Deltares

Enabling Delta Life

Modelling coastline evolution

Practices for the setup of coastline models

Deltares

Modelling coastline evolution

Practices for the setup of coastline models

B.J.A. Huisman

1209381-005

Title
Modelling coastline evolution

Client	Project	Reference	Pages
Rijkswaterstaat - De waterdienst	1209381-005	1209381-005-ZKS-0001	15

Keywords
Coastline modelling, Guidelines, Model components, UNIBEST, PONTOS

Summary
This document provides guidelines for the setup of coastline models along the Dutch coast. These guidelines are based on research of the performance of coastline models at Domburg within the framework of the KPP B&O kust programme (Deltares, 2011 & Deltares 2012). Chapter 2 provides an overview of available coastline models, Chapter 3 the main considerations for the setup of a coastline model and Chapter 4 the relevance of different model components. These guidelines provide minimum requirements for coastline modelling. The following conclusions are drawn with respect to the modelling:

- For the setup of a coastline model it is essential to define the specifications on the basis of the aims, associated time and spatial scales and the site specific characteristics.
- It is necessary to use appropriate model components and define the settings correctly. Special attention needs to be paid to:
  - The wave climate conditions. Since the wave climate determines the performance of the model to a large extent. In many cases the waves need to be transformed towards the shore with a wave model
  - The potential impact of horizontal and vertical tide (site specific).
  - Definition of the alongshore varying profiles (for non-uniform coastline sections).
  - The setting of the active height of the profile. This is of importance since the coastline response is directly related to this parameter.
  - The potential impact of offshore losses at steep slopes (site specific).
  - An appropriate sediment transport formulation. It should be suitable for the considered sedimentary environment. It should also be verified whether the sedimentary environment is variable along the coast.
  - Calibration of net alongshore sediment transport on the basis of historical data.
  - A complete overview of the history of the nourishments.
  - The inclusion of local wave climates at structures. Sheltered wave climates are essential for the local coastline development. Additionally, secondary flows may be of relevance.
  - Smooth coastlines, since spikes in the coast may affect model performance.
  - Numerical parameters should be set such that they do not impact the results.
  - Grid parameters since the model needs to have sufficient resolution

Version	Date	Author	Initials	Review	Initials	Approval	Initials
	sept. 2014	B.J.A. Huisman	[signature]	D.J.R. Walstra	[signature]	K.J. Bos	[signature]

State
final

Contents

1 Introduction

Framework
The research described in this report has been performed in the years 2012 and 2013 on the application of coastline models within the framework of the KPP B&O kust programme. This concerned the inter-comparison of three coastline models (i.e. Pontos, UNIBEST-CL+ and Longmor) and the relevant modelling components for setting up a model at the coast of Domburg (Deltares, 2011 & Deltares 2012). These studies provided a number of relevant attention points for the set-up of coastline models, which are summarised and extended in this report.

Scope
This report provides general guidelines for the setup of coastline models with the aim of improving the consistency of modelling studies for the Dutch coast. In fact this report condenses the findings of the research studies in 2012 and 2013 in guidelines.

Summary of previous studies
In 2012 an inter-comparison was made between the PONTOS, UNIBEST-CL+ and LongMor models for comparable situations (Phase 1). Differences were found in the way the models dealt with (1) wave refraction at the foreshore, (2) computation of sediment transport and the applied sediment transport formulations, (3) the relevance of sequencing of the wave conditions and (4) the interpolation of wave conditions along the coast.
When the models are calibrated and applied with similar settings for the coast of Domburg, the model results were very similar (Phase II). The application of similar settings did, however, come at the cost of sacrificing the specific strengths of the models. The simplified model setups resulted in an overestimation of the reshaping of the coast at Domburg. PONTOS and UNIBEST were therefore applied with model specific settings in 2013 for the coast of Domburg (Phase 3). It was then found that application of nearshore wave conditions is essential for a good hindcast of coastlines with complex foreshores such as at Domburg. For some cases it also proved to be relevant to calibrate the rate of alongshore sediment transport.

Outline
The report starts with an overview of coastline models that are available (Chapter 2). Considerations for the setup are then given in Chapter 3. Chapter 4 then discusses the most relevant model components and specific attention points.

2 Available coastline models

2.1 Introduction

This chapter describes the commonly applied coastline models for the Dutch coast. They can roughly be subdivided in one-line and multi-line models.

2.2 One-line models

One-line coastline models schematise the coast as a single line. Such models compute the aggregated sediment transport for all of the cross-shore transects along the considered coastal stretch on the basis of the coastline orientation and the dominant wave conditions. Additionally, the computed transport can be influenced to some extent by the profile shape, tidal water levels and currents. The predicted coastline changes are the results of the balance of these alongshore sediment transports in each of the alongshore grid points.

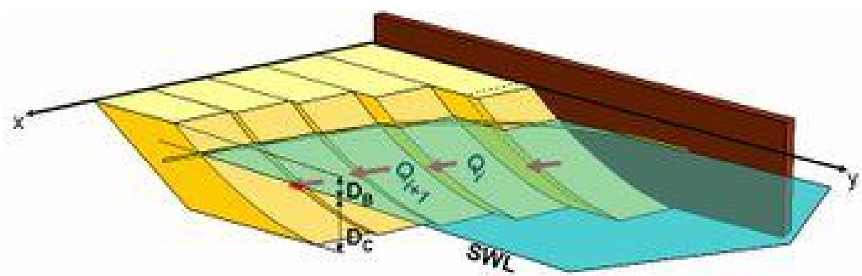


Figure 2.1 Illustration of coupled cells of a one-line model near to a structure (image from Genesis user manual)

Examples of such models are UNIBEST-CL+, Longmor and Genesis. The UNIBEST-CL+ model uses a more process-based approach, while the other models opt for a quick computation of the coastline changes. The UNIBEST-CL+ model computes the wave transformation over the cross-shore profile and more complex sediment transport formulations, which can be more accurate for complex coastlines. Furthermore, it is easy to apply nearshore wave conditions which are necessary for coasts with a complex foreshore (e.g. outer delta).

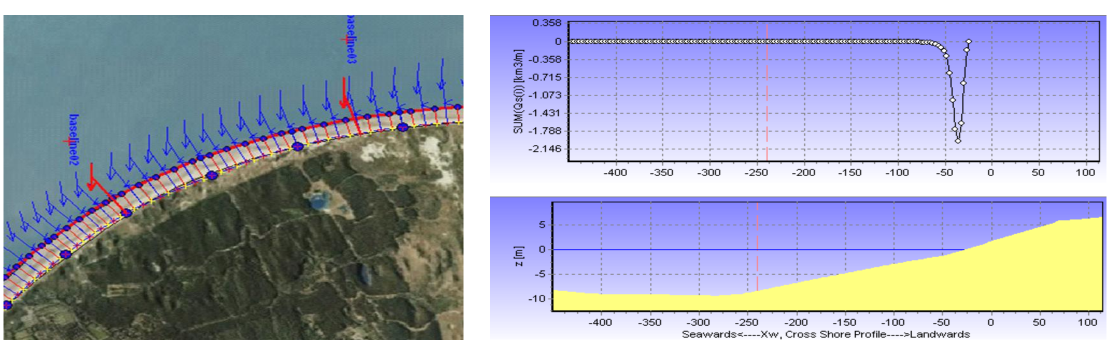


Figure 2.2 Illustration of UNIBEST-CL+ coastline, cross-shore profile and sediment transport distribution

The Longmor and Genesis models compute the alongshore sediment transport on the basis of the offshore wave conditions and a bulk-transport formulation (either CERC or an aggregated Van Rijn formulation). They have the advantage of being quick and simple. The computed transport does, however, require calibration for most situations.

2.3 Multi-line models

Multi-line models schematise a coastline profile by multiple lines. For each depth layer a separate coastline is defined. This allows for different rates of coastline changes at different depth levels. Cross-shore sediment transport is computed on the basis of the profile steepness of each layer, which is related to an equilibrium profile steepness. Nourishments can be included in the cross-shore layers of the models.

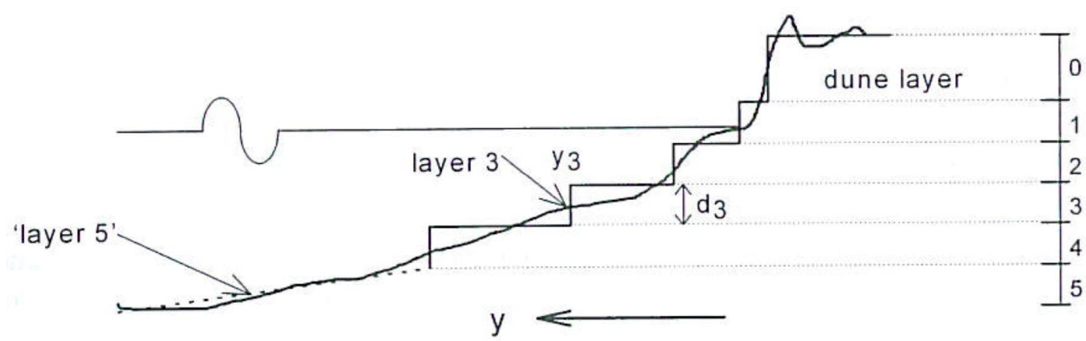


Figure 2.3 Layer schematisation in the PONTOS model

The only multi-line model in the Netherlands is the PONTOS model Which schematises the coast into 5 depth layers (Steetzel et al., 1998). A model of the Holland and Wadden coast is available, which couples a PONTOS model of the coastlines with ASMITA models for the estuaries of the Dutch Wadden Sea (Steetzel et al., 2000).

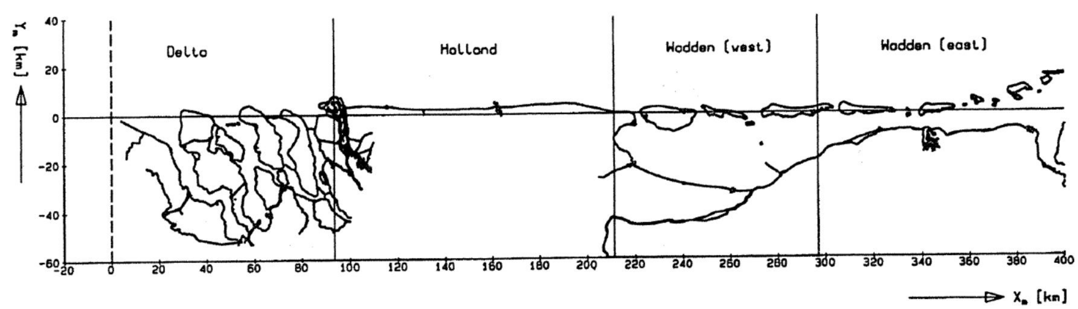


Figure 2.4 Schematisation of the Holland coast in the PONTOS model

The model is faster than a field model such as Delft3D, but it is much slower than a coastline model such as UNIBEST-CL+. A drawback of the model is that the derivation of the equilibrium slopes (for each layer) requires validation data and extensive calibration. Furthermore, it is difficult to include nearshore wave conditions, which are necessary for areas with non-uniform foreshores.

3 Considerations for model setup

3.1 Introduction

Typically, the most important aspects to account for when applying a coastline model are:

- Aims of the modelling effort
- Spatial and temporal scale
- Characteristics of the study area
- Model specific settings

3.2 Aims

When starting off with setting up a coastline model, it is relevant to clarify the aims of the study. Some studies require detailed information for a specific location (e.g. a specific town or an area with structures) while others aim at obtaining insight in the total aggregated volume of nourishment sand that is needed for a specific section of the coast (e.g. the budget for the Rijnland coast). Or even the aggregated volume required for the full coast during a decade (e.g. rapid assessment tools for policy making). Depending on the aim a more or less detailed model approach should be adopted.

3.3 Spatial and temporal scale

The considered time and spatial scale should also be accounted for in the coastline model setup. The assessment of coastline evolution near cities, harbours or industrial complexes (often for safety purposes) requires a good insight in the smaller scale developments and variations in coastline position over time (e.g. detailed computations near to structure on the basis of nearshore wave conditions and information on the cross-shore profile evolution) while aggregated studies of large coastal cells can be performed without considering the small alongshore variations in the wave climate (see Figure 3.1).

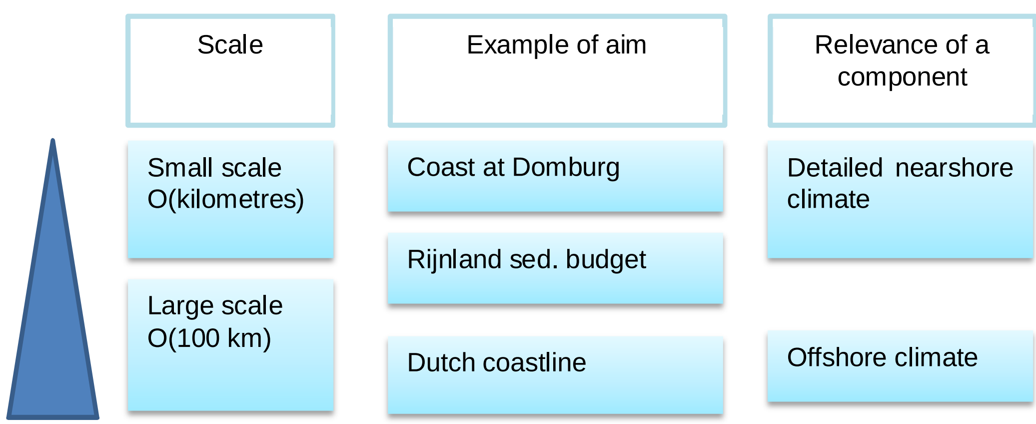


Figure 3.1 Small scale and large scale studies and some typical aims

In fact the aim of the study (as described in Section 3.2) strongly influences the relevant spatial and temporal scales at which the study should be resolved. Typically, coastline models are applied at a scale of 5 to 100 kilometres (see Table 1). For studies which aim at smaller spatial scales (e.g. size of the nourishment itself) it is more appropriate to apply models such as Delft3D, which resolves detailed sediment transports and wave transformation. In some cases, however, it may be useful to apply to a coastline model to quickly assess the initial response of nourishments and the global response of beach schemes.

Table 1 Overview of typical coastline modelling studies and their associate time and spatial scales

Aim	Spatial scale	Time scale
Long-term strategy development	O (100km)	Century
Indicative studies (landscape designers)	O (kilometres)	Yearly
Budget studies	O (10 km)	Years - Decades
Nourishment evaluation	O (kilometres)	Years - Decades
Impact of harbour moles / jetties	O (kilometres)	Years - Decades
Beach schemes with groynes / breakwaters	O (100 m)	Months - Decades
Long-term trends for safety assessment *	O (kilometres)	Years - Decades
Initial response of nourishments **	O (100 m)	Months

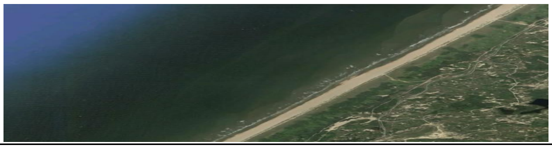
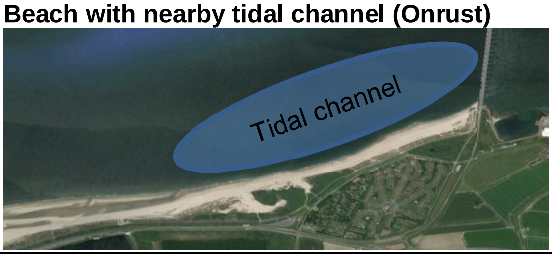
* additional to modelling of the impact of episodic events

** indicative studies on the initial development of nourishments

3.4 Characteristics of the study area

Besides the aims of the study, the physical characteristics also play a role (see Table 2). The relevant processes that drive longshore sediment transport should in any case be resolved in the model. This means that different approaches should be chosen for different parts of the coast. The simplest case concerns a uniform sandy coast with small tidal influence and waves from relatively ‘low angles’ (i.e. dominate by waves that come in at angles less than 45º from the shore-normal). Such a coast can be studied with a model that computes just the wave-driven alongshore current. For some areas also the tide is of importance. Additional to the hydrodynamic forcing conditions also other characteristics of the study area can significantly influence the long-term coastline behaviour. First of all, some coasts have complex foreshores which require the use of detailed wave computations and alongshore varying nearshore wave conditions. Secondly, there are beaches with large differences in water levels, which means that wave forcing conditions are absent during a part of the tidal cycle. Thirdly, beaches can experience considerable tidal flow velocities (e.g. close to tidal basins or at a protrusion of the coast) which should be accounted for by the inclusion of the effect of sediment transport due to the tide. Very specific situations along a coast may also require the estimation of cross-shore sediment transport. This holds especially, if a tidal channel is present very near to the shoreline. A particular, rather complex, situation concerns the detailed processes near to harbour moles or breakwaters. The hydrodynamics and transport processes are affected by wave diffraction and setup driven flows. Similarly complex is the modelling of small groynes along the coast, which requires an assessment of the partial blockage of the transport.

Table 2 Overview of typical study areas with some relevant processes

Type	Relevant processes
Uniform beach with moderate to small tide 	• Wave-driven alongshore transport. • Tidal flow impacting transport (gradients) depending on the modelling aims
Beach with a complex foreshore (Domburg) 	• Wave-driven alongshore transport with alongshore varying wave conditions • Tidal flow impacting transport (gradients) depending on the modelling aims
Beach with large tidal flow (Sand Motor) 	• Wave-driven alongshore transport with alongshore varying nearshore wave conditions. Wave focussing on the head of a coastline feature can be of relevance. • Tidal flow generating alongshore transport (gradients) and horizontal circulation patterns.
Beach with large tidal range (Wales) 	• Wave-driven alongshore transport (possibly with alongshore variability due to the shallow foreshore) • Tidal water levels impacting the duration of sediment transport at the beach, as it impacts the nearshore wave condtions. • Tidal flow driving transport on the beach
Beach with nearby tidal channel (Onrust) 	• Wave-driven alongshore transport with alongshore varying wave conditions to account for the effect of the tidal channel on wave propagation. • Tidal flow at the beach • Cross-shore transport towards the channel (either in the model or by application of known transports as sinks.
Coastline near to structures (IJmuiden) 	• Wave-driven alongshore transport • Wave diffraction and sheltering behind the breakwaters • Water level setup driven currents (e.g. rip currents)
Coast with small groynes (Noord-Holland) 	• Wave driven alongshore transport • Wave diffraction and sheltering behind the breakwaters • Tidal flow constriction • Water level setup driven currents • Impact of partial blockage of transport

3.5 Model specific settings

Finally, the model specific features are also of relevance. This concerns aspects such as the diffusion coefficient (alpha) in the PONTOS and LONGMOR models. This diffusion coefficient should be set at a value for which the model is stable, but also a value that minimises the artificial diffusion. Other aspects include the time and spatial discretisation which should be sufficient to resolve the considered processes. Furthermore, each of the considered processes requires a number of input settings which may be related to the modelling approach.

3.6 Conclusions

The general considerations for the setup of a coastline model following from this chapter are:

- Clearly define the aim of the model.
- Define the time and spatial scales that should be resolved.
- Investigate the site specific characteristics &
  Identify the processes that should be resolved
- Apply numerical settings which do not adversely affect the model results (i.e. a smaller time step or smaller spatial discretisation should give same result)

4 Relevant model components

4.1 Introduction

This chapter discusses different components of the UNIBEST, PONTOS and LONGMOR coastline models. It is expected that other coastline models have similar model components.

- Wave conditions
- Tide conditions
- Cross-shore profiles
- Sediment transport
- Nourishments
- Structures
- Coastline evolution

4.2 Wave conditions

Deriving wave conditions from data	The offshore wave data (to be applied for the wave model or direct model input) should be of sufficient quality. The time-series preferably cover at least a similar timeframe as the computation. Alternatively an effort should be made to show why the selected time frame is representative. Furthermore, there should not be a bias in the missing data (e.g. all the storms missing). Wave buoys without directional data are of very limited use for coastline modelling.
Offshore versus nearshore wave conditions	In some cases offshore wave conditions can be applied directly to the coastline model. This holds for longshore uniform beaches with spatially uniform wave climate conditions. Many coastline models do, however, require nearshore wave conditions (from 2D wave transformation models) as they are not alongshore uniform or have a complex geometry of the foreshore with shoals and tidal channels. It is noted that the application of nearshore conditions generally improves the model results and does not lead to performance degradation as long as the nearshore location is chosen outside of the active littoral zone of the profile.
Alongshore interpolation of wave conditions	Interpolation of sediment transport rates along the coastline differs between coastline models. Some coastline models (e.g. UNIBEST) interpolate the equilibrium coastline angle and coefficients of the schematised transport relations, which gives stable results. Other models (e.g. PONTOS) do, however, interpolate the wave conditions along the coast, which can lead to opposing zones of sediment transport convergence and divergence between the two models. In practice the impact of this issue will be small if the alongshore spacing of the wave climate locations is sufficiently small. LONGMOR is unable to compute transport under spatially varying wave conditions.
Climate vs. time series (net vs. gross transport)	The sediment transport can be computed on the basis of wave climates or time-series of wave conditions. The selection of a wave climate or wave time series approach may have an impact on the results, because a time-series option also accounts for the temporal variations in direction and magnitude of the transport while a model with a wave climate uses a stationary net transport. Applications where a time-series approach is of relevance are those where the model is aimed at

	relatively small time scale changes (i.e. seasonal or less) or if the coastline response near a structure or in a small pocket beach is concerned. UNIBEST-CL+ in default mode uses an approach with a wave climate while the PONTOS and LONGMOR models compute longshore transports every numerical time step, using simplified transport formulations.

4.3 Tide conditions

Horizontal tide	The horizontal tide has some influence on the resulting net sediment transport. For uniform beaches (e.g. Delfland coast) this influence is usually relatively small. Coastal sections near to tidal inlets (e.g. Strand bij de De Banjaard) and close to structures may, however, experience a significant impact of the tidal flow.
Vertical tide	It should be checked whether the considered study area experiences smaller or larger wave impacts during the high or low water phase of the tide. This is especially relevant for sandy macro-tidal coasts. A coupling between the tidal water levels and the wave simulation is needed in such a situation.

4.4 Cross-shore profiles

Alongshore variation of the cross-shore profile shape	The impact of variation of the cross-shore profile shape in alongshore direction is smaller than the influence of many other parameters such as the use of nearshore wave climate conditions or the selection of a transport formulation. It is, however, noted that large changes in cross-shore profile shape along the shore may have an influence on wave refraction towards the shore and therefore indirectly affect the alongshore sediment transport gradients significantly.
Active height of the profile (i.e. time scale)	The active height of the profile influences the time scale at which coastline changes (e.g. retreat, accretion or re-orientation) take place. Within PONTOS the active height is accounted for by the different layers, while it has to be specified in UNIBEST and LONGMOR on the basis of estimates of the depth of closure. The rate of coastline changes also differed, as the models respectively compute changes for a quickly reacting layer (PONTOS) or aggregate changes over the whole active height (UNIBEST / LONGMOR) which gives a slower response. Both approaches are valid, but should be used with care. It is advised to calibrate this parameter on the basis of computed and observed coastline changes.
Re-orientation of the coastline / foreshore	The way in which the coastline model accounts for re-orientation of the coastline during the simulations significantly affects the net transports for situations where considerable re-orientation of the coastline is expected throughout simulations. This works as follows: (1) net-gradients in alongshore transport enforce a coastline re-orientation more normal to the incoming waves, (2) the waves do then experience less refraction towards the shore and (3) the effective net alongshore transport is smaller. Typically, PONTOS and LONGMOR assume that

	the entire profile experiences re-orientation. UNIBEST assumes that only the nearshore part of the profile will re-orientate while the deeper foreshore will keep its orientation.
Cross-shore sediment transport	Cross-shore sediment transport generally has a small influence on coastline evolution of sandy coasts, since the magnitude of cross-shore transport is often small compared to the alongshore transport. However, for specific parts of the coast the cross-shore transports may affect the model predictions significantly. One can think of coastal sections with active tidal channels very near to the coast (e,g. near to tidal basins). Furthermore, an initial effect of cross-shore redistribution may take place for nourishments (e.g. large initial cross-shore redistribution at the Sand Motor). For the coast around Domburg the effect of the cross-shore layers was small, because the cross-shore sediment transport magnitude in this area is relatively small compared to the alongshore transport rates. The UNIBEST and LONGMOR models can include cross-shore sediment transport as losses or sources in the model. They assume that the sediment is taken from the whole of the active part of the surfzone. PONTOS uses an approach with multiple layers which allows for cross-shore flux of sediment between the nearshore layers and the offshore layers. The actual setting of the cross-shore transport parameters in PONTOS requires a detailed calibration.

4.5 Sediment transport

Transport formulations	Different sediment transport formulations are available in the models. Resulting in large differences in computed net-transport rates and sensitivity to environmental conditions. For the Dutch coast it is generally found that the Bijker and Van Rijn 2004 formulation provide reasonably good transport rates. Other coasts may, however require different formulations.
Calibration of net-alongshore transport	Differences in net longshore sediment transport rate were responsible for the majority of the variability in the nourishment predictions. In general it is therefore advised to check reference transport rates at the considered coast and calibrate the net longshore transport on the basis of the historical sediment budgets of the considered area. This holds especially for the PONTOS and LONGMOR models.
Sediment properties	The properties of the sediment are of relevance for the selection of the transport formulations. Some beaches may for example have a heterogeneous composition of gravel and medium grained sand. Beaches with sediment composition that is different from fine to medium grained sand should be treated with great care. Those situations require good information on the historical changes of the coastline. The same holds for beaches with alongshore variations in sediment composition.

4.6 Nourishments

Nourishment history	An overview should be obtained of the nourishments that were applied at the considered stretch of coast, as there may be differences between the official specifications and the actually applied measures.

Placement of nourishments in the profile	The inclusion of nourishments in coastline models requires interpretation of the impact of cross-shore redistribution in the model. Most one-line models include the sediment instantaneously in the littoral zone where the alongshore transport takes place, while this may take more time for nourishments in deeper water. Since this is an inherent property of one line models, this should be accounted for in the interpretation of model results. For models with multiple vertical layers, attention should be paid to the actual distribution over the vertical layers.
Predefined and pro-active nourishments	Sand sources can be included in advance or computed by the model based on thresholds for the coastline position that should be maintained. It was found that simulations with pro-active nourishments (i.e. supplying sediment such that the coastline remains in place) yielded similar results as pre-defined nourishments.

4.7 Structures

Inclusion of structures	Every coastline model has a different way to include structures in the model. The impact of the structure is generally represented by a (partial) blockage of the alongshore sediment transport (at groynes) and an impact on the wave climate near to the structure.
Bypass of structures	The bypass of sediment at groynes and harbour moles should always be accounted for if the structure is smaller than or of the same length as the width of the cross-shore distribution of the alongshore sediment transport. Furthermore, it should be noted that the tide may also drive currents which affect the bypass of sediment along structures. Consequently, the actual bypass rates are generally larger than the computed bypass rates (which are based only on the blocking of a part of the cross-shore distribution of the alongshore transport).
Local wave climate conditions	The wave climate near to structures can be significantly affected by the sheltering effect. It is strongly advised to account for this sheltering effect especially at the downdrift side of structures. Generally, this requires detailed wave computations with SWAN or other wave models. It is noted that this approach works best for relatively long groynes (longer than width of transport zone) or offshore breakwaters outside the active zone. Shorter groynes or offshore breakwaters within the active zone experience very different physics which are not resolved in coastline models and can therefore not be included directly. There may, however, be some reduction in alongshore transport and the rate of erosion (or accretion) at locations with short groynes.
Secondary flows	Secondary flows due to gradients in water levels are often not resolved by coastline models. They may, however, be of relevance since rip currents can be generated near to the structure. These rip currents may drive offshore losses at structures. Furthermore, it is noted that tidal flow may also drive eddies at the leeward side of structures which may transport sediment towards the structure.

4.8 Coastline evolution

Alongshore schematisation method of the coastline	The schematisation of the coastline differs for each coastline model. Some models directly schematise the coastline (e.g. LONGMOR and Genesis), while other models (UNIBEST and PONTOS) use an approach with a reference coastline which is located landward of the actual coast. For the latter, the actual coastline itself is specified as a distance from the reference line at each grid cell. Results should be similar for most models, but the approach with the reference coastline allows for the inclusion of abrupt changes in the coastline (e.g. different coastline position at both sides of a structure). In general it is advised to make smooth coastlines (without a strong local curvature) for which an approach with a reference line is needed in case of coastlines with abrupt changes.
Numerical scheme	The numerical scheme in some models (e.g. PONTOS and LONGMOR) may become instable if the numerical parameters are not set appropriately. It is advised to test the influence of numerical diffusion parameters (i.e. alpha parameter in PONTOS or Longmor) and set it to a minimum value for which the model is still numerically stable, as a too high alpha will result in considerable numerical diffusion.
Grid spacing	The grid spacing should not be too fine (between 50 and 1000 meters) since coastline model is not aimed at assessing changes at small spatial scales. Obviously, a too coarse schematisation may not be able to resolve detailed effects (e.g. some extra resolution may be required near to structures).
Time discretisation	Time discretisation should be such that the run is stable and unaffected by a decrease in the time step. In general the results are not very sensitive to this setting.

4.9 Conclusions

While setting up the model it is essential to check the following technical aspects:

- Wave conditions
  - Use good quality wave data
  - Determine whether nearshore wave climates are required
  - Define sufficient locations along the coast
  - Choose an approach with a wave climate or time-series
- Tide conditions
  - Check whether horizontal tide is of relevance
  - Check whether vertical tide is of relevance
- Cross-shore profiles
  - Define multiple profiles along shore (if necessary)
  - Set the active height of the model
  - Determine the part of the profile that is allowed to re-orientate
  - Check whether offshore losses can be of relevance (site-specific)
- Sediment transport
  - Use an appropriate sediment transport formulation
  - If possible use calibration data for the longshore transport rates
  - Check the homogeneity of the sediment properties

- Nourishments
  - Check the history of nourishments at the considered coastal stretch
  - Include nourishments correctly in the profile
  - Check whether an approach with predefined or pro-active nourishments is the most suitable (if the pro-active nourishments are available).
- Structures
  - Include structures
  - Estimate the bypass rates
  - Include local wave climate conditions
  - Check the relevance of secondary flows
- Coastline evolution
  - Include a smooth coastline shape in the model
  - Specify the grid and spatial discretisation and set the numerical parameters

5 Conclusions & Recommendations

5.1 Conclusions

This document provides guidelines for the setup of coastline models along the Dutch coast. These guidelines are based on research of the performance of coastline models at Domburg within the framework of the KPP B&O kust programme (Deltares, 2011 & Deltares 2012).
The following conclusions are drawn with respect to the modelling:

- For the setup of a coastline model is essential to define the specifications on the basis of the aims, associated time and spatial scales and the site specific characteristics.
- It is necessary to use appropriate model components and define the settings correctly. Special attention needs to be paid to:
  - The wave climate conditions. Since the wave climate determines the performance of the model to a large extent. In many cases the waves need to be transformed towards the shore with a wave model
  - The potential impact of horizontal and vertical tide (site specific).
  - Definition of the alongshore varying profiles (for non-uniform coastline sections).
  - The setting of the active height of the profile. This is of importance since the coastline response is directly related to this parameter.
  - The potential impact of offshore losses at steep slopes (site specific).
  - An appropriate sediment transport formulation. It should be suitable for the considered sedimentary environment. It should also be verified whether the sedimentary environment is variable along the coast.
  - Calibration of net alongshore sediment transport on the basis of historical data.
  - A complete overview of the history of the nourishments.
  - The inclusion of local wave climates at structures. Sheltered wave climates are essential for the local coastline development. Additionally, secondary flows may be of relevance.
  - Smooth coastlines, since spikes in the coast may affect model performance.
  - Numerical parameters should be set such that they do not impact the results.

The guidelines in this report provide minimum requirements for coastline modelling along the Dutch coasts. It is, however, noted that this does not guarantee success, since there are also other aspects that are of relevance (i.e. experience of the modeller, limitations to process knowledge and capabilities of the models).

5.2 Recommendations

The following recommendations are made:

- Following the guidelines in this report provides a minimum requirement for reliable coastline modelling (but not a guarantee for reliable modelling).
- Experienced modellers are needed to apply the coastline models, since the outcomes are influenced by the decisions during the setup of the modelling. In any case it is advised to ask for an expert review for each study.
- It is recommended to setup a database with reference transports along the Dutch coast, which can be used to calibrate new models and make model outcomes more consistent and better comparable.

Literature

Deltares, 2012. Modelling coastline maintenance: a review of three coastline models. Technical Report 1206171-005. Delft, The Netherlands.

Deltares 2013. Coastline modelling - Phase III : Investigation of the influence of model schematisation on a hindcast for the coast of Domburg. Deltares rapport, projectnummer 1207724-005.

Steetzel, H.J., J.H. de Vroeg, L.C. van Rijn, J.M. Stam, 1998. Morphological modelling using a modified multi-layer approach. Coastal Engineering Volume 1998.

Steetzel, H.J., J.H. de Vroeg, L.C. van Rijn, J.M. Stam, 2000. Long term modelling of the Holland coast. Coastal Engineering 2000.