment into suspension. To limit the impact on sensitive habitats (eg. corals & seagrass habitats) or nearby human activities, monitoring and predictive numerical modelling of the fate of these plumes is required. The extent of the impacts will depend on the quantity, frequency and duration of dredging, adopted methodology, site-specific conditions (wind, wave and current fields, grain-size distribution and water depth), proximity to sensitive sites and tolerance of living organisms to altered turbidity conditions.

Increased awareness has instigated stricter environmental legislation related to these activities. Project environmental permits often stipulate project-specific regulations, which can entail strict turbidity thresholds for these activities. Operational turbidity management in these projects is warranted, as exceeding turbidity thresholds can trigger corrective measures, increased monitoring efforts, relocation of dredge activity, a decrease in or –worst case - a cease of dredging and dredge spoil placement activities. The modelling tools presented in this paper add to the development of a system with which accurate real-time forecasting of the plume behaviour can be achieved. The operational planning of dredge operations a few days to a week ahead can be implemented in this forecasting environment. In case a violation of turbidity thresholds is predicted by the models, the operational planning is revised until no violations are predicted.

Trailer Suction Hopper Dredgers (TSHD's) often deploy an overflow system through which excess sea water is skimmed from the hopper. The overflow mixture contains a mass load of fine sediment material, partially descending gravitationally to the seabed, partially diluted to form passive turbidity plumes, often visible at the surface. A low excess density avoids the gravitational descent of passive plumes. Depending on the settling velocity of the sediments and on the degree of turbulent mixing, these plumes can travel over long distances. The plumes can therefore affect environmentally sensitive areas throughout coastal, river or offshore systems away from the dredging site.

An important open question in the research field of dredge plume forecasting has long been the determination of the fraction of released fine sediments entering the passive plume (and the remaining part sinking gravitationally to the seabed).

In the presented work, the highly complex, three-dimensional, multiphase flows of water-sediment-air mixtures near the overflow release have been studied using a physical model as well as Computational Fluid Dynamics (CFD). The insights gained from these modelling exercises lead to the development of a fast parameterised prediction model. At present, engineers at IMDC have coupled this parameter model to the existing far-field plume dispersion model codes, with improved plume dispersion accuracy as a result. In this paper, an overview

is given of the different near-field plume modelling tools developed during the project, and their current application to the improvement of turbidity assessment in planning phase and in operational phase. The presented research was initiated and executed at IMDC with support of Ghent University, KULeuven and Flanders' Agency for Innovation by Science and Technology (IWT). The authors have also received the PIANC De Paepe-Willems Award 2017 for the presented work.

Near-field CFD Model

A 3D numerical simulation model has been developed in the Ansys Fluent environment. The aim of the CFD model is to represent accurately the flow patterns of the water-sediment-air mixture in the direct vicinity of a hopper dredger while trailing. The CFD model solves for the 3D velocity vectors and diffusion of three phases: water, sediments and air bubbles. The actual geometry of an existing TSHD is embedded in the model grid. The model includes the mixing induced by the propeller jets and solves explicitly a large part of turbulent motions.

The CFD model was validated against both the physical model and against in situ measurements, taken behind a TSHD at work. After validation of this highly detailed simulation tool, the model has been used for two main applications:

1. Gaining insight in the behaviour of the near-field plumes under a variety of circumstances: different current velocity, dredging speed, sediment load, air bubble entrainment, the efficiency of a green valve, the shape of the overflow shaft, water depth, distance of the overflow from the stern and propeller mixing.
2. Derivation of a grey-box parameter model solving the vertical profile of the plume's sediment flux near the vessel. The model is based both on analytical plume solutions and empirical parameters, fitted to match the CFD results of a large number of cases.

Near-field Parameter model

A parameterised model is a trade-off between speed and accuracy. It will be less accurate compared to a CFD model, but will be fast enough to be applicable in cases where the CFD model simulation times are prohibitive, e.g. plume scenario simulations and real-time forecasting simulations. The parameter model is validated for a large range of boundary conditions and can be used to determine near-field plume behaviour in a large-scale model, as a function of time-varying water depth, currents and dredging vessel operation.

Discussion and conclusion

The sediment flux profiles generated by the grey-box parameter model can be imposed as source terms in a large-scale plume dispersion model, where the parameter model inputs are coupled with the large-scale flow properties. In this way, the fraction of released sediments moving to the large passive plume is determined every time step. This is a significant improvement over the rather arbitrarily chosen constant value used in the past.

Currently, the grey-box model is applied by consulting engineers at IMDC during environmental impact assessment of port development and maintenance, both in scenario analysis and in a real-time plume forecasting system.

Additionally, the model is to be applied as a tool to optimise the design of future dredging vessels to minimise the expected turbidity generation.