Deltares

BOI - Scaling of dimensional parameters in XBeach

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Project context (EN/NL)

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Dit rapport is onderdeel van het project Plan Zandige Waterkeringen. Plan Zandige Waterkeringen, gefinancierd door het Ministerie van Infrastructuur en Waterstaat, Rijkswaterstaat, STOWA, Waterschap Scheldestromen, Waterschap Hollandse Delta, Hoogheemraadschap van Delfland, Hoogheemraadschap van Rijnland, Hoogheemraadschap Hollands Noorderkwartier en het Wetterskip Fryslan, voorziet in de vernieuwing van het instrumentarium ten behoeve van het beheren, beoordelen en ontwerpen van zandige waterkeringen. Het project Plan Zandige Waterkeringen maakt deel uit van het programma BOI (Beoordeling en Ontwerp Instrumentarium).

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Summary

A summary in Dutch is provided on the next page.

The Action Plan for the Safety Assessment of Sandy Coasts ("*Plan van Aanpak Vernieuwd Instrumentarium Zandige Keringen*", in Dutch; Deltares/Arcadis, 2019a) describes the development of a new dune safety assessment methodology for the Dutch coast based on the process-based numerical model XBeach. The Action Plan describes a set of tasks required to enable implementation of this new method for safety assessment of dunes in 2023. This report describes the results of one of the tasks, the scaling of dimensional model parameters in the XBeach model.

In a later phase of the BOI project the XBeach model will be calibrated with the results from physical laboratory experiments. To ensure proper representation of the physical processes in XBeach when performing simulations on smaller laboratory scales, certain dimensional numerical parameters in XBeach need to be adapted. In this report, a general scaling approach was investigated for the relevant dimensional parameters. For certain parameters alternative and optimized parameters were defined and subsequently implemented in the source code.

More specifically, an inventory of all XBeach parameters identified six parameters relevant for the numerical simulation of small-scale morphodynamic laboratory experiments. The sensitivity of the model predictions (dune erosion volumes and dune front retreat) to the scaling of these parameters has been investigated based on small scale simulations. The scaling of two of the selected parameters has limited effect on the computed dune erosion. For these two parameters, Froude scaling is therefore considered acceptable. The remaining four parameters, and the corresponding formulations of the related processes, have been further investigated. Based on these findings the four parameters have been adapted to a non-dimensional form in the XBeach model code.

An additional focus of the study was the correct definition of the computational grid when performing simulations on laboratory scales. The predicted dune erosion volumes are seen to be sensitive to the chosen grid resolution. This study proposes, a new, standardized approach to correctly define the model grid.

With the help of the adjustments to four of the model parameters and the described scaling approach for the other two parameters, the XBeach model is ready to be calibrated using laboratory experiments, as foreseen in the next BOI project phase.

Samenvatting

Het Plan van Aanpak Vernieuwd Instrumentarium Zandige Keringen (Deltares/Arcadis, 2019a) beschrijft de ontwikkeling van een nieuw instrumentarium, op basis van het proces-gebaseerde, numerieke model XBeach, om de veiligheidsbeoordeling van de zandige kust van Nederland mee uit te voeren. Als onderdeel van het Plan van Aanpak is een aantal taken beschreven dat uitgevoerd moet worden om de toepassing van het nieuwe instrumentarium in de beoordelingsronde van 2023 mogelijk te maken. Dit rapport beschrijft de uitvoering en resultaten van één van de taken van het Plan van Aanpak, het correct gebruik van dimensievolle modelparameters in het XBeach model.

In een latere fase van het BOI-project wordt het XBeach-model gekalibreerd met de resultaten van fysieke laboratoriumexperimenten. Om een goede weergave van de fysische processen in XBeach te garanderen bij het uitvoeren van simulaties op kleinere laboratoriumschalen, moeten bepaalde dimensievolle numerieke parameters in XBeach worden aangepast. In deze studie wordt een standaard aanpak onderzocht om de relevante dimensievolle parameters te schalen. Voor enkele specifieke parameters zijn ook alternatieve manieren van optimalisatie bestudeerd en vervolgens geïmplementeerd in de rekencode.

Een inventarisatie van alle XBeach parameters resulteerde in zes parameters die relevant zijn voor de numerieke simulatie van morfodynamische laboratorium experimenten op kleine schaal. De gevoeligheid van de modelvoorspellingen (duinerosievolumes en duinfront-teruggang) voor de schaling van deze parameters is onderzocht aan de hand van simulaties op deze kleine schaal. De resultaten laten zien dat het schalen van twee van de zes geselecteerde parameters een beperkt effect hebben op de berekende duinerosie. Voor deze twee parameters wordt daarom Froude schaling aanvaardbaar geacht. De overige vier parameters en de bijbehorende formuleringen van de gerelateerde processen zijn verder onderzocht. Op basis van deze bevindingen zijn de vier parameters aangepast tot een dimensieloze vorm in de XBeach-modelcode.

Een extra aandachtspunt van het onderzoek was de juiste definitie van het rekenrooster bij het uitvoeren van simulaties op laboratoriumschalen. De voorspelde duinerosie volumes blijken gevoelig te zijn voor de gekozen resolutie van het rekenrooster. Daarom wordt in dit onderzoek een nieuwe, gestandaardiseerde aanpak voorgesteld om het modelraster correct te definiëren.

Met behulp van de aanpassingen aan de vier modelparameters en de beschreven benodigde schaling voor de andere twee parameters kan het XBeach worden gekalibreerd met laboratoriumexperimenten, zoals voorzien in de volgende BOI-projectfase.

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1 Introduction

1.1 Background

1.1.1 General

The Dutch dune system is a primary line of defence against coastal inundation and therefore periodic evaluation is required to assure that it fulfils its function. The current assessment of dune safety uses an evaluation method based on the empirical DUROS+ model that was originally developed in the eighties of the past century (Technische Adviescommissie voor de Waterkeringen, 1984; Expertise Netwerk Waterveiligheid, 2007). Currently, limitations in this approach due to underlying assumptions of the empirical model restrict the application of this methodology for large stretches of the Dutch coast (Deltares, 2015a). Furthermore, recent research (Deltares/Arcadis, 2019b) has pointed to inaccuracies in DUROS+ for high wave period conditions, throwing into doubt the validity of the model for the safety assessment of the Dutch dune coast.

In preparation for the next dune safety assessment in 2023 and the *Beoordeling en Ontwerp Instrumentarium* (BOI) project, Deltares and Arcadis developed an Action Plan for the Safety Assessment of Sandy Coasts ("Plan van Aanpak Vernieuwd Instrumentarium Zandige Keringen", in Dutch; Deltares/Arcadis, 2019a) on behalf of Rijkswaterstaat. The Action Plan for the Safety Assessment of Sandy Coasts, henceforth termed *Action Plan*, describes a transition from the current transect-based safety assessment methodology, to an improved, 2DH area-based assessment using the state-of-the-art process-based model XBeach (Roelvink et al., 2009). The Action Plan proposes a phased development of the new methodology, with four long-term development phases foreseen. The Action Plan describes a set of tasks to be carried out in development Phase 1 to allow for application of the new methodology, using XBeach, in a transect-based approach in the dune safety assessment of 2023. These tasks principally focus on the development and validation of the XBeach model, the development and validation of a probabilistic and semi-probabilistic version of the XBeach model, and a redefinition of the assessment methodology using the new modeling approach.

1.1.2 Current subproject

This report describes the results of one task relating to the scaling of dimensional model parameters in the XBeach model.

Within the BOI program, the XBeach model will be calibrated using several movable-bed laboratory experiments of storm conditions on the Dutch coast, to define the optimal parameter setting for the future Dutch dune assessments. Subsequently, in Phase 2 of the BOI program, the model will be validated using field data. The laboratory experiments that will be used for the calibration of XBeach model settings have originally been down-scaled from prototype scale. Ideally, a laboratory model of a movable bed should behave in all respects like a controlled version of the larger prototype, from hydrodynamic behaviour to sediment transport and morphological changes. To ensure that wave propagation and sediment transport in XBeach are well-described when performing simulations at the smaller laboratory scale, the current sub-project (part of Phase 1 of the BOI project) will examine which dimensional parameters are currently present in the numerical model and determine if and how these parameters need to be scaled or modified to be applicable to small laboratory scale as well.

Previously, a parameter was implemented in XBeach that, when activated for small-scale applications, scaled certain dimensional parameters based on Froude scaling (Brandenburg, 2010). It will be investigated whether this approach is still valid, and / or needs to be extended to other parameters. Detailed understanding of the role of each of the dimensional parameters is needed to define the proper way of scaling or optimization when applied on smaller laboratory scales. Another important question is related to the application of the XBeach model to more moderate wave conditions than for which the default settings have been determined. Considering that the XBeach default parameter settings have originally been derived for superstorm conditions (representative of offshore wave conditions H_{m0} of about 8 m, and peak wave period T_p of 12 s) in the Delta flume, they may need to be adapted additionally when modelling more moderate wave conditions.

The results of this subproject will not only be beneficial during the following steps of the BOI project, but also for other users that would like to calibrate their XBeach model set-up with laboratory data, or more generally, model more moderate wave conditions.

1.2 Research questions

The overall question that is addressed in this subproject is:

"*How can the dimensional numerical parameters in XBeach be scaled or optimized for laboratory-scale applications?*"

To answer this question, several research questions have been defined:

1. *What dimensional numerical parameters does XBeach have that could be optimized or scaled for laboratory-scale applications of the model?*
   a. *Which dimensional numerical parameters are relevant for the BOI project?*
   b. *What is / are the function(s) of these parameters?*

2. *Based on literature, what scaling laws should be applied to the selected parameters?*

3. *How sensitive are the dune erosion predictions to the parameter choice?*

4. *Are variations in wave conditions relevant to the scaling of the dimensional model parameters?*

5. *How can the parameters be adapted alternatively to avoid scaling errors?*
   a. *How can the selected parameters be linked to a physical process?*
   b. *How can the selected parameters be turned dimensionless or linked to another non-dimensional parameter?*

1.3 Outline

Firstly, the dimensional parameters present in the current XBeach model will be identified, as well as their purpose(s) (Chapter 2). In parallel, the possible scaling laws for each of these parameters will be defined based on literature (Chapter 2). Secondly, the sensitivity of the XBeach model results (here, dune front retreat rate and erosion volume) to parameter choice will be investigated (Chapter 3). Based on the sensitivity study, the dimensional parameters will be further optimized if needed (Chapter 4). The limitations and follow-up of the chosen scaling and optimization approaches will be discussed (Chapter 5), and the main conclusions and recommendations will be given (Chapter 6).

2 Approach

2.1 Overall approach

First of all, the dimensional numerical parameters present in XBeach and relevant for the BOI-project will be identified, and their function will be explained here below. Furthermore, scaling laws for each of the parameters will be defined based on literature. Subsequently, an initial analysis will be performed, named *Phase I*, wherein the sensitivity of the parameters will be tested by scaling all selected parameters and setting the individual parameters one-by-one as default. This will be done using an available set of laboratory experiments on geometric scales of 1:5-1:84 of a movable bed under storm conditions as framework for the XBeach model simulations. The sensitivity of the parameters will be determined by quantifying dune front retreat rate and erosion volume. In practice, it is most relevant to properly represent the beach and dune erosion volume changes (Figure 2.1). In red the erosive zone above the maximum high-water line during storm is depicted, which is typically considered during Dutch dune assessments – and is therefore also used in this study. In the follow-up stage, named *Phase II*, the dimensional parameters will be further optimized if needed following parameter-specific approaches.

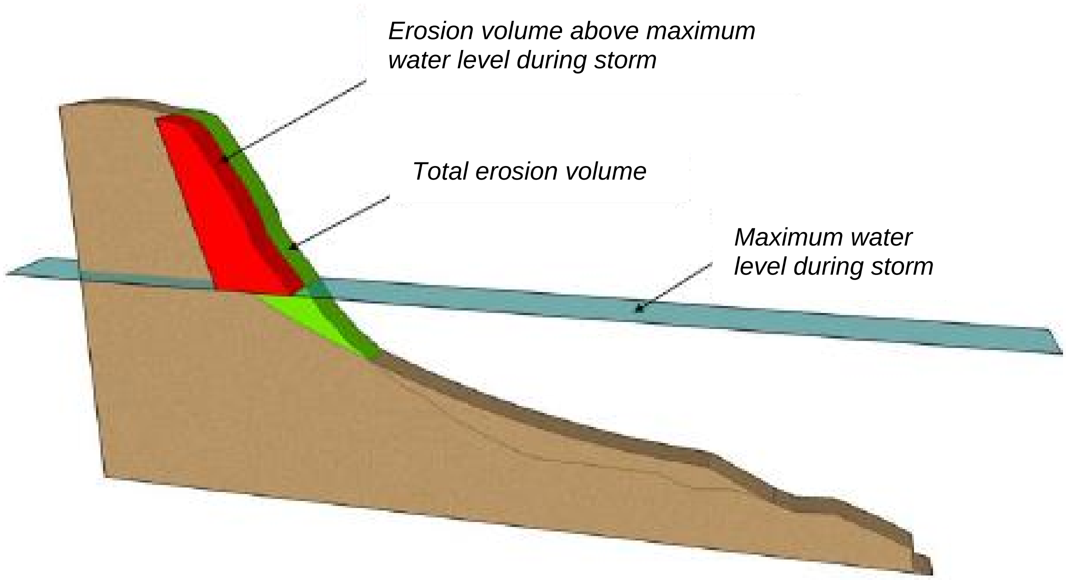

Figure 2.1 Reference figure of dune erosion volumes. In green the total erosion volume is depicted, and in red the erosive zone above the maximum high-water line during storm, of which the latter is typically considered during Dutch dune assessments.

2.2 Overview of selected dimensional numerical parameters

XBeach consists of a variety of dimensional parameters, not all of which are relevant for the overarching BOI project. Here we first present the selection protocol used to identify relevant parameters. The relevant parameters that were considered for this study are subsequently listed and the function(s) of these parameters are explained.

2.2.1 Selection protocol

The full list of XBeach parameters, as defined in the source file *params.def* (revision 5611 of the source code), was used as a basis for the selection. Parameters that matched at least one of the following criteria were excluded from this study:

1. Dimensionless parameters (i.e., parameters with a dimensionless unit);
2. Parameters that indicate a module switch, formulation switch, or a file name;
3. Physical parameters (e.g., *g* (gravitational acceleration), *nuh, reposeangle* and *rho*);
4. Case-specific model definition parameters:
    a. *Grid parameters;*
    b. *Model time parameters;*
    c. *Initial conditions;*
    d. *Wave boundary condition parameters;*
    e. *Wave-spectrum boundary condition parameters;*
    f. *Wind parameters;*
    g. *Bed composition parameters;*
    h. *Morphology parameters related to the morphological time*
    i. *Output variables;*
    j. *Constants/Variables not read as input;*
5. Parameters in the sections that are out of scope specifically for the BOI project:
    a. *Wave-current interaction parameters;*
    b. *Vegetation parameters*;
    c. *Groundwater parameters;*
    d. *Non-hydrostatic correction parameters;*
    e. *Sediment transport parameters related to the bed slope effect and parameters used in equations that are not considered in BOI (e.g.,* Arms*)*;
    f. *Alongshore transport gradient parameters*;
    g. *Wave numerics parameters* (only *maxerror*, *maxerror_angle* and *wavint*);
    h. *Parameters that have been superseded or are only included for backward compatibility (e.g., umin*).

2.2.2 Considered dimensional numerical parameters

Following the above selection protocol, six dimensional parameters remained: *Tsmin*, *hswitch*, *avaltime, eps, eps_sd* and *hmin*. Table 2.1 indicates the default values and short descriptions of these parameters. The default values were determined earlier using superstorm conditions in the Delta flume.

*Table 2.1 Overview of the considered dimensional parameters (including a reference to the section within the params.def file in which they occur, their default value and the description as given in the params.def file). *The parameters indicated with the asterisk were already scaled following Froude scaling based on the depth ratio.*

Name	Section	Default	Description
Tsmin	Sediment transport	0.5 s	Minimum adaptation time scale in advection diffusion equation sediment
*hswitch**	Morphology	0.1 m	Water depth at which is switched from *wetslp* to *dryslp*
avaltime	Morphology	10 s	Time scale for bed level change due to avalanching
*eps**	Flow numerics	0.005 m	Threshold water depth above which cells are considered wet
eps_sd	Flow numerics	0.5 m/s	Threshold velocity difference to determine conservation of energy head versus momentum
*hmin**	Flow numerics	0.2 m	Lower limit for the water depth in the Stokes drift computation

2.2.3 Function(s) of the parameters

The parameter descriptions in Table 2.1 provide the general purpose of the parameters. Here, more detail is given on their implementation in the code, including an indication whether a parameter is used for multiple purposes.

Tsmin

Tsmin is used as the lower limit of the adaptation timescale *Ts* (which is a function of the water depth and the fall velocity of sediment) in the advection-diffusion equation (equation 1 here below) of sediment. In this equation, the difference between the equilibrium sediment concentration and the actual sediment concentration (multiplied by the water depth) is divided by *Ts*. Therefore, a small value of *Ts* corresponds to a nearly instantaneous sediment concentration response. *Tsmin* is introduced to avoid instable sediment concentrations in the computations for too small values of *Ts* (see equation 2). The advection diffusion equation is

$$\frac{\partial hC}{\partial t} + \frac{\partial hCu^E}{\partial x} + \frac{\partial hCv^E}{\partial y} + \frac{\partial}{\partial x}\left[D_h h \frac{\partial C}{\partial x}\right] + \frac{\partial}{\partial y}\left[D_h h \frac{\partial C}{\partial y}\right] = \frac{hC_{eq} - hC}{T_s}, \qquad (2.1)$$

with here the adaptation time scale as

$$T_s = \max\left(f_{Ts}\frac{h}{w_s}, T_{s,\min}\right), \qquad (2.2)$$

where *C* represents the depth-averaged sediment concentration which varies on the wave-group time scale and D_H is the sediment diffusion coefficient. The entrainment of the sediment is represented by an adaptation time T_s, given by a simple approximation based on the local water depth *h* and sediment fall velocity w_s.

hswitch

Within the avalanching algorithm, sediment is moved across grid cells (following the avalanching algorithm) when the bed slope exceeds a critical bed slope. This critical bed slope is by default milder for a submerged bed (*wetslp,* default at 0.3) than for an emerged bed (*dryslp*, default at 1.0). As the bed is not suddenly fully wet when a very thin layer of water covers the bed, *dryslp* is still considered as the critical bed slope as long as the water depth in the grid cell does not exceed *hswitch*. The optimized *wetslp* and *dryslp* settings for the BOI program will be calibrated in detail in a follow-up phase.

avaltime

Furthermore, during very short submersion times (e.g., during a swash event), avalanching may not be fully completed as it takes time to avalanche. To account for this, the full bed level change by avalanching is spread out over time, by multiplying it with the time step and subsequently dividing it by the *avaltime*. In the past, the parameter *dzmax* (indicating the maximum bed level change resulting from avalanching within a time step), was used for this purpose (not in use anymore).

eps

For very small water depths, some processes need to be limited to prevent unrealistic behavior in the XBeach computations. Therefore, cells with a water depth below *eps* (typically O(mm) at prototype scale) are considered dry. Furthermore, at various occasions in the XBeach source code, *eps* is used as the lower limit for the water depth.

eps-sd

The flow is computed with the depth-averaged momentum equations. Within these equations, the advection term in *x*- and *y*-direction are computed based on conservation of momentum if the velocity differences across two cells is not too large (for which the limit is defined by *eps_sd*). For spatial differences in velocity exceeding *eps_sd*, conservation of energy head is applied instead.

hmin

The Stokes drift consists of a wave-induced mass flux and a roller contribution. Both components are a function of the water depth. To avoid unrealistic estimates of the Stokes drift, *hmin* is used here as the lower limit for the water depth (which is generally substantially larger than *eps*, see Table 2.1). Hence, for water depths smaller than *hmin*, the Stokes drift is still computed, but with a water depth equal to *hmin* (causing smaller Stokes drift contributions than without this limiter). Note that *hmin* additionally appears in other parts of the XBeach source code where it is used as a lower limit for the water depth.

2.3 Which scaling laws could be applied on the dimensional parameters?

Ideally, a laboratory model of a movable bed should behave in all respects like a controlled version of the larger prototype, varying from hydrodynamic behaviour to sediment transport and morphological changes. For coastal scale models the most relevant requirement is to attain similarity of the cross-shore equilibrium bed profiles between prototype and model, particularly in the surf zone and the beach and dune zone. In practice, it is most relevant to properly represent the beach and dune erosion volume changes (Figure 2.1).

Correct representation of the physical processes in laboratory experiments requires that the dimensionless numbers are the same as in nature. Examples of dimensionless numbers are the Froude number describing subcritical or supercritical flow, the Reynolds number for laminar of turbulent flow, the surf-similarity parameter for the type of breaking and the Shields parameter for intensity of sediment transport and type of bed forms. Often, it is sufficient for these dimensionless numbers to be in a certain range, rather than imposing a fixed value (Van Rijn et al. 2011). For more detailed information on scaling laws, please refer to Van Rijn et al. (2011).

The representation of scaling in numerical simulations with XBeach was investigated before by Brandenburg (2010), who adopted the Froude scaling for a correct representation of the wave dynamics (e.g., Vellinga, 1986). The dynamics of water motion under oscillatory waves is reasonably well described by linear wave theory:

$$\frac{du}{dt} = \frac{g\pi H}{L}\frac{\cosh[2\pi(d-y)/L]}{\cosh 2\pi d/L}\sin\left(\frac{2\pi x}{L} - \frac{2\pi t}{T}\right) \qquad (2.3)$$

$$\frac{dv}{dt} = \frac{-g\pi H}{L}\frac{\sinh[2\pi(d-y)/L]}{\cosh 2\pi d/L}\cos\left(\frac{2\pi x}{L} - \frac{2\pi t}{T}\right) \qquad (2.4)$$

In which: x is the horizontal distance from the reference position, y is the vertical distance from the time-averaged water level, u and v are the horizontal and vertical component of the velocity, t is time, d is water depth, H is the wave height, L is the wave length and T is the wave period. The dynamics of water motion under oscillatory waves is required to be similar for prototype and scaled laboratory experiments:

$$n\left(\frac{du}{dt}\right) = n\left(\frac{dv}{dt}\right) = 1 \qquad (2.5)$$

In which n indicates the ratio of the value in prototype over the value in the model. When combining (5) with (3) and (4) gives,

$$n\left(\frac{g\pi H}{L}\right) = 1, \qquad \text{so } n_H = n_L \qquad (2.6)$$

$$n\left(\frac{\frac{2\pi}{(d-y)}}{L}\right) = n\left(\frac{2\pi h}{L}\right) = 1, \quad \text{so } n_d = n_L \tag{2.7}$$

$$n\left(\frac{2\pi x}{L}\right) = n\left(\frac{2\pi t}{T}\right) = 1, \quad \text{so } n_x = n_L \quad \text{and } n_t = n_T \tag{2.8}$$

this results in:

$$n_L = n_H = n_d = n_x \tag{2.9}$$
$$n_t = n_T \tag{2.10}$$

In which n_L is the wave-length factor, n_H is the horizontal length scale factor, n_d = depth-scale ratio, n_x is the horizontal scale length factor (profile length), n_t is the morphological time-scale factor and n_T is the wave-period scale factor. Parameters *L*, *d* and *T* are related through the dispersion relation:

$$\left(\frac{2\pi}{T}\right)^2 = \frac{2\pi g}{L} tanh\left(\frac{2\pi d}{L}\right) \tag{2.11}$$

When combining the above equations 2.10 - 2.12, this gives:

$$n_H = n_L = n_d = n_T^2 = n_t^2 \tag{2.12}$$

These scaling laws are valid for deep water. As imposed wave conditions have been scaled on the outer boundary of the laboratorium experiments representing deep water (and thus equally the BC for the XBeach model) we assume eq. 2.12 to be valid for this application. These scaling laws are translated in Table 2.2 to implications for the general XBeach model set-up. For the six parameters selected in paragraph 2.2.2 this results in the scaling laws presented in Table 2.3.

Table 2.2 From Brandenburg et al. 2010. Settings that need to be adapted for testing the hydrodynamics model in XBeach, according to Froude scaling.

	Wave board		**Bathymetry**			**Time**
Scale factor	H_{m0}	T_p	x-grid	y-grid	Waterlevel	Simulation time
n_d (1-30)	n_d	$\sqrt{n_d}$	n_d	n_d	n_d	$\sqrt{n_d}$

Table 2.3 Description of the 6 selected dimensional numerical parameters in XBeach, and the respective scaling laws.

Name	**Scaling**	**Default**
Tsmin	$\sqrt{n_d}$	0.5 s
hswitch	n_d	0.1 m
avaltime	$\sqrt{n_d}$	10 s
eps	n_d	0.005 m
eps_sd	$\sqrt{n_d}$	0.5 m/s
hmin	n_d	0.2 m

The default parameters have been determined for a super storm condition in the Delta flume (H_{m0} = 8 m on prototype scale), therefore we will also test whether additional scaling needs to be applied based on the used offshore wave when it is smaller than the super storm conditions.

2.4 Laboratory experiments

In order to address the scaling of the parameters needed for various laboratory scales, a series of movable-bed laboratory experiments was used as reference frame. It must be noted that the laboratory experiments are used here merely as guidance to set-up the XBeach model for assessing the sensitivity of the results to the settings of the selected model parameters (paragraph 2.2.2). In the current study it is not the goal to reproduce these laboratory experiments at best, as a proper calibration requires a scope of parameters larger than the set of dimensional parameters under consideration in this subproject. The detailed calibration of the XBeach model, using the laboratory experiments as reference, will be the object of a follow-up project within the KPP WK02 2020 – BOI project, called “BOI Default Settings – Calibration of the XBeach model parameters”.

The set of laboratory experiments used here covers three experimental campaigns performed between 1976 and 1984 by WL | Delft Hydraulics (now Deltares) which had as goal to provide the basis for a dune erosion prediction model for the Dutch coast, DUROS (Vellinga, 1984). This research program consisted of numerous 1D small-scale and larger-scale laboratory experiments, of which in total 26 tests have been performed (Table 2.4). The beach and dune profiles of these experiments are Froude scaled versions of the Dutch reference profile. All the 26 laboratory tests will be used in the model framework (see paragraph 2.5).

Table 2.4 Overview of the available laboratory experiments and scales. A detailed overview can be found in Appendix A.

	Research program	**Number of experiments**	**Scale (n_d)**	**D50 (µm)**	**References**
Large-scale Delta flume	MS1263-III	3	5	225	WL | Delft Hydraulics (1984)
Small-scale Wind flume	MS1263-I	17	26-84	225	WL | Delft Hydraulics (1976)
	MS1263-II	6	26-84	225	WL | Delft Hydraulics (1981)

Overall, the tests correspond to a prototype wave height H_{m0} of 8 m and a peak wave period T_p of 12 s. An example of one of the Delta flume experiments is shown in Figure 2.2, where dune front retreat is observed under storm conditions. A detailed overview of all considered laboratory experiments during this study can be found in Appendix A. In addition, several numerical tests on prototype scale have been performed, based on the geometric upscaling of the Delta flume *Test-1* experiment and Froude scaling of the boundary conditions.

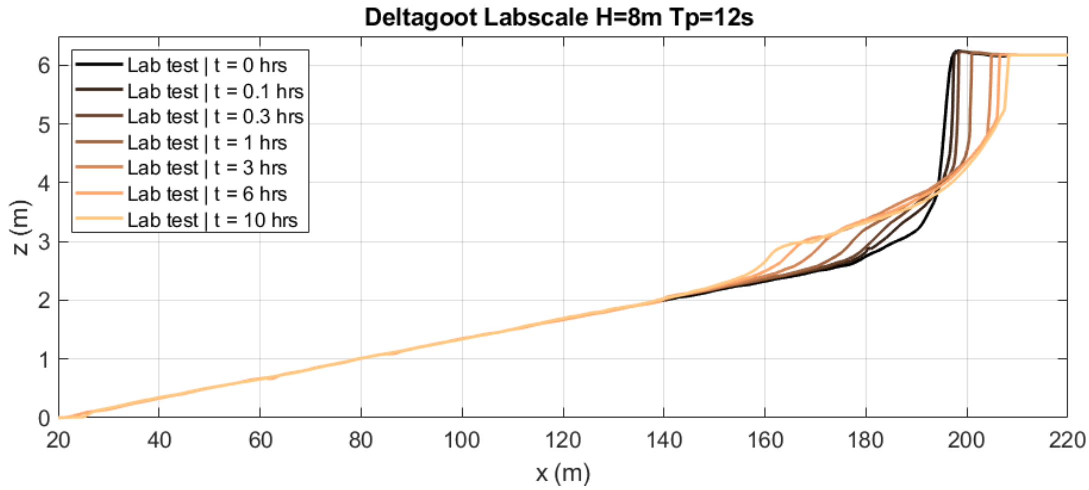

Figure 2.2 Example of typical considered 1D profile in the laboratory experiments, based on the Dutch Reference Profile for the Holland Coast. The results of Test-1 of the Deltagoot experiments (nd = 5) are shown here (WL | Delft Hydraulics - 1984), with wave conditions of H_{m0} = 1.6 m and T_p = 5.4 s, corresponding to H_{m0} = 8 m and T_p = 12.1 s on prototype scale.

2.5 Model framework

As described in the previous section, the laboratory experiments and one additional fictitious prototype experiment – based on Froude upscaling of the Delta flume experiments - form the basis of the model setup, because they span a wide range of modelling scales with waves ranging from H_{m0} = 0.1 m, T_p=1.3 s on the smallest scale to H_{m0}= 8 m, T_p = 12 s on prototype scale. For normative conditions with H_{m0}=8 m, T_p=12 s, this range of wave conditions is equivalent to Froude scaling of {1,5,26,47 and 84}. As such, they cover a broad range of scales to test sensitivity and effect of model results to model parameter choices.

The general model-setup for the simulations was chosen at the start of the project and variations of these did not form part of the project:

- Starting point of the model is the newest XBeach revision 5612
- True 1-dimensional grids were used (ny=0), without directional spreading of the wave energy, e.g. *ntheta*=1, corresponding to the conditions experienced in the wave flumes.
- Boundary conditions were drawn from Jonswap spectra with characteristics for significant wave height H_{m0}, peak period T_p and Nyquist frequency appropriate for the peak period. The boundary conditions were made reproducible by ensuring a fixed draw from the spectra through specifying *random*=0.
- The resolution of the grid was made appropriate for the scale of the waves that were modeled and wave conditions imposed. On prototype scale, a grid resolution of 2 m on the subaerial beach was used, this value was subsequently Froude scaled to the appropriate laboratory scale. Towards the wave board the grid resolution decreases, where the decrease is governed by a constant Courant criterion of 0.7, based on the relation between shallow water group velocity and water depth. The aspect ratio between adjacent cells was limited to a maximum of 1.1 (e.g. maximum 10% length difference between adjacent grid cells) For laboratory experiments, the minimal grid resolution was reduced by the scaling factor n_d. An example of the grid resolution used for four laboratory experiments each at a different depth scale is shown in Figure 2.3.
- A Smagorinsky model was applied to viscosity and diffusivity. This model makes the viscosity and diffusivity grid size dependent in order to reduce the effect of grid choice on the simulated viscous and diffusive stresses. This proved to be important as grid resolution

scales geometrically with the depth scale of the laboratory experiments. Without the Smagorinsky model, the diffusive transports can become unstable for small lab-scales.

- Settings for parameters not under investigation in this sub-task were left on default. Calibration of these parameters to the laboratory results did not form part of the current project. WTI settings will be updated in a next project and are therefore not considered here.
- All default processes are included for all depth scales. A complete overview of the default model formulations that were part of Revision 5612 and remained so in Revision 5619 (final version after this report) is found in Appendix F. The parameters that are the topic of this report are excluded here because their value varied between numerical experiments discussed in this report.

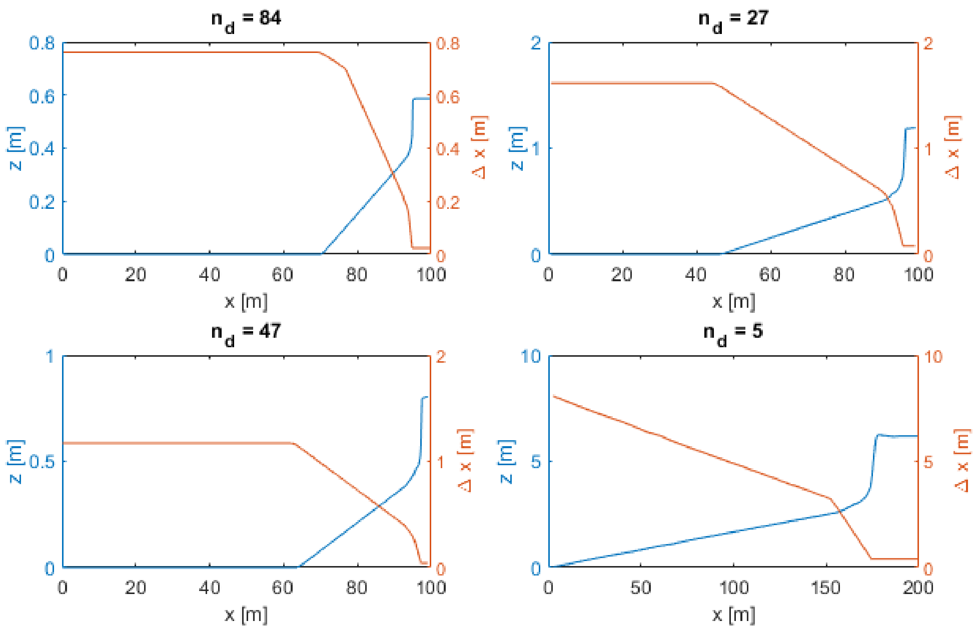

Figure 2.3 Examples of the modelled profiles of four laboratory experiments at different depth scales (blue) and its varying grid resolution (red).

3 Phase I – Sensitivity analyses

3.1 Approach

In the previous chapters, a set of 6 dimensional numerical XBeach parameters has been introduced. Based on a series of laboratory experiments comprising a wide range of modelling scales (see paragraph 2.5), a sensitivity study has been performed to investigate the importance of scaling these parameters. As already emphasized, this study focusses on the sensitivity of the XBeach results to the scaling of these parameters, rather than reproducing the laboratory results. The model skill on the reproduction of the various lab scales is discussed in paragraph 5.1.

For each of the dimensional numerical parameters, a scaling law has been introduced in section 2.3 based on Froude scaling. The proposed scaling laws, depending on a depth-scale ratio between prototype-scale and laboratory scale, are applied to reduce the default values of the 6 parameters as presented in Table 2.3. As a starting point for the sensitivity study, a simulation in which all 6 parameters are scaled according to these scaling laws is performed for all lab experiments. To investigate the importance of scaling each parameter, simulations are performed in which the scaling law of that specific parameter is omitted, i.e. the default value of that parameter is used. For example, to investigate the role of *Tsmin,* simulations are performed with a *Tsmin* of 0.5 s, whereas the other five parameters (*hswitch*, *avaltime, eps, eps_sd* and *hmin)* are scaled according to the scaling laws as presented in Table 2.3. This set-up of simulations results in 7 simulations per lab-experiment. The importance of scaling is then determined by comparing the results of the base case (all parameters Froude scaled) with the results of the simulations in which the scaling of one of the parameters is omitted.

To ensure robustness of the conclusions, two evaluation criteria are used to capture the effect of not scaling one of the parameters (both criteria are visualized in Figure 3.1):

- **Dune front retreat**: as a consequence of the dune erosion, a landward migration of the dune front is observed in all laboratory experiments. This horizontal migration is relatively uniform over the different bed elevations that are part of the dune front. The horizontal migration is traced at an elevation just below the maximum initial crest elevation (well enough above the maximum storm surge level and well below the minimum crest elevation). More precisely, the dune front was traced at the maximum initial crest elevation minus 1.5 times the minimal horizontal grid size. This was manually checked and found to be a robust estimate of dune front retreat throughout all experiments and scales. Hence, the dune front migration '*ds*' is the horizontal difference between the intersection at the start of the simulation and the intersection at a certain point in time.
- **Erosion volumes:** as only 1D simulations are considered, the erosion volumes are defined as the eroded volume above the maximum storm surge level per linear meter ('V_{ero}'). This is in line with WTI storm impact metrics (see also Figure 2.1).

Ideally, both criteria result in similar conclusions as they are both indicators for dune erosion.

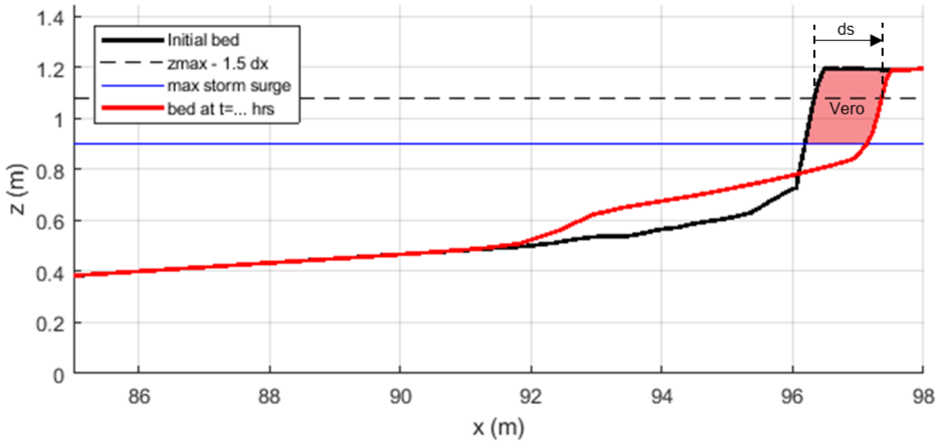

Figure 3.1 Schematic overview of the two evaluation criteria (dune front migration 'ds' and erosion volume 'V_{ero}') used to assess the sensitivity of XBeach to the scaling of the six considered parameters.

3.2 Results

Geometric scaling

As introduced in the previous section, the results of the simulations are evaluated based on two criteria. To introduce the reader to the method of evaluation, this section starts with discussing the results of a sensitivity study of an individual laboratory experiment and for a single moment in time. After that, the results of the entire set of experiments will be presented in comprehensible tables.

Dune erosion occurs over time, hence the two criteria for the sensitivity of the model can be assessed over time as well. In analogy with the measurements carried out in the laboratory experiments, multiple time-steps have been selected for each numerical experiment at which the dune front migration and the erosion volumes will be determined. An example can be seen in Figure 3.2, in which dune profiles are shown after 1 hour of simulation time for Wind flume experiment 121. Since the dune profiles of some of the simulations hardly differ, a close-up of the dune front migration is presented in Figure 3.3.

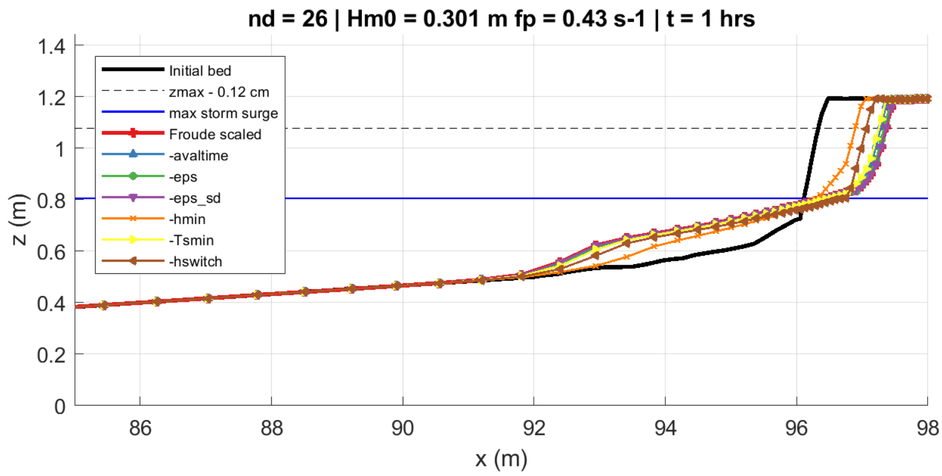

Figure 3.2 Results of the sensitivity study for Wind flume experiment 121 after 1 hour of simulation. The red line (hardly visible) represents the simulation at which all 6 numerical dimensional parameters are Froude scaled, whereas the lines named '-parameter' represent the simulation in which that specific parameter is not scaled (default value is used).

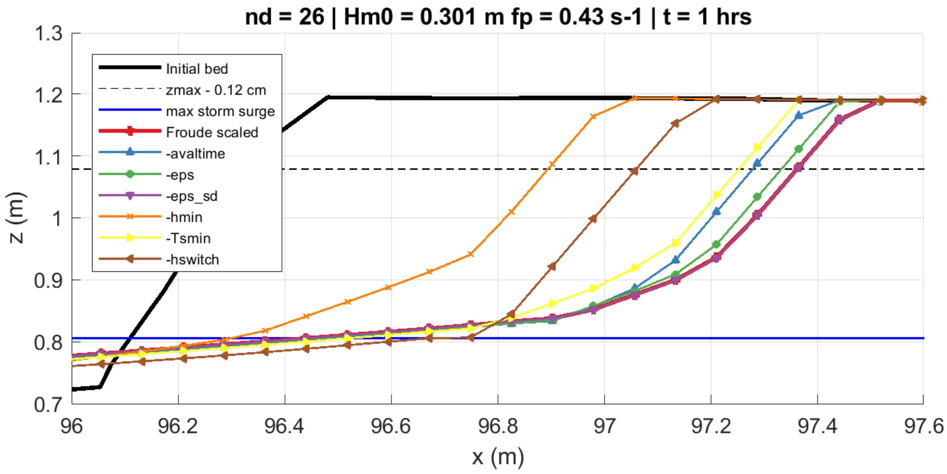

Figure 3.3 Close-up to Figure 3.2 on the dune front of Wind flume experiment 121 after 1 hour of simulation.

Figure 3.2 and Figure 3.3 show that the main differences between the simulations arise where the dune front erodes. The shape of the dune profile is quite similar between the different simulations, indicating that the 6 investigated parameters affect predominantly the erosion rates, and do not considerably alter the general behavior of the underlying processes. Only some differences in shape are visible when not scaling *hmin* and *hswitch*. For example, the transition between the dune front and the beach profile is considerably sharper in the simulation in which *hswitch* is not scaled (precisely at the max storm surge level). Because of the relatively small differences in shape, the focus remains on the differences in erosion volume/migration of the dune front across the different simulations.

The dune front migration and the erosion volumes are the largest when all 6 numerical dimensional parameters are Froude scaled. Omitting the scaling of one of these parameters reduces both the dune front migration and the erosion volumes, though this reduction fluctuates from one parameter to another. Omitting the scaling of *eps_sd* hardly affects the results, whereas omitting the scaling of *hmin* drastically reduces the dune front migration and erosion volume, indicating the sensitivity of dune erosion volume to the return flow representation in shallow water.

The analysis of the sensitivity of the model results to the scaling of the numerical dimensional parameters has been extended to all laboratory experiments for multiple timesteps. The outcome of this analysis has been tabulated in two vertically compressed tables (Table 3.3 and Table 3.4). An explanation of how to read these tables is presented in Box 1, here below.

Box 1 – Explanation of compressed tables

As an introduction to the compressed tables, a fraction of the full-size tables is shown in Table 3.1. Each row represents one of the selected time steps for a single experiment. This particular one shows the dune front migration of experiments with a depth-scale of 84. The dune front migration for the simulation in which the 6 numerical dimensional parameters are Froude scaled is presented in the 4th column. The last 6 columns present the relative difference in front migration of the simulations for which the scaling of the parameter which is mentioned in the column-title is omitted, with respect to the front migration of the 4th column. The cells in the last 6 columns are conditionally colored, based on their value (see Table 3.2) to distinguish the parameters which are sensitive to the scaling from the parameters that are insensitive to the scaling. The full-size tables that are the basis for the compressed tables are presented in Appendix C.

Table 3.1 Example table that shows the relative change in predicted dune foot retreat (ds in m) by not scaling one of the numerical dimensional parameters introduced in the first chapters, for example ds [-avaltime] has all dimensional parameters scaled with respect to the default settings following Table 2.3, while keeping avaltime on the default setting. The background colour of a cell depends on its value (Table 3.2)

Experiment	Nd	t model [h]	ds [Fr_scaled]	Δds [-avaltime]	Δds [-eps]	Δds [-eps_sd]	Δds [-hmin]	Δds [-Tsmin]	Δds [-hswitch]
'111'		1,00	0,28	-5%	-8%	0%	-63%	-9%	-27
'111'		6,00	0,49	-2%	-7%	0%	-65%	-5%	-19
'115'		1,00	0,21	-9%	-11%	0%	-76%	-12%	-33
'115'		6,00	0,39	-3%	-9%	0%	-74%	-6%	-21
'CT14'		0,33	0,31	-16%	-7%	0%	-65%	-14%	-31
'CT14'		2,00	0,53	-3%	-4%	1%	-61%	-6%	-17
'CT16'	84,0	0,33	0,30	-14%	-7%	0%	-60%	-13%	-31
'CT18'		0,33	0,23	-14%	-8%	0%	-59%	-12%	-32
'CT63'		0,17	0,28	-28%	-9%	0%	-56%	-18%	-41
'CT63'		0,33	0,35	-14%	-7%	0%	-57%	-12%	-29
'CT63'		3,00	0,65	-3%	-5%	0%	-55%	-6%	-15
'DT64'		0,17	0,26	-27%	-10%	0%	-58%	-18%	-38
'DT64'		0,33	0,33	-13%	-7%	0%	-59%	-13%	-28
'DT64'		3,00	0,64	-3%	-5%	0%	-56%	-6%	-16

Table 3.2 Legend for compressed tables.

Relative change with respect to Fr_scaled			
<5%	5% < … < 10%	10% < … < 20%	> 20%

Table 3.1 indicates already some time dependency in the sensitivity of the model results (compare results for *t(h)* at de first time step with a later time step, for instance the first two rows). Especially while omitting the scaling of *avaltime* and *Tsmin*, significant relative differences can be found in the very beginning of the simulation that reduce significantly over time.

An overview of the dune front migration for all selected time steps of simulations is presented in Table 3.3. The rows, each representing a single timestep of one simulation, are vertically compressed in order to make the figures more comprehensible. The color of a column provides information about the importance of scaling of that specific parameter for various depth scales. It can be seen that scaling creates no considerable difference for *eps* and *eps_sd*, since both columns are entirely colored green. In other words, omitting the Froude scaling of *eps* and *eps_sd* results in a relative change of the dune front migration less than 10% in almost all cases (i.e., the results are almost not sensitive to the scaling). For the parameters *avaltime* and *Tsmin* some larger offsets can be observed, and occasionally even above 20%, indicating that omitting the scaling for these parameters can result in relative changes in dune front migration over 20% (i.e., the results are quite sensitive to the scaling). For both parameters, some time-dependency can be observed, indicating that the scaling is especially of importance during the first part of the simulation. Omitting the scaling of *hswitch* and *hmin* results in almost all cases in relative errors of over 20% and even up to 80% for *hmin* (i.e., the results are very sensitive to the scaling).

Similar to the evaluation of the dune front migration at different timesteps for all simulations, an assessment of the erosion volumes has been made. The results of this study are presented in Table 3.4. The sensitivity of the results is very similar to the previous results on dune front migration rates, confirming that the migration of the dune front is a proper indicator for the dune erosion process.

Table 3.3 Relative difference in dune front migration. Here, in contrast to Table 3.1, all results are presented after vertically compressing the rows and omitting the numbers. The background colour of a cell represents its value (Table 3.2), different experiments are divided by thin black lines and the thick black lines indicate different depth scales. Note that the columns describing the experiment, timestep and reference erosion volume have been omitted.

Nd	Δds [-avaltime]	Δds [-eps]	Δds [-eps_sd]	Δds [-hmin]	Δds [-Tsmin]	Δds [-hswitch]
84,0						
47,0						
26,0						
5,0						

Table 3.4 Relative difference in erosion volumes. Here, in contrast to Table 3.1, all results are presented after vertically compressing the rows and omitting the numbers. The background colour of a cell represents its value (Table 3.2), different experiments are divided by thin black lines and the thick black lines indicate different depth scales. Note that the columns describing the experiment, timestep and reference erosion volume have been omitted.

Nd	ΔVero [-avaltime]	ΔVero [-eps]	ΔVero [-eps_sd]	ΔVero [-hmin]	ΔVero [-Tsmin]	ΔVero [-hswitch]
84,0						
47,0						
26,0						
5,0						

Wave-height scaling of model parameters

The default parameter settings of the XBeach model have originally been derived for storm conditions (H_{m0} = 8 m, T_p = 12 s). However, are the default settings of the dimensional parameters representative for more moderate wave conditions as well? And if not, should additional scaling be performed when simulating moderate wave conditions at laboratory scale? As the reproduced laboratory experiments in this study all represent storm conditions, where the wave-height was down-scaled from prototype scale as well with the appropriate depth scale, this sensitivity has not yet been identified.

Therefore, additional numerical simulations with moderate wave conditions were performed at Prototype (n_d = 1) and Delta Flume (n_d = 5) scale, with or without additional wave-height scaling of certain dimensional parameters (Table 3.5). More specifically, here the parameters *hmin* and *hswitch* where scaled with n_H, as these parameters in particular, were previously observed to have the most effect on predicted dune erosion volumes.

Table 3.5 : Overview of the performed supplementary numerical simulations with moderate wave conditions performed at Prototype (n_d = 1) and Delta Flume (n_d = 5) scale, with or without additional wave-height scaling of the parameters hmin *and* hswitch

Case	scale	Wave conditions	hswitch	hmin
1	Prototype (n_d = 1)	H_{m0} = 3 m, T_p = 12 s	Default = 0.1	Default = 0.2
2	Prototype (n_d = 1)	H_{m0} = 3 m, T_p = 12 s	n_H-scaled = (3 / 8) x 0.1 = 0.0375	Default = 0.2
3	Prototype (n_d = 1)	H_{m0} = 3 m, T_p = 12 s	Default = 0.1	n_H-scaled = (3 / 8) x 0.2 = 0.075
4	Delta flume (n_d = 5)	H_{m0} = (3 / 5) = 0.6 m, T_p = (12/√5) = 5.4 s	Default = 0.1	Default = 0.2
5	Delta flume (n_d = 5)	H_{m0} = (3 / 5) = 0.6 m, T_p = (12/√5) = 5.4 s	N_d-scaled = 0.1 x (1 / 5) = 0.02	N_d-scaled = 0.2 x (1 / 5) = 0.04
6	Delta flume (n_d = 5)	H_{m0} = (3 / 5) = 0.6 m, T_p = (12/√5) = 5.4 s	N_d-scaled = 0.1 x (1 / 5) = 0.02	n_H-scaled = 0.2 x (0.6 / 8) = 0.015
7	Delta flume (n_d = 5)	H_{m0} = (3 / 5) = 0.6 m, T_p = (12/√5) = 5.4 s	n_H-scaled = 0.1 x (0.6 / 8) = 0.0075	N_d-scaled = 0.2 x (1 / 5) = 0.04

Results are shown in Figure 3.4. As discussed in the previous sections, in general, the dune retreat rate is quite sensitive to depth-scaling of the selected numerical parameters *hmin* and *hswitch*, even on the limited depth-scale of n_d = 5. However, when applying additional wave-height scaling, results show very limited variations in dune erosion volume < 5% (also on Prototype scale), indicating that dune erosion volumes are not sensitive to the wave-height scaling for the range of conditions it is expected XBeach will be applied to.

The conclusion that the default settings are representative for all wave conditions is particularly relevant to the application of the XBeach model to simulate storms of varying magnitude (annual storms up to extreme events) at the prototype scale.

As the depth-scale that needs to be applied is not always obvious when modeling laboratory experiments, the wave-height scaling (w.r.t. storm conditions at prototype scale) is seen as a representative alternative.

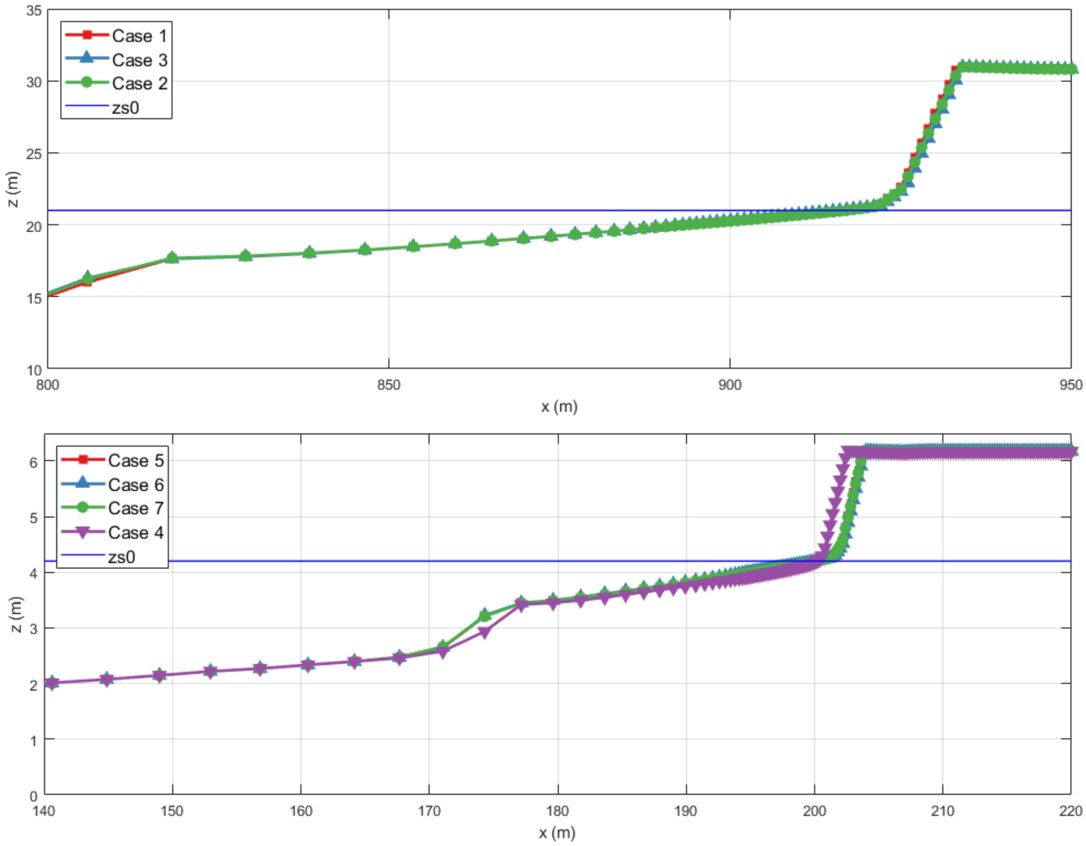

Figure 3.4 Final profiles from four numerical experiments on Prototype (top panel) and Delta flume (bottom panel) scale for H_{m0} = 3 m, and T_p=12 s. Note: red, blue and green results are overlapping each other.

3.3 Conclusions

The sensitivity of the XBeach predictions to the Froude scaling of the six selected dimensional parameters (*Tsmin, hswitch*, *avaltime, eps, eps_sd* and *hmin*) was seen to vary considerably between the individual parameters. On the one hand, scaling of *eps* and *eps_sd* did not considerably alter dune erosion volumes (< 10%) with respect to the default parameter settings, and the type of scaling will therefore not be that important. Applying Froude scaling is therefore considered a robust enough approach. On the other hand, the predicted dune erosion volumes are observed to be sensitive to the other dimensional parameters (*Tsmin, hswitch*, *avaltime* and *hmin*), especially for *hmin* and *hswitch*, where erosion volume variations vary >20%. Applying the correct scale factor is then especially important to mitigate numerical scale effects of the related physical processes. For this reason, the definition of *Tsmin, hswitch*, *avaltime* and *hmin* in the source code will be reassessed in detail in the next *Phase II*. The parameter-scaling will be tried to be linked to physical parameters, and/or turned dimensionless to guarantee a proper scaling of the model physics at different scales.

The current default settings of the dimensional parameters have previously been determined for storm conditions. Here, they are found to be representative for all wave conditions. This confirmation is particularly relevant to the application of the XBeach model to simulate storms of varying magnitude (annual storms up to extreme events) at the prototype scale. As the depth-scale that needs to be applied is not always obvious when modeling laboratory experiments, the wave-height scaling (w.r.t. storm conditions at prototype scale) is seen as a representative alternative.

4 Phase II – Adaptation dimensional parameters

The predicted dune erosion volumes were seen to be sensitive to scaling of four of the dimensional parameters (*hmin, hswitch, avaltime* and *tsmin).* Therefore, in the second phase of the project we evaluate the function and implementation of the dimensional parameters to see if we can relate them more closely to physical parameters, e.g., wave conditions or the time scale of the imposed boundary conditions, such that the limiters can be expressed in dimensionless form.

4.1 Approach

For four out of six dimensional parameters identified in Chapter 3 we propose a redefinition that either makes the parameter obsolete or changes it to a dimensionless form. These changes are cast in XBeach revision 5619 and are discussed in Section 4.2. For each of the changes, we verify the correct implementation and similarity of the results with earlier XBeach revisions using 'old' parameter definitions. These verifications are performed on a reduced set of the laboratory experiments from research program MS1263. The reduced set consists of 4 flume setups, one for each depth scale present in the MS1263 program and complemented with the fictitious prototype setup, see Table 4.1.

Table 4.1 Lab experiments for validation of adapted parameters

Protype	Nd=5	Nd=26	Nd=48	Nd=84
Protoype D1	Deltagoot 1	Wind flume 125	Wind flume 105	Wind flume 115

After verifying that the adaptations in the dimensional parameters do not affect model results on Delta flume scale, the complete set of experiments from MS1263 is revisited again as a second step. Here, the sensitivity of the modelled erosion volumes to scaling or omitting to scale dimensional parameters is assessed with the new revised XBeach version 5619.

4.2 Redefining dimensional parameters

Hswitch

The parameter *Hswitch* initially introduced a hysteresis effect in dune slumping on the interface of wet and dry, as it defined a threshold water depth which had to be reached first in a cell before the avalanching was triggered to adapt the equilibrium slope. If not down-scaled properly, the threshold water depth stays too large, thereby avalanching of the dry slope is not initiated and therefore the erosion does not onset either. This was necessary in the old formulation of avalanching using the parameter *dzmax*, but since the current implementation of avalanching already distributes the transport of slumped material over a timescale *avaltime*, we hypothesize that the parameter may have become redundant. Its potentially limiting effect on the erosion rates can also be realized through a slightly larger value of *avaltime*.

Avaltime → nTrepAvaltime

The value of parameter *Avaltime* was calibrated on the Delta flume tests to 10 s, which is a fixed dimensional value. The sensitivity analysis of Phase 1 (Section 3) showed that Froude scaling of the avalanching timescale altered the results somewhat, although variations were always limited to a 10% difference in erosion volume or landward erosion extent.

One function of the avalanching timescale is to provide numerical stability by preventing a too large bed level change in one timestep, if it overshoots the intended flattening of the slope. Physically, it is also likely that slumping does not occur instantaneously when the dune slope is covered with water. Water needs time to infiltrate the pores between grains of sand. This infiltration will take place at a timescale not smaller than a typical timescale for individual waves. For the implementation of *avaltime*, we propose therefore to couple this timescale to the representative period of the offshore waves. Since an *avaltime* of 10 s appeared to be appropriate for erosion in calibration of the Delta flume experiments, where T_p=12 s, the coupling between *avaltime* and wave period of offshore conditions is O(1). Thereby, *avaltime* is proportional to $T_{m-1,0}$ (T_{rep} in XBeach), where we express the proportionality factor as *nTrepAvaltime*.

hmin → Deltahmin

Another parameter that initially was fixed in time and calibrated with the Delta flume experiments is *hmin*. From the sensitivity analysis it is apparent that some form of scaling of this parameter is very important to obtain realistic model results. The current implementation requires Froude scaling of this parameter to allow for correct computation of the Stokes drift. We propose an alternative implementation of this limiter

$$hmin = \begin{cases} h & H \leq h \\ h + \delta_{hmin} * H\left(\frac{H}{h} - 1\right) & H > h \end{cases} \quad (4.1)$$

where h is the water depth [m], H is the wave height [m], and δ_{hmin} is a dimensionless calibration coefficient [-]. This new implementation introduces also a smoother transition zone from deep water ($H \leq h$), where no limiter is imposed, to very shallow water ($H > h$), where *hmin* is applied in Stokes drift computations instead of the actual water depth. This definition of the Stokes drift limiter eliminates scaling concerns by replacing it by δ_{hmin}, a dimensionless calibration coefficient. The new default for the δ_{hmin} parameter is now defined as 0.1, but needs to be carefully calibrated in a following sub-project of the BOI program.

Tsmin → dtlimTs

A last change in parameter implementation is proposed for the parameter *Tsmin*. This limiter on the minimal sediment adaptation timescale *Ts* was previously calibrated to 0.1 seconds for Delta flume experiments. The sensitivity analysis of Phase 1 showed that the simulated final profiles were only mildly affected by Froude scaling or no scaling of this parameter. This implies that the limit is not often exceeded by the computed adaptation timescale, or that limiting the adaptation timescale does not affect the bed levels much. The main function of the limiter is preventing overshoot of entrainment or sedimentation by the explicit discretization of numerical equation. That implies that it is also sufficient to define the minimal adaptation timescale to be only slightly larger than the numerical timestep. By coupling it to the timestep, a user does not have to scale this limiter explicitly anymore, because the timestep will automatically be scaled when resolution is chosen appropriately for the scenario at hand through the Courant criterion. For consistency with the earlier defined 0.1 s for Delta flume experiments, a numerical limiter *Tsmin* is defined as *Tsmin* = $5 \cdot \Delta t$

To ensure backward compatibility with earlier XBeach versions, a set of keywords was introduced to switch between old implementation of parameters and new parameters (by default the new implementation is used):

- *oldhmin* 0/1 (0: old dimensional implementation, *hmin* default or read from *params.txt*, 1: *deltahmin* implementation, *deltahmin* default value or read from *params.txt*)
- *fixedavaltime* 0/1 (0: *avaltime* fixed throughout simulation based on parameter *avaltime* read from *params.txt*, 1: *avaltime* computed from *Trep* of offshore boundary conditions multiplied with parameter *nTrepAvaltime* which can be read from *params.txt*)
- *oldTsmin* 0/1 (0: old dimensional implementation of *Tsmin*, *Tsmin* default or read from *params.txt*, 1: new interpretation as numerical limiter based on timestep and *dtlimTs* read from *params.txt*)

4.3 Results

4.3.1 Effects of each individual modification

Each of the proposed modifications to dimensional parameters was tested individually and compared to the computed profiles with the old implementation of dimensional parameters (Figure 4.1). The results confirm that the proposed modifications are appropriate: they result in comparable results as the former implementation did and therefore do not change the function or effect of the parameters. This figure also shows that discrepancies between the final profile in the numerical experiments and the final profile as measured in the lab increases with increasing depth scale. This is not a result of the improvements proposed in this chapter, because the effect was already present in the Froude scaled results of Phase 1. This is an important aspect for the calibration phase and is reflected upon further in Chapter 5.

When examining the predicted erosion volumes for all new numerical experiments, changes between the old and new implementations are up to 10% (Table 4.1). Since profile shape is relatively similar between all numerical experiments, the differences in erosion rate are not deemed prohibitive as they can be adapted in the calibration phase.

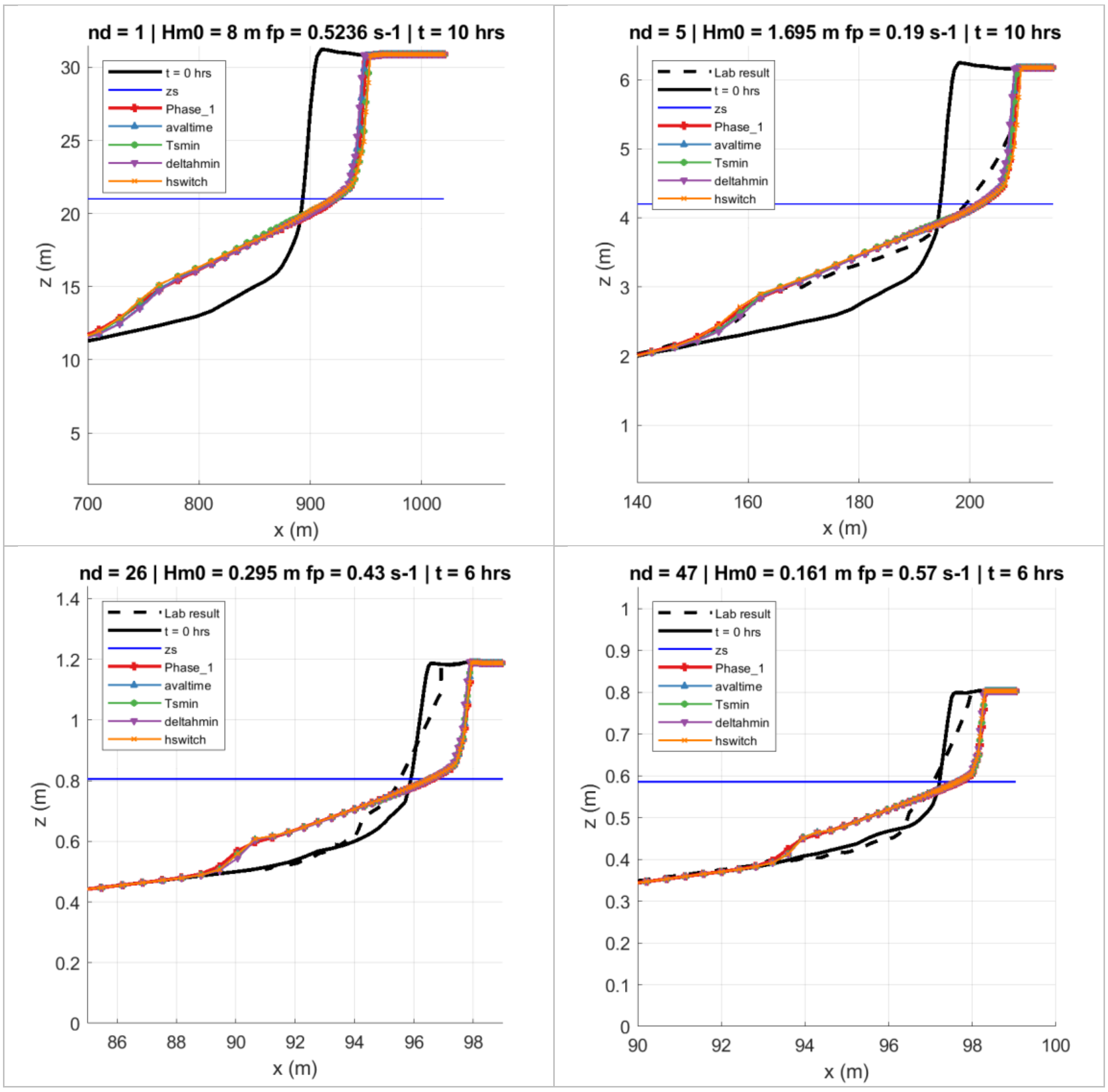

Figure 4.1 Final bed profiles from laboratory and numerical experiments on 4 depth scales using the new implementation of previously dimensional parameters. The variations were tested one by one, keeping all other parameters to the old, conventional Froude (n_d) scaled default values.

Table 4.2 Erosion volumes V [m³/m] for numerical experiments of Figure 4.1. Colors represent percentual changes in erosion volume with respect to Phase 1 results according to legend in Table 3.2, dark green corresponds to <5% change and light green to 5% < ...< 10% change.

	Phase 1	Avaltime coupled to Trep	Tsmin coupled to timestep	hmin replaced by Delta_{hmin} approach	Hswitch turned off
Prototype (nd = 1)	**4.50E+02**	4.34E+02	4.72E+02	4.21E+02	4.75E+02
Delta flume (nd=5)	**2.28E+01**	2.20E+01	2.24E+01	2.15E+01	2.35E+01
Wind flume (nd=26)	**5.52E-01**	5.46E-01	5.40E-01	5.23E-01	5.52E-01
Wind flume (nd=47)	**1.73E-01**	1.69E-01	1.71E-01	1.66E-01	1.69E-01
Wind flume (nd=84)	**4.75E-02**	4.67E-02	4.67E-02	4.60E-02	4.70E-02

4.3.2 Sensitivity to the choice of δ_{hmin}

Implementation of δ_{hmin} over the previous *hmin* parameter removes the dimensionality of the parameter, but the dimensionless value of δ_{hmin} remains a calibration parameter. To investigate the sensitivity of the eroded volume to this new parameter, additional numerical experiments were performed on the subset of the laboratory experiments. The resulting erosion volumes are summarized in Table 4.3. The erosion volume can change up to 20% depending on the tested value of δ_{hmin}. The erosion volume at smaller depth scales (closer to protype) is more sensitive to the choice of δ_{hmin} (20%) than the experiments on smaller depth scale (10%). The definite value of this parameter should be derived in a calibration study (i.e., the “derivation of BOI settings” task of Phase 1 of the Action Plan).

Table 4.3 Sensitivity of Erosion V [m³/m] to the choice of δ_{hmin} [-]. Colours represent percentual changes in erosion volume with respect to Phase 1 according to legend in Table 3.2, dark green corresponds to <5% change and light green to 5% < ..< 10% change, yellow to 10 < ..< 20% change.

	Phase 1	$\delta_{hmin} = 0$	$\delta_{hmin} = 0.1$	$\delta_{hmin} = 0.3$	$\delta_{hmin} = 0.5$	$\delta_{hmin} = 0.7$
Prototype	4.50E+02	4.39E+02	4.21E+02	3.98E+02	3.82E+02	3.69E+02
Delta flume (nd=5)	2.28E+01	2.23E+01	2.15E+01	2.03E+01	1.95E+01	1.89E+01
Wind flume (nd=26)	5.52E-01	5.41E-01	5.23E-01	4.98E-01	4.81E-01	4.66E-01
Wind flume (nd=46)	1.73E-01	1.69E-01	1.66E-01	1.61E-01	1.57E-01	1.54E-01
Wind flume (nd=84)	4.75E-02	4.67E-02	4.60E-02	4.50E-02	4.42E-02	4.35E-02

4.3.3 Sensitivity to the choice of dtLimTs

The new implementation of a limiter on the adaptation time scale in the advection-diffusion equation of sediment is no longer considered to have a physical interpretation but is solely a limiter to ensure numerical stability of the entrainment-deposition process. Therefore, we coupled it to the numerical timestep. Results for numerical experiments where the minimal adaptation timescale is coupled to the timestep by a factor {2,5,10,20} for the reduced set of laboratory experiments are summarized in Table 4.4. All simulations are seen to remain stable if *dtLimTs* is chosen larger than or equal to 2. We do see, however, a slight reduction of the erosion volumes with increasing *dtLimTs*. The effect of a numerical limiter should be as minimal as possible, provided stability is assured. Therefore, we recommend setting this parameter *(dtLimTs)* to 5, as it is closest to the old implementation of *Tsmin*=0.1s in the Delta flume experiment that had an average timestep of 0.02 s. The optimal value will be determined during the calibration phase.

Table 4.4 Sensitivity of Erosion V [m^3/m] to the choice of dtLimTs [-]. Colours represent percentual changes in erosion volume with respect to Phase 1 according to legend in Table 3.2, dark green corresponds to <5% change, light green to 5% < ..< 10% change and yellow to 10 < ..< 20% change.

	Phase 1	$dtLimTs = 2$	$dtLimTs = 5$	$dtLimTs = 10$	$dtLimTs = 20$
Prototype	-4.50E+02	-5.00E+02	-4.70E+02	-4.70E+02	-4.70E+02
Delta flume (nd=5)	-2.28E+01	-2.30E+01	-2.20E+01	-2.20E+01	-2.10E+01
Wind flume (nd=26)	-5.52E-01	-5.50E-01	-5.40E-01	-5.20E-01	-5.00E-01
Wind flume (nd=46)	-1.73E-01	-1.70E-01	-1.70E-01	-1.70E-01	-1.60E-01
Wind flume (nd=84)	-4.75E-02	-4.70E-02	-4.70E-02	-4.60E-02	-4.50E-02

4.3.4 Sensitivity to remaining dimensional parameters

The sensitivity study of Phase 1 is repeated here on the new XBeach version with modified parameters. The only dimensional parameters remaining are *eps* and *eps_sd*. The necessity of applying or omitting scaling of these two variables is investigated by comparing erosion volumes with and without scaling of either *eps*, or *eps_sd*, or both. We revisit this analysis to show the proposed adaptations to the sum of the four parameters, when all combined, do not affect the sensitivity to scaling of the remaining dimensional *eps and eps_sd*. Table 4.5 summarizes the values of the newly-introduced parameters that are used in this sensitivity study, and Table 4.6 shows the “compressed” results.

Table 4.5 Parameter settings for newly introduced parameters in XBeach revision 5619 for the sensitivity analysis of remaining dimensional parameters.

Parameters	Value
nTreoAvaltime [-]	1
dtLimTs [-]	5
Deltahmin [-]	0.1
Hswitch [-]	0
OldTsmin [0/1]	0
oldHmin [0/1]	0
fixedAvaltime [0/1]	0

All experiments show light green erosion volumes (<10%) or bright green erosion volumes (<5%) volume changes compared to the standard Froude scaled experiment. Therefore, there are no longer experiments or timesteps that show a large deviation in erosion volumes when scaling of any of the remaining dimensional variables or all the remaining dimensional parameters is omitted. In other words, omitting the Froude scaling of *eps* and *eps_sd* results in a relative change of the dune erosion volumes of less than 10% in all cases. This is a large improvement on the unscaled result and on the results from Phase 1. There we showed that omitting scaling of just one dimensional parameter could lead to changes in erosion volumes up to 80% (Table 3.3 and Table 3.4). Therefore, with the new set of parameters, it is acceptable to Froude scale these two parameters, but the effect of error propagation due to uncertainty on a correct scaling factor or even omitting scaling of the two remaining dimensional parameters all together is limited.

Table 4.6 Compressed overview of differences in computed erosion volumes over the full range of experiments investigated with the new parameter set. See Table 3.1 for interpretation of the column set-up and naming in uncompressed form. The background colour of a cell represents percentual difference in computed erosion volume compared to the complete Froude-scaled implementation of the remaining dimensional parameters. Different experiments are divided by thin black lines and the thick black lines indicate different depth scales. Dark green corresponds to <5% change and light green to 5% < ..< 10% change with respect to Froude scaled results. Note that the columns describing the experiment, timestep and reference erosion volume have been omitted.

Nd	ΔVero [-eps]	ΔVero [-eps_sd]	ΔVero [not scaled]
84,0			
47,0			
26,0			
5,0			

4.4 Summary

Table 4.7 summarizes the improvements in robustness of model results made by the improved set of dimensional parameters of Phase II. It shows that with new parameters we can stay close to the model behaviour when performing Froude-scaling of all the dimensional parameters (compare column B to A – especially the final time steps of each test). With the improved set of dimensional parameters, making an error in Froude scaling will not have large consequences, because even not applying any scaling on the remaining dimensional parameters *eps* and *eps_sd* leads to differences < 10% in erosion volumes (column D), whereas omitting the scaling on the original set of six dimensional parameters led to nearly always >20% differences in erosion volumes (column C).

Table 4.7 Compressed overview of effect that scaling of dimensional parameters has on computed erosion volumes with the improved set of dimensional parameters as compared to the set in Phase I. Column A is the reference column of erosion volumes as computed in Phase I with Froude scaling applied to all dimensional parameters. Column B represent changes in erosion volumes using the improved set of parameters of Phase II, Froude scaling the two remaining dimensional parameters (… and …), and compared the volumes to column A. Column C shows differences in computed erosion volumes with parameter set from Phase I if no scaling is applied compared to column A. Column D shows differences in computed erosion volumes with parameter set from Phase I if no scaling is applied compared to column B. Note that the columns describing the experiment, timestep and reference erosion volume have been omitted.

Nd	A Vero phase I [Froude scaled]	B ΔVero phase II [Froude scaled] w.r.t. A	C ΔVero phase I [not scaled] w.r.t. A	D ΔVero phase II [not scaled] w.r.t. B
84.0				
47.0				
26.0				
5.0				

4.5 Conclusions

Modifications were proposed that change the limiters from being dimensional to dimensionless for four of the six dimensional parameters identified in section 2.1, to ensure proper representation of the physics in the model on all laboratory scales and to limit the number of choices a user needs to make. These include the *Hswitch, Avaltime, Tsmin and Hmin.* They are replaced by the dimensionless *nTrepAvaltime, dtlimTs,* δ_{hmin}, while *Hswitch* is removed as it is considered redundant in combination with *nTrepAvaltime*.

Some dimensional parameters were intended to be (numerical) limiters to guarantee stability of the model results. The proposed modifications to these limiters also show stable model results. None of the proposed modifications of dimensionless parameters changed the final profile shape and all led to differences in erosion volume smaller than 10%, compared to the *Phase I* results (Froude-scaled settings). These differences are sufficiently small to be compensated by a recalibration of the larger set of calibration parameters.

5 Discussion

5.1 Model skill on small-scale laboratory experiments

5.1.1 Dune profile

As noted in Chapter 2, in this subproject the laboratory data have only been used as a *framework* to test the sensitivity of the XBeach predictions (erosion volume and dune front migration rate) to the selected dimensional parameter settings. A best-fit with the laboratory evolution was not the current objective and will be treated in a later stage within the BOI project to calibrate and define the default parameters for the BOI project. However, when looking more qualitatively at the modelled profile evolution, one can generally observe a large deviation between the predicted and observed beach and dune profile evolution for the smaller lab-scales 1:47 and 1:84 (Figure 5.1, centre and bottom panels).

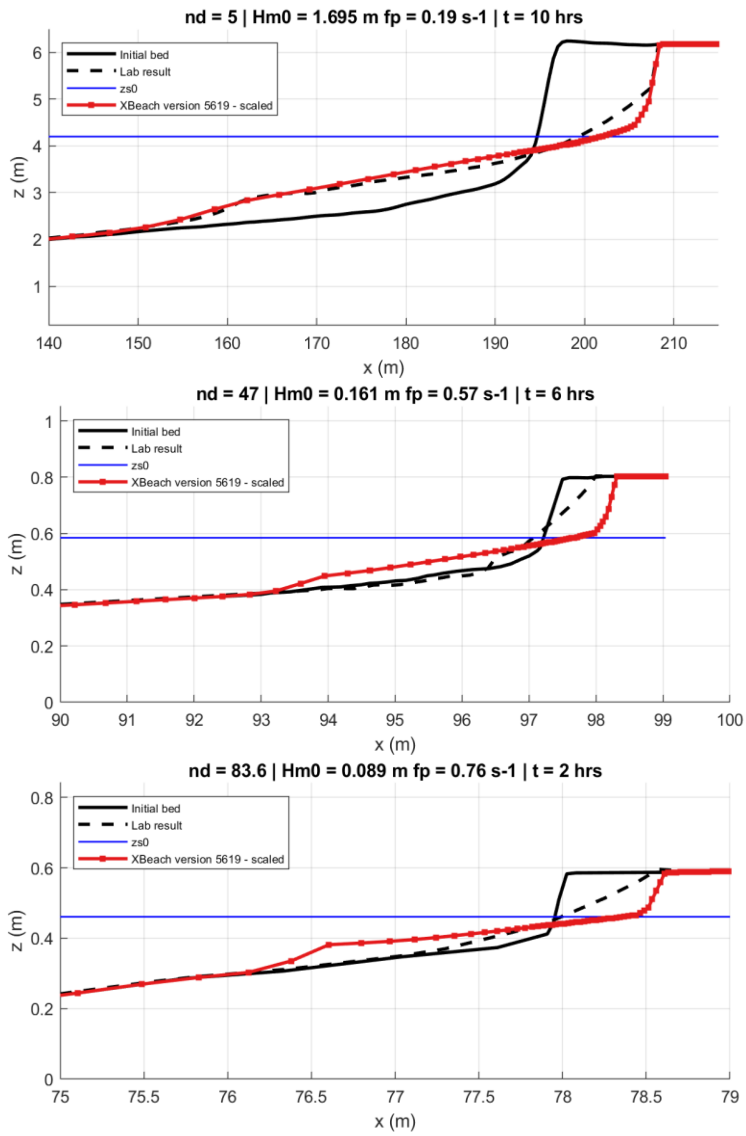

Figure 5.1 Comparison between laboratory (dashed black line) and XBeach predictions after Phase 2 adaptations (red line) for three typical lab-scales, from top to bottom Test-1 (Delta flume -nd = 5), Test-105 (Wind flume II = nd = 47) and CT-14 (Wind flume I – nd = 83.6).

Whereas the XBeach predictions on Delta flume scale show a relatively good fit with the scaled default settings (for which they were originally calibrated), without further calibration, the XBeach predictions show large offsets for the smaller laboratory scales. The difference between the measured and predicted bed slope is considerable for the slope of the dune front (although on the Delta flume scale the steep dune front is well represented). This deviation seems independent of the six selected dimensional parameters studied here. The predicted XBeach beach profile stays roughly similar for variations in the parameters assessed here, and only the migration rate of the dune front is affected.

During the calibration process at a later stage of the BOI project this mismatch with the laboratory data will be addressed. One of the factors responsible for the overestimation in erosion might be the turbulence representation in the source code – this is discussed briefly below. One of the parameters that could help to improve the profile fit is the *bermslope*-parameter (not included in the current simulations), which defines the equilibrium swash-zone slope for (semi-) reflective beaches, by calibrating it based on the observed laboratory slope.

In addition, when observing this "smeared out" profile for the smallest lab-scales, one might question the representability of the smaller scale (n_d > 30) lab experiments, as the grainsizes were not scaled to this smaller scale, which might affect the bed-current interactions and mobility thresholds of the sediment considerably.

5.1.2 Near-bed turbulence

In his thesis, Brandenburg (2010) mentions that turbulence effects are overestimated at the smallest lab-scales. At present, this effect is tested by turning off the near-bed turbulence, which indeed reduces erosion rates considerably, but on all scales (Appendix E). It is out of the current scope, but we recommend that the current representation of turbulence is investigated in more depth in the calibration of the BOI settings.

5.2 Implications of sensitivity study

Phase 1 indicated that XBeach predictions are especially influenced by the Froude scaling of four dimensional parameters. Each of these four parameters was subsequently assessed in Phase 2. The only two remaining dimensional parameters *eps* and *eps_sd* are shown to not impact model results strongly (typically <5%) when Froude scaling is omitted, however for the smaller laboratory scales the sensitivity increases. Applying simple Froude scaling for these parameters is therefore considered a robust enough approach. As the correct scale to apply is not always known – laboratory experiments are sometimes distorted – it is recommended to scale with respect to the normative offshore wave-height of 8, but only when the depth-scaling is unknown. For prototype models with different wave conditions than the standard Dutch normative conditions, the wave-height scaling factor will generally not exceed 10 (compared to H_{m0} = 8 m and T_p =12 s). In these applications, it is not considered important to down-scale *eps* and *eps_sd*, and rather to maintain consistency in model settings between simulations.

This implies that scaling effects only need to be taken into consideration for the BOI project in the setting up of laboratory experiments that are used for calibration. For the application of XBeach in BOI on prototype scale a user only needs to consider a proper scaling of the computational grid through wave-height and wave-length scaling of the minimal grid resolution and a sufficient grid resolution on the offshore boundary based on the typical wave length of infragravity waves. An extensive recommendation for users is included in Appendix D.

The sensitivity of the dune erosion predictions to the newly defined non-dimensional parameters should be carefully investigated in the calibration phase.

6 Conclusions and recommendations

6.1 Conclusions

The overall question for this project is: "*How can the dimensional numerical parameters in XBeach be scaled or optimized for laboratory-scale applications?*"

XBeach model predictions for dune erosion were found to be sensitive to the scaling of especially four of the six investigated dimensional parameters. Modifications were proposed that alter the four parameters from being dimensional to dimensionless, by linking them to the relevant physical process or numerical timescale. This to ensure proper parameter scaling – and therefore the physical process representation in the model – as well as to simultaneously reduce the number of parameter choices for the model user. The two remaining dimensional parameters are recommended to be scaled according to the Froude scaling (ratio of the wave-height with normative Dutch conditions).

Answers to the specific sub-questions are given below:

1. **What dimensional numerical parameters does XBeach have that could be optimized or scaled for laboratory-scale applications of the model?**
   a. What dimensional numerical parameters are currently present in XBeach?
   b. What is / are the function(s) of these parameters?

Six dimensional parameters were identified that are seen to particularly affect the dune erosion rate:

Parameter	Function
Avaltime [s]	Time scale for bed level change due to avalanching
Hswitch [m]	Water depth at which is switched from *wetslp* (equilibrium slope for underwater profile) to *dryslp* (equilibrium slope for dry profile)
Tsmin [s]	Threshold for adaptation time scale in advection diffusion equation for sediment
Eps [m]	Threshold water depth above which cells are considered wet
Eps_sd [m/s]	Threshold velocity difference to determine conservation of energy head versus momentum
Hmin [m]	Lower limit for the water depth in the Stokes drift computation

2. Based on literature, what scaling laws should be applied to the selected parameters?
Based on the argument of maintaining dynamic similarity, the Froude number in the laboratory needs to be equal to Froude number in prototype scale. This results in scaling rules for dimensional variables $n_H = n_L = n_d = n_T^2 = n_t^2$. In which n_H is the horizontal length scale factor, n_L is the wave-length factor, n_d = depth-scale ratio, n_T is the wave-period scale factor and n_t is the time-scale factor. From that follows that *Tsmin*, *eps_sd* and *avaltime* can be scaled with $\sqrt{n_d}$, and *eps*, *hmin* en *hswitch* with n_d.

3. How sensitive are the dune erosion predictions to the parameter choice?

Whether or not *eps* and *eps_sd* are Froude scaled has no significant (< 10%) implications for the simulated dune erosion for laboratory experiments with Froude scaling in the laboratory experiments considered (scaling range from 1:5 to 1:84). The dune erosion predictions proved to be sensitive to the scaling of the other four parameters (*Tsmin, hswitch*, *avaltime* and *hmin),* especially *hmin* and *hswitch*.

4. Are variations in wave conditions relevant to the scaling of the dimensional model parameters?

Default settings of the dimensional parameters were previously determined based on laboratory experiments of storm conditions. Here, they are found to be representative for all wave conditions. This confirmation is particularly relevant to the application of the XBeach model to simulate storms of varying magnitude (annual storms up to extreme events) at the prototype scale. Secondly, as the depth-scale that needs to be applied is not always obvious when modeling laboratory experiments (distorted profiles or no known reference scale), the Froude scaling based on the wave-height ratio (w.r.t. storm conditions at prototype scale) of *eps* and *eps_sd* is seen as a representative alternative.

5. How can the parameters be adapted alternatively to avoid scaling errors?

a. How can the relevant dimensional parameters be linked to a physical process?
b. How can the relevant dimensional parameters be made dimensionless or linked to another non-dimensional parameter?

The scaling of two of the selected parameters (*eps* and *eps_sd*) has limited effect on the computed dune erosion, the type of scaling is therefore not that important. For these two parameters, therefore, Froude scaling is considered acceptable. The four other parameters were successfully expressed in a dimensionless form by linking them to a physical or numerical process, thereby removing the need to apply scaling to their values and avoiding incorrect parameter choices by the user. The new dimensionless parameters are showing robust results that are close to the original model behaviour when performing Froude-scaling of all the dimensional parameters (< 5% offset).

Old parameter	New parameter	Link to physical process	Interpretation new parameter
Avaltime [s]	nTrepAvaltime [-]	Physical time scale: link to wave period	Same function as initially, now dimensionless through a coupling of avalanching time scale to representative wave period. Default: 1
Hswitch [m]	-	-	No function in new implementation, Hswitch not necessary for numerical stability any more, left-over of old dzmax implementation. Is replaced by calibration of nTrepavaltime
Tsmin [s]	*dtlimTs [-]*	Numerical limiter: link to time step	Function interpretation changed: numerical limiter on entrainment and deposition in advection-diffusion equation for sediment, coupled to numerical time step. Default: 5
Hmin [m]	*Deltahmin [-]*	Physical water depth: link to wave height	Same function as initially, now dimensionless through coupling to wave height relative to water depth. Additional side effect is smoothening of the transition from unlimited to depth-limited Stokes drift zone. Default: 0.1

6.2 Recommendation for application in BOI

For future tasks within BOI it is recommended using the four new dimensionless parameters. The new dimensionless parameters achieve generally the same result as Froude scaling of dimensional parameters but are now linked to a physical process or the time step and are not susceptible to possible errors induced by the user in the determination of the scaling factor. When performing numerical simulations of the laboratory experiments during the calibration process (“derivation of BOI settings” task of Phase 1 of the Action Plan), two dimensional parameters, *eps* and *eps_sd*, need to be Froude scaled. This can be done using the wave-height ratio with normative Dutch conditions.

At all scales, it is of utmost importance to ensure the computational grid is appropriate for the variability of the topography and scale of wave conditions to be assed, in order to resolve the hydro-morphodynamic processes well in the model. This means that for the simulation of laboratory-scale experiments, the minimal grid resolution needs to be geometrically scaled (using the wave height as a measure of the scaling) and grid resolution on the offshore boundary needs to be sufficient to resolve the infragravity waves based on the wave period. A step-by-step recommendation for setting-up the grid resolution appropriately is included in Appendix D.

During the “derivation of BOI settings” task of Phase 1 of the Action Plan, a detailed calibration of the model parameters will be performed using laboratory observations. During the overall model calibration, it is recommended to calibrate the newly defined dimensionless parameters. Current default settings indicate an overestimation of the erosion rates and a too steep predicted profile shape for especially the smallest laboratory scales. One of the model components that may require calibration to reduce simulated erosion at small scale is the parameterization of near-bed turbulence and its effect on sediment transport. Similarly, application of the *bermslope*-approximation of the equilibrium swash-zone slope (not included in the current simulations) in the model calibration, may increase accuracy of the model for the more reflective beach states of the smaller-scale laboratory experiments. In addition, when observing the very gently-sloping dune front of the smallest lab-scales, one might question the representability of the smallest ($n_d > 30$) lab experiments in relation to the relative scaling of the sediment grain size.

7 References

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Deltares

Appendix

A Used symbols

avaltime	(Old parameter) Timescale for bed level change due to avalanching (s)
bermslope	Defines the equilibrium swash-zone slope for (semi-) reflective beaches [-]
C	Depth-averaged sediment concentration (kg/m^3)
d	Water depth (m)
D_H	Sediment diffusion coefficient (m^2/s)
δ_{hmin}	Dimensionless lower limit for the water depth in the Stokes drift computation [-]
Dryslope	Equilibrium value for dry slope [-]
ds	Dune front migration distance (m)
dtlimTs	Numerical limiter on entrainment and deposition in advection-diffusion equation for sediment, coupled to numerical time step [-]
eps	Threshold water depth above which cells are considered wet (m)
eps_sd	Threshold velocity difference to determine conservation of energy head versus momentum (m/s)
H	Wave height (m)
H_{m0}	Wave height based on the zero moment (m0, integral) of the power spectrum (m)
hmin	(Old parameter) Lower limit for the water depth in the Stokes drift computation (m)
hswitch	(Old parameter) Water depth at which is switched from *wetslp* to *dryslope* (m)
L	Wave length (m)
n	Ratio of the value in prototype over the value in the model [-]
n_d	Depth-scale ratio [-]
n_H	Horizontal length-scale factor [-]
n_L	Wave-length factor [-]
n_t	Morphological time-scale factor [-]
n_T	Wave-period scale factor [-]
nTrepAvaltime	Dimensionless timescale for bed level change due to avalanching [-]
n_x	Horizontal scale length factor [-]
t	Time (s)
T	Wave period (s)
T_p	Peak wave period (s)
T_{rep}	Representative wave period used in XBeach (s)
T_s	Adaptation time (s)
Tsmin	(Old parameter) Threshold for adaptation time scale in advection diffusion equation for sediment (s)
u	Horizontal component of velocity (m/s)
v	Vertical component of velocity (m/s)
V_{ero}	Erosion volume (m^3/m)
wetslope	Equilibrium slope for underwater profile [-]
W_s	Sediment fall velocity (m/s)
x	Horizontal distance from the reference position (m)
y	Vertical distance from the time-averaged water level (m)

B Overview of laboratory experiments

Tabel B.1 Overview of laboratory experiments

	Dimensions			Hydrodynamics						Waveboard			morphology
Case	n_d	n_l	$S_f = n_d/n_L$	$W_{L,P}$	$W_{L,L}$	$T_{p,P}$	$T_{P,L}$	$H_{s,P}$	$H_{s,th}$	$H_{s,wb} = H_{m0}$	f_p	$F_{nyq} = 5*f_p$	D_{50} (μm)
Test-1	5.0	7.85	1.57	“	4.2	12.1	5.40	8.3	1.669	1.695	0.19	0.93	225
Test-2	5.0	7.85	1.57	“	4.2	12.1	5.40	8.0	1.597	1.7231	0.19	0.93	225
Test-3	5.0	7.85	1.57	“	3.374	10.1	4.50	5.4	1.080	Variable	0.22	1.11	225
CT46	26.0	61.81	2.38	5	0.806	12.0	2.35	7.7	0.298	0.29	0.42	2.12	225
CT73	26.0	61.81	2.38	6	0.806	12.0	2.35	7.6	0.292		0.42	2.12	225
CT93	26.0	61.81	2.38	5	0.806	9.0	1.76	7.6	0.292		0.57	2.84	225
CT97	26.0	61.81	2.38	5	0.806	12.0	2.35	4.2	0.163		0.43	2.13	225
CT34	26.0	61.81	2.38	5	0.806	12.0	2.35	7.6	0.292	0.282	0.42	2.12	225
CT48	26.0	61.81	2.38	5	0.806	12.0	2.35	7.6	0.294	0.294	0.42	2.12	225
CT74	26.0	61.81	2.38	5	0.806	12.0	2.35	7.6	0.291	0.296	0.42	2.12	225
CT94	26.0	61.81	2.38	5	0.806	9.0	1.76	7.6	0.292		0.57	2.84	225
Test-121	26.0	64.87	2.50	“	0.806	12.0	2.35	7.8	0.301	0.301	0.43	2.13	225
Test-125	26.0	64.33	2.47	“	0.806	12.0	2.35	7.7	0.295	0.295	0.43	2.13	225
CT24	46.6	130.56	2.80	5	0.585	12.0	1.76	8.0	0.172	0.174	0.57	2.85	225
CT26	46.6	130.56	2.80	5	0.585	12.0	1.76	7.6	0.163	0.16	0.57	2.85	225
CT28	46.6	130.56	2.80	5	0.585	12.0	1.76	7.6	0.163	0.164	0.57	2.85	225
DT98	46.6	130.56	2.80	5	0.806	16.0	2.35	7.6	0.163		0.43	2.13	225
Test-101	47.0	143.53	3.05	“	0.585	12.1	1.76	7.7	0.163	0.154	0.57	2.84	225
Test-105	47.0	143.53	3.05	“	0.585	12.1	1.76	7.7	0.163	0.161	0.57	2.84	225
CT14	83.6	275.77	3.30	5	0.461	12.0	1.31	7.4	0.089	0.089	0.76	3.81	225
CT16	83.6	275.77	3.30	5	0.461	12.0	1.31	7.4	0.089	0.091	0.76	3.81	225
CT18	83.6	275.77	3.30	5	0.461	12.0	1.31	7.6	0.091	0.091	0.76	3.81	225
CT63	83.6	275.77	3.30	5	0.461	12.0	1.31	8.1	0.097	0.098	0.76	3.81	225
DT64	83.6	275.77	3.30	5	0.461	12.0	1.31	8.1	0.097	0.099	0.76	3.81	225
Test-111	84.0	295.28	3.52	“	0.461	12.0	1.31	7.6	0.091	0.082	0.76	3.82	225
Test115	84.0	296.47	3.53	“	0.461	12.0	1.31	7.6	0.091	0.096	0.76	3.82	225

C Full-size tables sensitivity study phase I

Tabel C.1 Relative difference in dune front migration. The background colour of a cell represents its value (Table 3.2), different experiments are divided by thin black lines and the thick black lines indicate different depth scales.

Experiment	Nd	t model [h]	ds [Fr_scaled]	Δds [-avaltime]	Δds [-eps]	Δds [-eps_sd]	Δds [-hmin]	Δds [-Tsmin]	Δds [-hswitch]
'111'		1,00	0,28	-5%	-8%	0%	-63%	-9%	-27%
'111'		6,00	0,49	-2%	-7%	0%	-65%	-5%	-19%
'115'		1,00	0,21	-9%	-11%	0%	-76%	-12%	-33%
'115'		6,00	0,39	-3%	-9%	0%	-74%	-6%	-21%
'CT14'		0,33	0,31	-16%	-7%	0%	-65%	-14%	-31%
'CT14'		2,00	0,53	-3%	-4%	1%	-61%	-6%	-17%
'CT16'	84,0	0,33	0,30	-14%	-7%	0%	-60%	-13%	-31%
'CT18'		0,33	0,23	-14%	-8%	0%	-59%	-12%	-32%
'CT63'		0,17	0,28	-28%	-9%	0%	-56%	-18%	-41%
'CT63'		0,33	0,35	-14%	-7%	0%	-57%	-12%	-29%
'CT63'		3,00	0,65	-3%	-5%	0%	-55%	-6%	-15%
'DT64'		0,17	0,26	-27%	-10%	0%	-58%	-18%	-38%
'DT64'		0,33	0,33	-13%	-7%	0%	-59%	-13%	-28%
'DT64'		3,00	0,64	-3%	-5%	0%	-56%	-6%	-16%
'101'		1,00	0,55	-7%	-5%	0%	-60%	-11%	-29%
'101'		6,00	0,97	-3%	-4%	0%	-56%	-6%	-19%
'105'		1,00	0,44	-8%	-6%	0%	-65%	-12%	-35%
'105'		6,00	0,83	-3%	-5%	0%	-62%	-7%	-24%
'CT24'		0,33	0,57	-17%	-4%	0%	-52%	-14%	-45%
'CT24'		0,67	0,73	-8%	-4%	0%	-50%	-10%	-30%
'CT24'		2,00	1,03	-4%	-3%	0%	-48%	-7%	-21%
'CT24'		6,00	1,41	-2%	-3%	0%	-47%	-5%	-16%
'CT26'	47,0	0,33	0,40	-15%	-4%	0%	-59%	-15%	-40%
'CT26'		0,67	0,54	-8%	-4%	0%	-58%	-11%	-31%
'CT26'		6,00	1,07	-2%	-4%	0%	-54%	-5%	-19%
'CT28'		0,33	0,33	-12%	-6%	0%	-57%	-16%	-41%
'CT28'		0,67	0,45	-8%	-6%	0%	-60%	-12%	-34%
'CT28'		14,50	1,23	-2%	-4%	0%	-57%	-5%	-19%
'DT98'		0,33	0,56	-16%	-6%	0%	-60%	-16%	-37%
'DT98'		0,83	0,79	-8%	-5%	0%	-59%	-12%	-27%
'DT98'		6,00	1,43	-4%	-4%	0%	-58%	-7%	-18%

'CT46'		0,33	0,35	-21%	-8%	0%	-64%	-20%	-53%
'CT46'		0,83	0,54	-10%	-5%	0%	-63%	-15%	-40%
'CT73'		0,17	0,54	-30%	-2%	0%	-44%	-18%	-54%
'CT73'		0,33	0,77	-19%	-3%	0%	-46%	-16%	-42%
'CT73'		1,00	1,23	-8%	-2%	0%	-42%	-11%	-28%
'CT93'		0,33	0,45	-15%	-4%	0%	-50%	-17%	-54%
'CT93'		0,67	0,63	-8%	-3%	0%	-48%	-13%	-42%
'CT93'		2,00	0,94	-4%	-4%	0%	-45%	-9%	-31%
'CT93'		6,00	1,37	-2%	-4%	0%	-43%	-7%	-25%
'CT97'		0,33	0,48	-12%	-3%	0%	-55%	-16%	-45%
'CT97'		0,83	0,73	-6%	-3%	0%	-53%	-11%	-34%
'CT97'		6,00	1,42	-2%	-3%	0%	-45%	-5%	-22%
'DT34'		0,33	0,66	-17%	-4%	0%	-49%	-16%	-41%
'DT34'		0,67	0,91	-10%	-4%	0%	-47%	-13%	-31%
'DT34'	26,0	2,00	1,35	-5%	-3%	0%	-44%	-9%	-22%
'DT48'		0,33	0,82	-20%	-3%	0%	-46%	-16%	-47%
'DT48'		0,83	1,21	-8%	-3%	0%	-42%	-11%	-31%
'DT48'		2,00	1,64	-5%	-3%	0%	-40%	-8%	-23%
'DT48'		6,00	2,32	-2%	-2%	0%	-37%	-6%	-17%
'DT48'		15,00	3,10	-1%	-3%	0%	-38%	-5%	-14%
'DT74'		0,17	0,51	-28%	-7%	0%	-47%	-18%	-53%
'DT74'		0,33	0,71	-17%	-4%	0%	-47%	-16%	-41%
'DT74'		1,00	1,15	-8%	-4%	0%	-45%	-12%	-29%
'DT94'		0,33	0,59	-17%	-4%	0%	-46%	-16%	-53%
'DT94'		0,67	0,80	-9%	-3%	0%	-41%	-12%	-41%
'DT94'		2,00	1,14	-3%	-2%	0%	-38%	-7%	-28%
'DT94'		6,00	1,60	-2%	-3%	0%	-37%	-5%	-24%
'121'		1,00	1,03	-8%	-3%	0%	-45%	-11%	-29%
'125'		6,00	1,52	-3%	-4%	0%	-51%	-8%	-20%
'Test-1'		0,17	1,26	-22%	-3%	1%	-4%	-1%	-13%
'Test-1'		0,33	2,06	-16%	-1%	0%	-4%	-1%	-9%
'Test-1'		1,00	4,24	-8%	-1%	0%	-7%	-3%	-7%
'Test-1'		3,00	7,21	-4%	-1%	0%	-11%	-3%	-4%
'Test-1'		6,00	9,64	-2%	-1%	0%	-12%	-3%	-3%
'Test-1'	5,0	10,00	11,85	-2%	-1%	0%	-12%	-3%	-3%
'Test-2'		0,17	0,88	-21%	-1%	4%	-3%	-1%	-16%
'Test-2'		0,33	1,59	-17%	-1%	1%	-8%	-1%	-13%
'Test-2'		1,00	3,31	-8%	-1%	0%	-10%	-2%	-8%
'Test-2'		3,00	5,85	-4%	-2%	0%	-13%	-3%	-5%
'Test-2'		6,00	8,03	-2%	-1%	0%	-14%	-4%	-4%
'Test-2'		10,00	10,04	-2%	-1%	0%	-15%	-3%	-3%

Tabel C.2 Relative difference in erosion volumes. The background colour of a cell represents its value (Table 3.2), different experiments are divided by thin black lines and the thick black lines indicate different depth scales.

Experiment	Nd	t model [h]	Vero [Fr_scaled]	ΔVero [-avaltime]	ΔVero [-eps]	ΔVero [-eps_sd]	ΔVero [-hmin]	ΔVero [-Tsmin]	ΔVero [-hswitch]
'111'	84,0	1,00	-0,03	-4%	-7%	0%	-67%	-10%	-25%
'111'		6,00	-0,06	-2%	-6%	0%	-69%	-5%	-18%
'115'		1,00	-0,03	-5%	-9%	0%	-80%	-11%	-28%
'115'		6,00	-0,05	-2%	-7%	0%	-78%	-6%	-19%
'CT14'		0,33	-0,04	-14%	-6%	0%	-68%	-14%	-28%
'CT14'		2,00	-0,07	-3%	-4%	0%	-62%	-6%	-16%
'CT16'		0,33	-0,04	-12%	-6%	0%	-65%	-13%	-29%
'CT18'		0,33	-0,03	-12%	-7%	0%	-67%	-14%	-31%
'CT63'		0,17	-0,03	-24%	-7%	0%	-64%	-19%	-40%
'CT63'		0,33	-0,04	-13%	-6%	0%	-64%	-13%	-27%
'CT63'		3,00	-0,08	-2%	-4%	0%	-58%	-6%	-14%
'DT64'		0,17	-0,03	-23%	-7%	0%	-66%	-19%	-36%
'DT64'		0,33	-0,04	-12%	-6%	0%	-66%	-14%	-27%
'DT64'		3,00	-0,07	-2%	-4%	0%	-60%	-6%	-15%
'101'	47,0	1,00	-0,11	-5%	-4%	0%	-64%	-10%	-26%
'101'		6,00	-0,20	-2%	-3%	0%	-59%	-5%	-17%
'105'		1,00	-0,09	-5%	-4%	0%	-68%	-11%	-29%
'105'		6,00	-0,17	-2%	-4%	0%	-64%	-6%	-20%
'CT24'		0,33	-0,12	-15%	-3%	0%	-58%	-14%	-44%
'CT24'		0,67	-0,15	-8%	-3%	0%	-55%	-10%	-28%
'CT24'		2,00	-0,21	-3%	-3%	0%	-51%	-6%	-19%
'CT24'		6,00	-0,29	-2%	-3%	0%	-48%	-4%	-14%
'CT26'		0,33	-0,09	-12%	-4%	0%	-64%	-15%	-36%
'CT26'		0,67	-0,11	-7%	-3%	0%	-61%	-11%	-28%
'CT26'		6,00	-0,23	-2%	-3%	0%	-55%	-5%	-16%
'CT28'		0,33	-0,07	-10%	-5%	0%	-67%	-16%	-39%
'CT28'		0,67	-0,09	-6%	-4%	0%	-66%	-12%	-31%
'CT28'		14,50	-0,25	-1%	-3%	0%	-60%	-5%	-16%
'DT98'		0,33	-0,10	-12%	-4%	0%	-69%	-17%	-32%
'DT98'		0,83	-0,15	-6%	-4%	0%	-66%	-11%	-23%
'DT98'		6,00	-0,27	-2%	-3%	0%	-62%	-6%	-14%
'CT46'	26,0	0,33	-0,13	-12%	-4%	0%	-67%	-18%	-37%
'CT46'		0,83	-0,20	-6%	-4%	0%	-63%	-13%	-31%
'CT73'		0,17	-0,19	-26%	-2%	0%	-52%	-21%	-50%
'CT73'		0,33	-0,28	-16%	-2%	0%	-50%	-17%	-39%

'CT73'		1,00	-0,44	-6%	-2%	0%	-44%	-10%	-24%
'CT93'		0,33	-0,17	-13%	-4%	0%	-54%	-17%	-51%
'CT93'		0,67	-0,23	-7%	-3%	0%	-49%	-13%	-38%
'CT93'		2,00	-0,34	-3%	-3%	0%	-45%	-8%	-29%
'CT93'		6,00	-0,50	-2%	-3%	0%	-43%	-6%	-23%
'CT97'		0,33	-0,18	-11%	-2%	0%	-61%	-17%	-45%
'CT97'		0,83	-0,27	-5%	-2%	0%	-55%	-11%	-33%
'CT97'		6,00	-0,52	-1%	-2%	0%	-46%	-5%	-21%
'DT34'		0,33	-0,24	-14%	-4%	0%	-54%	-17%	-38%
'DT34'		0,67	-0,33	-8%	-3%	0%	-50%	-12%	-27%
'DT34'		2,00	-0,49	-4%	-3%	0%	-45%	-8%	-18%
'DT48'		0,33	-0,31	-17%	-3%	0%	-49%	-16%	-43%
'DT48'		0,83	-0,45	-7%	-2%	0%	-43%	-10%	-28%
'DT48'		2,00	-0,60	-4%	-2%	0%	-39%	-7%	-20%
'DT48'		6,00	-0,86	-2%	-2%	0%	-37%	-5%	-14%
'DT48'		15,00	-1,14	-1%	-3%	0%	-38%	-5%	-12%
'DT74'		0,17	-0,16	-23%	-4%	0%	-56%	-22%	-48%
'DT74'		0,33	-0,24	-14%	-3%	0%	-54%	-17%	-37%
'DT74'		1,00	-0,38	-6%	-3%	0%	-47%	-10%	-24%
'DT94'		0,33	-0,22	-15%	-3%	0%	-50%	-16%	-52%
'DT94'		0,67	-0,29	-8%	-2%	0%	-44%	-11%	-39%
'DT94'		2,00	-0,42	-3%	-2%	0%	-39%	-7%	-25%
'DT94'		6,00	-0,59	-1%	-2%	0%	-37%	-5%	-21%
'121'		1,00	-0,36	-6%	-2%	0%	-49%	-10%	-26%
'125'		6,00	-0,55	-2%	-3%	0%	-52%	-7%	-15%
'Test-1'		0,17	-2,25	-16%	-1%	0%	-4%	-1%	-8%
'Test-1'		0,33	-3,98	-12%	-1%	0%	-6%	-1%	-7%
'Test-1'		1,00	-8,23	-7%	-1%	0%	-8%	-2%	-5%
'Test-1'		3,00	-13,92	-3%	-1%	0%	-10%	-3%	-3%
'Test-1'		6,00	-18,58	-2%	-1%	0%	-11%	-3%	-2%
'Test-1'	5,0	10,00	-22,79	-2%	-1%	0%	-12%	-3%	-2%
'Test-2'		0,17	-1,74	-14%	-1%	1%	-6%	-2%	-7%
'Test-2'		0,33	-3,16	-11%	-1%	0%	-8%	-2%	-7%
'Test-2'		1,00	-6,56	-6%	-1%	0%	-11%	-3%	-5%
'Test-2'		3,00	-11,38	-3%	-1%	0%	-13%	-3%	-3%
'Test-2'		6,00	-15,56	-2%	-1%	0%	-14%	-3%	-2%
'Test-2'		10,00	-19,44	-1%	-1%	0%	-15%	-3%	-2%

D Grid resolution

In setting up an XBeach model it is necessary to take the scale of the conditions to be modelled into consideration. First and foremost, the resolution of the discretized profile should be fine enough to resolve dune crest appropriately and capture relevant bed forms such as shoals and the beach slope. On top of these topographic and bathymetric features, the resolution should also be appropriate for the wave conditions to be modelled. This means that there should be sufficient grid points to resolve the infragravity waves associated with the short-wave period such that the infragravity component of the swash motions is resolved.

An appropriate discretization of the profile can be constructed with the Matlab-script xb_grid_xgrid2. Input for this function is the minimal grid size, the representative period, *eps* and two arrays *x* and *z* that prescribe the shape of the profile (with arbitrary resolution). The minimal grid resolution the user prescribes is used on the wet-dry interface. This minimal grid resolution is of the order 0.5-2 m on prototype scale for Dutch normative conditions, depending on the beach slope and width of the dune. When simulating scaled laboratory experiments, this minimal grid resolution should be geometrically scaled with the wave height ratio to Dutch normative conditions (H_{m0} = 8 m, T_p = 12 s), and similarly the user must scale *eps*. Towards the offshore boundary, the resolution is coarsened based on a constant-Courant number criterion, while considering sufficient grid points present to resolve the infragravity waves, for which the wave period is input. Calling the Matlab script is done through:

[xgr, zgr] = xb_grid_xgrid2(xin,zin,'Tm',Tp,'dxmin',dxmin_grid,'wl',wl,'minh',minh_grid,'eps',eps_grid);

Where *xin* = xgrid for profile input, *zin* = zgrid for profile input, *Tp* = peak wave period, *dxmin_grid* = minimal grid resolution to be used on wet-dry interface, *wl* = typical water level to identify wet-dry interface, *eps_grid* = minimal water depth below which cells are considered dry.

There are other optional input variables such as the maximum change in aspect ratio between adjacent grid cells. It is recommended to keep this aspect ratio between two adjacent cells smaller than 1.15.

E Sensitivity to turbulence

To investigate the role of the turbulence representation on the overprediction of erosion volume observed for the smallest laboratory scales, additional simulations have been performed excluding turbulence. Results show that excluding turbulence reduces erosion volumes on all scales with ~40-50% (Tabel E.1).

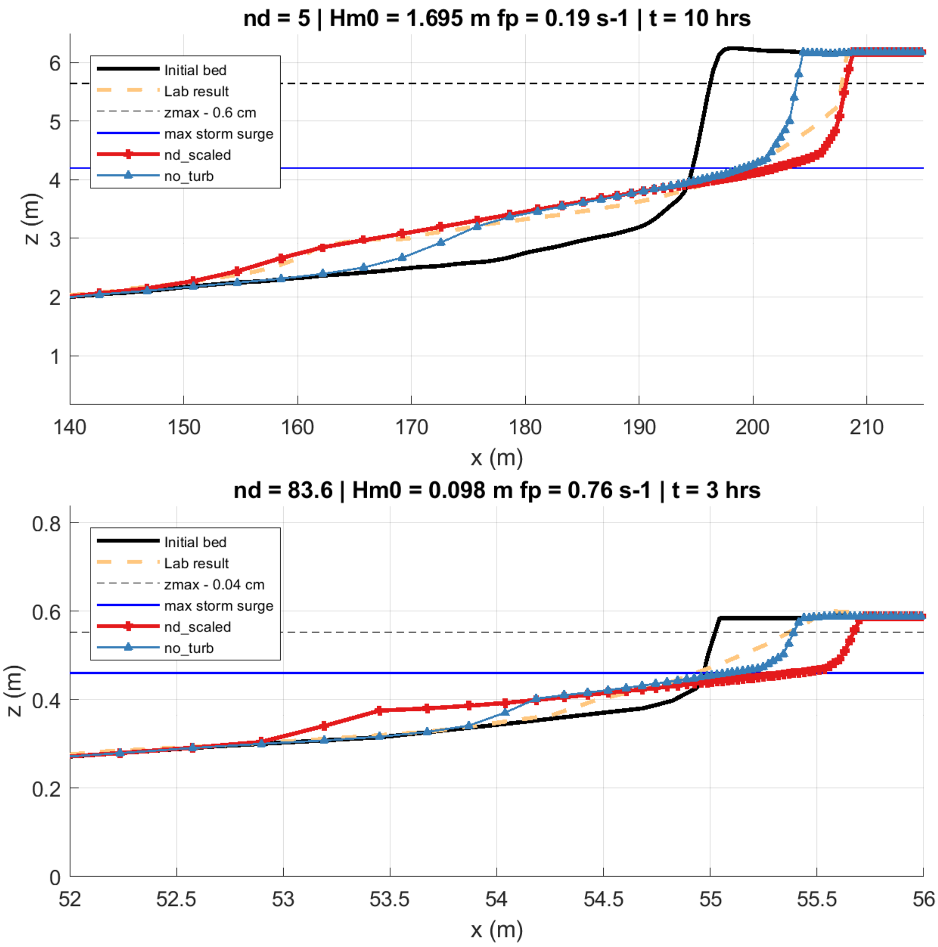
Tabel E.1 Relative difference in erosion volumes. Here, all results are presented after vertically compressing the rows. The background colour of a cell represents its value, different experiments are divided by thin black lines and the thick black lines indicate different depth scales.

Experiment	Nd	t model [h]	Vero [Fr_scaled] [turb=bore-averaged]	ΔVero [turb=0]
	84.0			
	47.0			
	26.0			
	5.0			
	1.0			

Relative change with respect to Fr_scaled			
<5%	5% < … < 10%	10% < … < 20%	> 20%

However, while the reduction in erosion volume results in a better correspondence with the laboratory observations on small scales, it results in a considerable underestimation of the erosion volume for the larger Delta flume experiments FigureApx E.1.

As in the current report no best-fit with laboratory data was aimed for, this does not affect the observed trends and conclusions. However, the representation of turbulence could be of importance when wanting to reproduce the smallest laboratory experiments during the follow-up phase of the BOI-project, where the XBeach model will be calibrated in detail with laboratory data to deduce robust default settings.



FigureApx E.1 Comparison between laboratory (dashed orange line) and XBeach predictions after Phase 2 adaptations, with eps and eps_sd nd scaled, for a simulation with (red) and without (blue) turbulence. Top: Test-1 (Delta flume -nd = 5), bottom: CT-14 (Wind flume I – nd = 83.6).

F Overview processes and parameters

This appendix shows all **DEFAULT** processes and parameters that form input for XBeach **OTHER** than the parameters discussed in this report and is extracted from the XBeach log file of one of the numerical experiments performed for this report (XBeach version 5619).

```
--------------------------------
  Physical processes:
                  wavemodel =surfbeat
                     cyclic =0 (no record found, default value used)
                      swave =1 (no record found, default value used)
                 single_dir =0 (no record found, default value used)
                      lwave =1 (no record found, default value used)
                       flow =1 (no record found, default value used)
                   sedtrans =1 (no record found, default value used)
                 morphology =1 (no record found, default value used)
                avalanching =1 (no record found, default value used)
                     gwflow =0 (no record found, default value used)
                      ships =0 (no record found, default value used)
                 vegetation =0 (no record found, default value used)
                   setbathy =0 (no record found, default value used)
                  viscosity =1 (no record found, default value used)
                  advection =1 (no record found, default value used)
                       wind =0 (no record found, default value used)
  --------------------------------
  Grid parameters:
                   gridform =xbeach (no record found, default value used)
                       xori =20.0000
                       yori =.0000
                       alfa =.0000
                         nx =107
                         ny =0
                     posdwn =-1.0000
                    depfile =bed.dep
                      vardx =1
                         dx =-1.0000 (no record found, default value used)
                      xfile =x.grd
                      yfile = None specified
                         nz =1 (no record found, default value used)
                   thetamin =-180.0000
                   thetamax =180.0000
                  thetanaut =0 (no record found, default value used)
                     dtheta =360.0000
  --------------------------------
  Model time parameters:
                        CFL =.7000 (no record found, default value used)
                      dtset =.0000 (no record found, default value used)
                      tstop =36000.0000
                   maxdtfac =50.0000 (no record found, default value used)
  --------------------------------
  Physical constants:
```

```
                         rho =1000.0000
                           g =9.8100
 -------------------------------
 Initial conditions:
               zsinitfile = None specified
 -------------------------------
 Wave boundary condition parameters:
                  wbctype =parametric
                   bcfile =jonswap.txt
                    taper =100.0000 (no record found, default value used)
                     nmax =.8000 (no record found, default value used)
              lateralwave =neumann (no record found, default value used)
 -------------------------------
 Wave-spectrum boundary condition parameters:
                   random =0
                  fcutoff =.0000 (no record found, default value used)
                  trepfac =.0100 (no record found, default value used)
                  sprdthr =.0800 (no record found, default value used)
               Tm01switch =0 (no record found, default value used)
                       rt =3600.0000 (no record found, default value used)
                     dtbc =1.0000 (no record found, default value used)
             nspectrumloc =1 (no record found, default value used)
 -------------------------------
 Flow boundary condition parameters:
                    front =abs_1d (no record found, default value used)
                     left =neumann (no record found, default value used)
                    right =neumann (no record found, default value used)
                     back =abs_1d (no record found, default value used)
                    order =2.0000 (no record found, default value used)
                 highcomp =0 (no record found, default value used)
                 freewave =0 (no record found, default value used)
                     epsi =-1.0000 (no record found, default value used)
                 tidetype =velocity (no record found, default value used)
 -------------------------------
 Tide boundary conditions:
                  tideloc =0
 -------------------------------
 Discharge boundary conditions:
            disch_loc_file = None specified
     disch_timeseries_file = None specified
               ndischarge =0 (no record found, default value used)
              ntdischarge =0 (no record found, default value used)
                     beta =.1000 (no record found, default value used)
 -------------------------------
 Wave breaking parameters:
                    break =roelvink2 (no record found, default value used)
                    gamma =.5500 (no record found, default value used)
                   gammax =2.0000 (no record found, default value used)
                    alpha =1.0000 (no record found, default value used)
                        n =10.0000 (no record found, default value used)
                    delta =.0000 (no record found, default value used)
                       fw =.0000 (no record found, default value used)
                   fwfile = None specified
                 fwcutoff =1000.0000 (no record found, default value used)
```

```
            breakerdelay =1.0000 (no record found, default value used)
  -------------------------------
  Roller parameters:
                  roller =1 (no record found, default value used)
                     rfb =0 (no record found, default value used)
  -------------------------------
  Wave-current interaction parameters:
                     wci =0 (no record found, default value used)
                    hwci =.1000 (no record found, default value used)
                 hwcimax =100.0000 (no record found, default value used)
                    cats =4.0000 (no record found, default value used)
  -------------------------------
  Flow parameters:
             bedfriction =chezy
             bedfricfile = None specified
             bedfriccoef =65.0000
                   droot =.5000 (no record found, default value used)
                   dstem =.5000 (no record found, default value used)
                   maxcf =.0400 (no record found, default value used)
                     nuh =.1000 (no record found, default value used)
                  nuhfac =1.0000 (no record found, default value used)
                    smag =1 (no record found, default value used)
  -------------------------------
  Coriolis force parameters:
                  wearth =.0417 (no record found, default value used)
                     lat =.0000 (no record found, default value used)
  -------------------------------
  Sediment transport parameters:
                    form =vanthiel_vanrijn (no record found, default value
used)
                waveform =vanthiel
                     sws =1 (no record found, default value used)
                     lws =1 (no record found, default value used)
                   BRfac =1.0000 (no record found, default value used)
                   facua =.1000 (no record found, default value used)
                   facSk =.1000 (no record found, default value used)
                   facAs =.1000 (no record found, default value used)
                   Tbfac =1.0000 (no record found, default value used)
                    turb =bore_averaged (no record found, default value
used)
                 turbadv =none (no record found, default value used)
                     sus =1 (no record found, default value used)
                     bed =1 (no record found, default value used)
                    bulk =0 (no record found, default value used)
                   facsl =.1500 (no record found, default value used)
                      z0 =.0060 (no record found, default value used)
                    smax =-1.0000 (no record found, default value used)
             bdslpeffmag =roelvink_total (no record found, default value
used)
             bdslpeffini =none (no record found, default value used)
             bdslpeffdir =none (no record found, default value used)
             reposeangle =30.0000 (no record found, default value used)
                   tsfac =.1000 (no record found, default value used)
                   Tsmin =.5000 (no record found, default value used)
```

```
                   facDc =1.0000
                     lwt =0 (no record found, default value used)
                   betad =1.0000 (no record found, default value used)
              fallvelred =0 (no record found, default value used)
               dilatancy =0 (no record found, default value used)
--------------------------------
Bed composition parameters:
                     ngd =1 (no record found, default value used)
                      nd =3 (no record found, default value used)
                     por =.4000 (no record found, default value used)
                     D50 =.0002
                     D90 =.0003
                    rhos =2650.0000
                     dzg =.1000 (no record found, default value used)
                    dzg1 =.1000 (no record found, default value used)
                    dzg2 =.1000 (no record found, default value used)
                    dzg3 =.1000 (no record found, default value used)
 sedcal =1.0000 (no record found, default value used)
 ucrcal =1.0000 (no record found, default value used)
--------------------------------
Morphology parameters:
                  morfac =1.0000 (no record found, default value used)
               morfacopt =1 (no record found, default value used)
                morstart =.0000 (no record found, default value used)
                 morstop =36000.0000 (no record found, default value used)
                  wetslp =.3000 (no record found, default value used)
                  dryslp =1.0000 (no record found, default value used)
                  struct =0 (no record found, default value used)
--------------------------------
Output variables:
                 timings =1 (no record found, default value used)
                  tunits = None specified
                  tstart =.0000 (no record found, default value used)
                    tint =360.0000
                tsglobal = None specified
                   tintg =600.0000
                tspoints = None specified
                   tintp =360.0000 (no record found, default value used)
                  tsmean = None specified
                   tintm =36000.0000 (no record found, default value used)
              nglobalvar =4
                 npoints =0 (no record found, default value used)
                nrugauge =0 (no record found, default value used)
               npointvar =0 (no record found, default value used)
               nrugdepth =1 (no record found, default value used)
 rugdepth =.0000 (no record found, default value used)
                nmeanvar =0 (no record found, default value used)
            outputformat =netcdf
         outputprecision =double (no record found, default value used)
              ncfilename = None specified
netcdf output to:xboutput.nc
            remdryoutput =1 (no record found, default value used)
--------------------------------
Output projection:
```

```
          projection = None specified
              rotate =1 (no record found, default value used)
--------------------------------
Wave numerics parameters:
              scheme =warmbeam (no record found, default value used)
              snells =1 (no record found, default value used)
--------------------------------
Flow numerics parameters:
                umin =.0000 (no record found, default value used)
                hmin =.2000 (no record found, default value used)
            secorder =0 (no record found, default value used)
--------------------------------
Sediment transport numerics parameters:
            thetanum =1.0000 (no record found, default value used)
                cmax =.1000 (no record found, default value used)
--------------------------------
Bed update numerics parameters:
             frac_dz =.7000 (no record found, default value used)
              nd_var =2 (no record found, default value used)
               split =1.0100 (no record found, default value used)
               merge =.0100 (no record found, default value used)
```