WorkPackage Plan

Delft Cluster project: Duurzame ontwikkeling van Noordzee en kustzone.
WorkPackage4: Morfodynamiek van Noordzee en kust en kustverdediging
January 2006

Background

The workpackage consists of the following three activities:

WorkPackage 4A: Sedimentation modelling
The workplan for this part of the workpackage is described in this document.

WorkPackage 4B: Prediction of water levels and surges along the Dutch coast
This sub-workpackage is directly connected to the Delft Cluster project Veiligheid tegen overstroming (WP A3) and therefore, the workplan for this part of the workpackage is not described in this document.

WorkPackage 4C: Flexibele kustverdediging met geosystemen
This sub-workpackage is separately handled by GeoDelft and WL|Delft Hydraulics and therefore, the workplan for this part of the workpackage is not described in this document.

Workpackage 4A: *Sedimentation modelling*

Introduction

The suspended particulate matter (SPM) concentration and the siltation rate in navigation channels and harbour basins along the Dutch coast are governed by the availability of sediment and by transport processes. Sediment availability is, for an important part, driven by the meteorological forcing, which has a stochastic nature: sediment can be mobilized by wave action and/or carried by river floods. Sediment transport is primarily steered by deterministic processes such as tide and density currents, but also includes stochastic forcing components such as wind and river discharge.

Models to predict SPM levels and siltation rates can either be deterministic or data-driven. An example of a process-based numerical model is DELFT3D, which has frequently been applied to model both large-scale and small-scale sediment transport and siltation in the Dutch coastal zone. A drawback of these process-based models is that they are computationally expensive because of the requirements on:

- simulation time because of the large residence time of sediment in the Dutch coastal zone;
- domain size because of the large length scale of the Rhine river plume and meteorological effects such as wind;
- grid resolution because of the observed strong sediment concentration gradients perpendicular to the Dutch coast and to enable the impact assessment of local geometric changes such as land extension for Maasvlakte-2.

To account for the full natural variability of the system, simulation periods of a few years would be required, which is currently very hard to achieve because of computational limitations. Therefore the meteorological variability is often schematized within a much shorter period, which is assumed to be representative for the complete period. In such a way, computation times remain within feasible limits, but at the cost of some realism. In addition, although the model formulations do include the most prominent features of the physical processes occurring, they remain simplifications, especially regarding water-bed exchange of sediment.

Data-driven models are also used, for example the neural network model ANN, which was developed in the previous Delft Cluster project to predict siltation in the Maasmond area. It was trained on the data from 1992 to mid 1998, and tested for the period of mid 1998 – 2000. Although the performance of data-driven models is satisfactory when sufficient data are available for calibration, they have as disadvantage that their outcomes are difficult to interpret because of their 'black box' nature. Also, data-driven models can not, by definition, predict the impact of future changes in the environment that are not represented in the existing data, such as changes in bathymetry (e.g. land reclamation) and river flow (e.g. discharge regime Haringvliet).

It is therefore proposed to integrate the data-driven and process-based approach by incorporating the appropriate physics into a data-driven model. Such a hybrid model is a good reflection of both the stochastic and deterministic nature of sediment transport and siltation. The following aspects should be analysed:

- Definition of domains. The domain resolution should be defined such that sufficient spatial detail is available, whereas the domain size should be such that dominant processes for SPM levels and silation along the Dutch coast occur within the model. Probably two domains are required to meet these demands. A process that is modelled in a deterministic way in one domain may be treated as stochastic in another domain.
- Description of physical processes: is the physical description for sediment availability and transport sufficient in the existing process-based models? Can improvements be recommended based on an analysis of the SPM and siltation data along the Dutch coast?
- Description of forcing: how do the stochastic and deterministic forcings influence the physical processes?
- Analysis of the relationship between input data, physical processes and SPM and siltation model results and data.

Figure 1 schematizes the line-of-thought behind the last bullet point. The analysis allows for a proper assessment of the natural variability of the different components, such as the amount of SPM in the system, and the driving forces responsible for this variability in particular and the variability of the whole system in general. The analysis will reveal which part of the model functions best on a process-based basis and which part on a data-driven basis. In principle, deterministic elements are best represented by a process-based description, but if this algorithm is insufficiently accurate or computationally too expensive, a data-driven approach may be preferred. This also applies to stochastic elements.

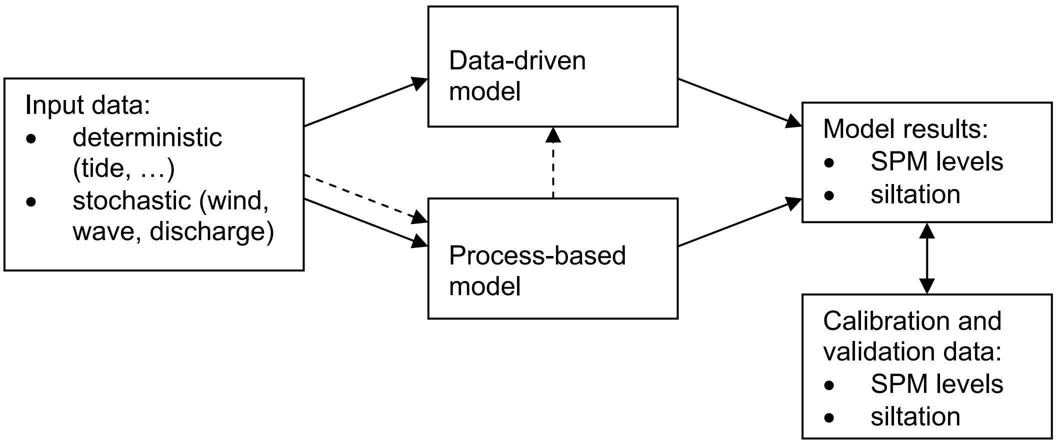

Figure 1: Schematic representation of interaction between data, process-based model and data-driven model.

As an example, consider the siltation rate in the Maasmond area. The amount of siltation is determined by the sediment availability at the North Sea, the transport rate towards the Maasmond and the local trapping efficiency. The transport rate is a function of the tidal filling, salinity-induced density currents (gravitational circulation) and meteorological filling, *i.e.* the flow rate into or out of the Maasmond access channel and harbour basins by a set-up or set-down at the North Sea. Meteorological filling is a stochastic process, which can be assessed from a harmonic analysis of the water level at Hoek van Holland. Tidal filling and meteorological filling both affect the gravitational circulation, of course in combination with the Rhine discharge. Salinity data can be used to establish this relationship.

Hence through such a decomposition one can assess the various contributions to the siltation rate, and establish a number of relations. Some of these relations will more pronounced than others, some can be established from physical analysis, others can only be derived from a data-driven model, etc. The strategy is to identify and, if possible, to reduce the overall uncertainty by reducing uncertainties in sub-components.

We expect that this approach will provide means to drive process-based models, such as DELFT3D, more cleverly than based on the current practice of selecting a short period of stochastic forcing assumed to be representative for a much longer period or, if sufficient computional force is available, the hindcasting of a number of randomly chosen years. Also, the analysis of the numerical results would become less tedious, as we improve our understanding on how the various stochastic processes affect the various system components. The latter can be illustrated through the previous example. If we have established the relationship of river flow, astronomical and meteorological tide with the gravitational circulation, we can improve the prediction on the impact of a variation of river discharge, for instance as a result of climate change (not only on the mean effect, but also on its variability).

It is further noticed that a process-based model such as DELFT3D can also be used to generate data to calibrate a data-driven model, either based on numerical data alone, or based on a combination of numerical data and field observations. This is represented by the dashed arrows in Figure 1.

Objectives

The objective of this project is to develop a methodology using a composite (hybrid) approach to predict sediment transport rates and accretion rates in channels, estuaries or harbour basins based on deterministic, stochastic and data-driven approaches using knowledge and measured parameters. This objective can be divided into the following parts:

- Exploration and analysis of the data available from different organisations such as DNZ, Port of Rotterdam, TUD, RIZA, etc.;
- Comparison of several approaches and development of a hybrid approach combining the data-driven modelling approach with physically-based models. A hybrid approach is a suitable method to combine the best aspects of each model; both sedimentation and sediment supply will be addressed.
- Application of the methodology for sedimentation prediction in coastal zones and harbours using a hybrid approach; the applicability will be tested by carrying out one or more case studies.
- Introduction of the findings into the practice of DC organisations and external partners through knowledge dissemination by publications, seminars and workshops.

Activities

The following activities will be carried out to realise the objectives:

1. literature study and description of the physical system;
2. data gathering and analysis;
3. setting up of models a) large-scale (North Sea and Dutch coast); b) small-scale (for example Maasmond, IJmuiden or Haringvliet);
4. developing a hybrid modelling methodology by combining data-driven and physically-based numerical modelling approaches, and building prototypes;
5. calibration and validation of hybrid model(s) for example by prediction of seasonal fluctuations in SPM concentration, prediction of siltation, etc.;
6. application of the hybrid modelling approach for a number of years: magnitude of variability and dominant causes;
7. conclusions and reporting;
8. communication with stakeholders and related projects (inside and outside DC).

1 Literature study and description of the physical system

A lot of literature and previous literature studies are available, so the literature study should not start from scratch, but focus on new developments and on existing examples of hybrid modelling in this field of research. The literature study could result in a further refinement of this workplan and a change in the activities, if it is concluded that this better meets the demands of the objectives. One of the deliverables of the literature review is a state-of-the-art physical system description of silt transport and siltation in the Dutch coastal zone, with a distinction between proven knowledge and hypothesis. This will act as the conceptual framework of the study..

2 Data gathering and analysis

Data are available on surface SPM (available in DONAR database), CEFAS-measurements at Noordwijk, Siltman data of Maasmond, remote sensing images, local dredging volumes in

Rotterdam harbour and IJmuiden, measurements at Botlek during NWO – TUDelft project (Michel de Nijs - TUD). Data availability is also discussed in the WL | Delft Hydraulics proposal on t_0-measurement for Maasvlakte-2. When applicable, permission should be obtained to use the data. All data should be collected and stored at a single disc location accessible for all team members. Three types of data should be discerned:

1. meteo data such as wind, waves, river discharge, water level setup
2. sediment concentration data along the Dutch coast
3. siltation data in harbours such as Rotterdam and IJmuiden derived from dredging volumes

The analysis will adopt a two-step approach, i.e. linking type 1 (meteo) with type 2 (SPM) and subsequently linking type 2 with type 3 (dredging volumes). The first step should focus on the relative contribution of the tide, wind and river discharge on the SPM signal and establish the magnitude of the stochastic component. It should also be assessed which part of the SPM signal is dominated by local processes and which part by advection. This analysis will show which parts of the modelling chain can be best addressed by a physically-based model and by a data-driven model.

3 Setting up of models

The starting point for the large-scale physically-based model is ZUNO-coarse. The hydrodynamics are already available for a number of years (1996 – 2003). Local refinement is required along the Dutch coast, in the Maasmond and/or near IJmuiden, *e.g.* with the RIJMAMO model (coarse version). It is important that the model should initially be less computationally expensive, *e.g.* with a maximum of 1 day of calculation time per year of simulation. Also, the DELFT3D models are a tool within the hybrid modelling exercise and not an objective in itself, so existing model lay-outs will be used as much as possible.

4 Developing a hybrid modelling methodology

This activity is at the heart of the study. This methodology will be based on the findings of the literature review and data analysis. The focus will be to address the stochastic components of the process with the data-driven modelling approach and the deterministic components of the process with a numerical model (Delft3D). Data-driven modelling may also be used as a complimentary model to reduce systematic errors of the numerical model. It may also be used in uncertainty assessment of model predictions. Three major steps are envisaged:

- Developing a data-driven modelling approach
- Developing a hybrid modelling approach
- Building a prototype

The result of the above activities is a working prototype that can be used for the subsequent activity, the calibration and validation of the model. Of course, this is an iterative process, if the calibration results are not satisfying, the set-up of the prototype can be further optimised.

5 Calibration and validation

This activity will be carried out for example by modelling the SPM supply along the Dutch coast from the meteo forcing, modelling the siltation volume from the SPM supply, etc. The main focus during the calibration will be on the error level of the SPM and siltation prediction: how large is the error, how does it compare with the required accuracy, how can the error be further reduced and how feasible is this within the project and in general? Special elements from the model output to consider are: water-bed exchange, the relative importance of local versus global processes, horizontal versus vertical exchange, residence time of sediment, total mass in system (in the water column and on the bed).

6 Application of the hybrid modelling approach

Quantification of key processes resulting in observed yearly variability. What is the simplest possible model that describes most variability? What is the data-driven contribution and what is the physically-based contribution? A case study on Rotterdam harbour/ IJmuiden harbour/ Haringvliet will illustrate the potential of the model to stakeholders.

7 Conclusions and reporting

The report will discuss the (proven) advantage of the hybrid modelling approach compared to a physically based model or a data-driven model. It will discuss the relative importance of different forcing mechanisms to the SPM levels along the Dutch coast and to siltation in harbours/ coastal zones of interest. It will discuss the error level of the predictions, the improvements made in the present project and compare the error levels with the required accuracy from a managerial point of view. It will identify the remaining error sources (e.g. spatial or temporal resolution of meteo forcing, spatial resolution of numerical models, insufficient physical process description in numerical model, inherent stochastic variability). Focus on publication in peer-reviewed journals.

8 Communication with stakeholders and related projects

During the project, there will be regular meetings (2-3 times a year) with stakeholders. These meetings will be on the one hand informative, but on the other hand stakeholders are offered the possibility to interact (to a certain extent, within the overall objectives) with the work plan. The spin-off of the project will benefit from this.

Deliverables

- Report

  The report will include work-plan, literature study, description of the physical system, description of available data and data analysis, availability of physically based numerical models (based on DELFT3D), note on construction of hybrid models, working prototype of hybrid models, calibration/validation report of hybrid models and conclusions and recommendations.
- peer-reviewed publications

Time schedule

• workplan:	01-2006
• literature study and description of the physical system	03-2006
• data gathering and data analysis	06-2006
• setting up of numerical models	08-2006
• developing a data-driven modelling approach	11-2006
• developing a hybrid modelling approach	06-2007
• building a hybrid prototype	09-2007
• calibration/validation and application of hybrid model	12-2007
• conclusions and recommendations	01-2008
• reporting	05-2008
• peer-reviewed publications	12-2008

Thijs: the project ends in Dece, 2008. How do we describe our activity during Sep, 2007 to Dec, 2008?

Dates for meetings (internal/external): 2 to 3 times a year

People

Dimitri Solomatine (UNESCO-IHE) (Workpackage leader)
Thijs van Kessel (WL|Delft Hydraulics)
Han Winterwerp (WL|Delft Hydraulics)
Biswa Bhattacharya (UNESCO-IHE)
Roland Price (UNESCO-IHE)
Tony Minns (WL|Delft Hydraulics)

Additionally, the members of the clients' group/ sounding board will be involved.

Responsibilities

• workplan	WL and IHE
• literature study (except data-driven & hybrid modelling)	WL
• literature study (with data-driven & hybrid modelling)	IHE
• description of the physical system	WL
• data gathering	WL
• data analysis	IHE
• setting up of numerical models	WL
• developing a data-driven modelling approach	IHE
• developing a hybrid modelling approach	IHE
• building a hybrid prototype	IHE
• calibration/validation and application of hybrid model	IHE & WL
• conclusions and recommendations	IHE & WL
• reporting	IHE & WL
• peer-reviewed publications	IHE & WL