Coast - Suspended sediment transport

You have selected: Coasts  Sediment Transport  Suspended sediment transport

Case: Suspended sediment transport

Modelling steps

Intro

Within the Delft3D software package, Delft3D-WAQ can be used to model suspended sediment transport. Delft3D-WAQ is a 3D water quality model framework. It solves the advection-diffusion-reaction equation on a predefined computational grid and for a wide range of model substances. Suspended sediments are an important environmental factor in many coastal seas and concentrations can be affected by natural or human interventions, such as dredging and sand mining.

In order to monitor the effect of varying environmental conditions and compliment often sparse in-situ data of suspended sediment, a suspended sediment model can be set-up and calibrated.

Conceptual

Suspended Particulate Matter (SPM) is most commonly defined as all matter (inorganic and organic) that stays on a glass fibre filter with an approximate pore size of 0.7 micrometres. Heavy metals and various organic micropollutants adsorb to SPM, the transport of which can affect the ecosystem. High concentrations of SPM cause turbidity which in turn affects the underwater light conditions, thus influencing primary production by phytoplankton and other algae in coastal waters (e.g. Devlin et al., 2008; Tian et al., 2009).

Suspended sediments in the North Sea

The North Sea is bordered by the main industrialised countries of Northern Europe. It receives industrial and agricultural run-off from major rivers and coastal industries and is therefore a relatively heavily impacted marine system of which its hydrodynamics, ecology and water quality are topics of concern. Therefore there are many applied and fundamental research and monitoring studies.

Fine grained sediment dynamics in the North Sea is and still is the subject of many studies (e.g. Eisma and Kalf, 1987; Van Alphen, 1990; Fettweis and van den Eynde, 2003; Fettweis et al., 2007; Winterwerp, 2006; Pietrzak et al., 2010; Blaas et al., 2012). SPM in the Dutch coastal zone partly originates from rivers and cliff erosion, partly from local sea bed resuspension and partly from sources outside the North Sea. In particular, there is a long term net inflow of suspended particulate matter (SPM) from the Channel, through the Dover Strait into the North Sea.

Certain areas, such as the Flemish Banks, are localised sources of SPM.

In general, offshore SPM concentrations in the southern North Sea are low, ranging from a few mg/l in the northern part to a few tens of mg/l further south. Concentrations vary strongly on short time scales because of wave and tidal action, but also on a seasonal scale. In the coastal zone, high concentrations are found. The highest values are found in the Belgian-Dutch coastal zone and in the mouth of the Thames Estuary. Observed SPM concentrations during storms demonstrates that on a short timescale, vertical exchange of sediment between the seabed and the water column is dominant (Van Kessel et al., 2007).

Approach

Delft3D-WAQ makes use of the hydrodynamic conditions (velocities, discharges, water levels, vertical eddy viscosity and vertical eddy diffusivity) derived from one of a variety of hydrodynamic models such as Delft3D-FLOW. Wave characteristics, which are important in the sediment resuspension and settling, can be derived from the Delft3D-WAVE (SWAN) module or separate input files. As a basis of the modelling of SPM transport in Delft3D-WAQ, a good quality general transport model is required.

When setting up a hydrodynamic simulation to be used in a water quality simulation, communication files should be output which will be coupled to the water quality grid. This can be done with the Delft3D coupling program. The water quality grid may be at a coarser resolution than the hydrodynamic grid. From these communication files all the necessary conditions, such as current velocities, shear stresses, discharges, viscosity and diffusivity are input into Delft3D-WAQ. Bed shear stress due to waves may also be included, either by coupling to Delft3D-WAVE or by suppling the water quality model with a segment function file containing the shear stress values due to waves in order to include these effects 'offline'. Various switches may be used, depending on the methodology applied and these are described in the Delft3D-WAQ Processes Technical References Manual.

Model setup and Calibration

Below is a list of general steps to be taken to set up a suspended sediment model in Delft3D-WAQ:
1. Once the hydrodynamic and wave fields have been coupled (using coupling program) to the grid (see * below), conservation of mass in the model should be checked by running a simulation with a continuity value of 1. Values should not deviate far from 1 by the end of the simulation. The chosen time-step can effect the results.

2. Several sediment fractions can be included in the model by creating a substance file from the processes library. In the substance file (.sub) the setting velocity and grain size parameter of each fraction can be defined. These values can be found in the literature or from field data.

3. Next, the concentrations of SPM, associated with the discharges and also open boundaries should be prescribed.

4. Observation points and areas can be added for locations in which there are measurements.

5. Once the model is running it should be calibrated to achieve the correct concentration of suspended sediments in the water column, whilst at the same time maintaining an equilibrium mass in the bed. This can be achieved by adjusting the parameters controlling erosion and sedimentation. Sedimentation is the process describing the settling of particles and is described in the formulation by Krone (1962). Erosion of bed material occurs when the bed shear forces exceed the resistance of the bed sediment. The formula for erosion of homogeneous beds is based on Partheniades (1962).

* DIDO is a tool that can be used to aggregate a hydrodynamic grid to create a courser water quality grid if required. It is an interactive grid editor for coupling Delft3D-FLOW with Delft3D-WAQ. It produces the administration files needed to connect the hydrodynamic files to a coarser water quality grid.

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**Post-Processing and Results**

When assessing the performance of a Delft3D-WAQ suspended sediment transport model several types of plots can be created and analysed with Delft3D-QUICKPLOT, MUPPET or using available MatLab tools to assess if the model is behaving correctly:

1. Timeseries plots of suspended sediment concentrations either near the surface or at the bed

2. Profile plots of sediment concentrations

3. Maps of surface suspended sediment distribution
Various statistical measures may also be used to assess the model performance such as the bias between observations and model; RMSE between observations and model etc.

Publications