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DG Rijkswaterstaat – National Institute for Coastal and Marine Management

SBW Plan of Action on the Boundary Conditions for the Waddenzee

Report

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Contents

1 Introduction

1.1 Problem description

In compliance with the Flood Defences Act ("Wet op de Waterkering, 1996"), the primary coastal structures must be checked every five years (2001, 2006, 2011 etc.) for the required level of protection on the basis of the Hydraulic Boundary Conditions (HBC) and the Safety Testing Regulation (VTV: *Voorschrift op Toetsen op Veiligheid*). These HBC must be derived anew every five years and established by the Minister of Transport, Public Works and Water Management.

There is a degree of uncertainty concerning the quality of the current HBC, in particular those for the Waddenzee. This is because they were obtained from an inconsistent set of measurements and design values (WL, 2002a), while for the rest of the Dutch coast (the closed Holland Coast and the Zeeland Delta) the SWAN wave transformation model has been applied.

However, there is currently insufficient confidence in the wave model, so it is not yet possible to use this model to obtain reliable boundary conditions in an area such as the Waddenzee. One of the reasons for this lack of confidence is that a previous version of the wave model provided an unsatisfactory simulation of swell penetration in an area that strongly resembles the Waddenzee (Norderneyer Tidal Inlet, see Kaiser en Niemeyer, 2001). The assumption that this observation also applies to the Dutch part of the Waddenzee and to the current version of the model (version number 40.41ABa) must be substantiated by model verification using hindcasts on the basis of available data. Measurements near the Emmapolder in Groningen have shown that swell provides a considerable contribution to the wave height, in the order of 30% (personal communication F. den Heijer, RIKZ).

This problem was the direct cause for the request from the subproject "Boundary Conditions", which is part of the main project "Strength and Loading of Coastal Structures (SBW: *Sterkte en Belasting Waterkeringen*)", at WL | Delft Hydraulics to formulate a Plan of Action in which a strategy would be determined to answer the principle question: "How do we arrive at reliable Hydraulic Boundary Conditions for the Waddenzee for 2011?" In addition to the penetration aspect, we must determine the general suitability of the SWAN wave model in the Waddenzee and specify the improvements required to produce reliable HBC in the Waddenzee.

In respect of this, we refer to the RIKZ/2005/06311 request for a proposal on 18 November 2005 and the RIKZ/2005/01651 contract of 5 January 2006.

This Plan of Action is the responsibility of the SBW project because it has the task of improving the quality of the models and methods used to derive the HBC to enable the managers and experts to have sufficient confidence to use these tools for the five-yearly tests (SBW, 2005). This is achieved by performing activities such as carrying out measurements and developing methods and models to be able to transform the deep-water statistics into statistics in front of coastal structures and to consider the higher loads on, and the failure mechanisms of, these defences.

The report you are currently reading contains this Plan of Action. The Plan also briefly considers the entire chain that is used to derive the Hydraulic Boundary Conditions and focuses on improving the predictions of the wave boundary conditions produced by the wave model that are required to make the transformation from deep water to coastal structures.

1.2 Purpose of the assignment

The purpose of the assignment is to answer the question of which strategy is required to improve the quality of the models and methods to enable better Hydraulic Boundary Conditions to be produced for the Wadden Area for 2011. This strategy was formulated in a Plan of Action that specifies both the general strategy and the details of the planned implementation for the first year (2006).

1.3 Demarcation

As described above, the Plan of Action involves the strategy to improve the HBC in the Waddenzee and focuses primarily on improving the wave model. The Project Leader of the SBW Boundary Conditions for the Natural Environment can use this Plan of Action to initiate concrete actions to achieve actual improvements in the wave model, in a broad sense and therefore including wave model input, to improve the reliability of the HBC in the Waddenzee.

The Plan of Action covers part of the task of the "SBW Boundary Conditions for the Natural Environment" subproject that extends to all the Dutch water systems, including the remaining parts of the coast, estuaries, upper rivers, tidal rivers and lakes. Of all these water systems, the Waddenzee is the most complex area in which many different physical phenomena occur, whereas only a limited number of phenomena will dominate in other water systems. This means that measurements and model results from other water systems can be applied to examine isolated, partial aspects of the Waddenzee physics. On the other hand, the Plan of Action contains a number of generic methods that can also be applied to other simplified water systems. Care should be taken to ensure the choices made to achieve improvement are not in conflict with choices made for other water systems, in particular the Holland Coast and Zeeland Delta.

In compliance with the assignment, the Plan of Action focuses on improving the wave model. However, while executing this assignment it proved impossible to view these improvements separately from the entire chain used to determine the HBC. We will therefore first outline this chain and then specify a number of problems that have been mentioned repeatedly by experts.

The Plan of Action is also relevant to the Project Leaders of two other subprojects, "SBW Field Measurements" (*SBW-Veldmetingen*) and "SBW Failure Mechanisms" (*SBW-Faalmechanismen*), because they must mutually align their subproject plans and supply the required information to each other, namely from Failure Mechanisms to Boundary

Conditions and from Boundary Conditions to Field Measurements. There is therefore a clear interdependence.

The objective of SBW Boundary Conditions is to improve the accuracy and reliability of the methods and models required for the transformation from deep-water statistics to statistics in front of coastal structures, to enable reliable HBC to be produced for 2011. The SBW project must therefore produce a state-of-the-art product by 2009 at the latest, in terms of the best model and method that can be used with confidence, to enable the computations to be carried out to determine these HBC during the project "Hydraulic Boundary Conditions 2011" (HR2011). In a worst case scenario, this product could be one of the fall-back options as specified in this document. It is therefore essential for there to be communication from both sides and alignment with the HR2011 Project Team, and for as long as this has not been formally established, with the HR2006 Project Team. It is quite possible that activities will be continuing in 2009 that cannot be completed in time for use in the HR2011 project. These activities will continue after 2009 and contribute towards the product that can be used for the HR2016 project. Subsequent HR projects will therefore use increasingly improved models.

1.4 Report layout

The report is laid out as follows. Chapter 2 discusses the approach of the present study. Chapter 3 contains a description of the entire chain from the measurements to the HBC in which the wave model is used. Chapter 4 contains the actual Plan of Action for the improvement of the wave model that is used as the basis for the wave boundary conditions. Chapter 5 provides a summary.

2 Approach

2.1 Setup

The Plan of Action is set up using a chain approach from the measurements to the HBC as described in Chapter 3. One part of this involves the wave model used to transform deep-water statistics for use at the toe of the structure. The improvement of this wave model is the theme of the Stage Plan for the model predictions, measurements and validation, as described in Chapter 4.

Available literature and expertise was used to make an inventory of the missing aspects in each element of the Stage Plan. These aspects were presented to a number of experts. Processing this information resulted in an analysis of the most important elements in relation to the Hydraulic Boundary Conditions and to a prioritisation of the method. This prioritisation will be presented in a timetable of the work that has to be carried out until 2011, with details included for 2006.

2.2 Staging

The work involved in this study can be distinguished into three stages:

1. Make an inventory and write the initial memo.
2. Interviews.
3. Write a report in the form of a Plan of Action.

Stage 1: Make an inventory and write the initial memo

During this stage, the available literature will be consulted and the initial memo will be written. Part of this literature is in the possession of WL | Delft Hydraulics and part is in the possession of RIKZ. This initial memo contains an initial draft of the Plan of Action. A list was drawn up in consultation with the Contracting Authority of experts and interested parties that had to be interviewed (see Table 1). The list of interviewees included experts from RIKZ, DWW, RIZA, Bouwdienst, SBW subproject leaders, Delft University of Technology, Alkyon and WL | Delft Hydraulics. The initial memo was distributed to all the interviewees.

Stage 2: Interviews

During this stage, the experts and interested parties were interviewed. The interviews were held in seven sessions. Experts that were unable to attend the sessions provided their contribution by phone or email. The following people were interviewed during Stage 2 of the project:

First name	Surname	Organisation	Interview date
Herbert	Berger	RWS, RIZA	19 Jan
Marien	Boers	RWS, RIKZ	16 Jan
Marcel	Bottema	RWS, RIZA	Email 18 Jan
Houcine	Chbab	RWS, RIZA	16 Jan
Johan	Dekker	WL | Delft Hydraulics	20 Jan
Ferdinand	Diermanse	WL | Delft Hydraulics	19 Jan
Ulrich	Förster	RWS, DWW	23 Jan
Frank	Heijer, den	RWS, RIKZ	17 Jan
Gijs	Hoffmans	RWS, DWW	16 Jan
Cornelis	Israël	RWS, RIKZ	Phone 31 Jan
Hans	Janssen	RWS, Bouwdienst	24 Jan
Annette	Kieftenburg	RWS, RIKZ	17 Jan
Mark	Klein Breteler	WL | Delft Hydraulics	20 Jan
Mark	Koningsveld, van	WL | Delft Hydraulics	24 Jan
Ad	Reniers	Delft University of Technology	24 Jan
Robert	Slomp	RWS, RIZA	19 Jan
Henk	Verheij	WL | Delft Hydraulics	26 Jan
Gerbrant	Vledder, van	Alkyon	24 Jan
Hans	Waal, de	RWS, RIZA	19 Jan
Ard	Wolters	RWS, DWW	23 Jan
Annette	Zijderveld	RWS, RIKZ	16 Jan
Marcel	Zijlema	RWS, RIKZ and Delft University of Technology	17 Jan

Table 1: List of interviewees

These people received the initial memo in advance of the interview. The initial memo included a draft Plan of Action, including previous versions of Figures 1 and 2 from the document you are reading. These figures form the basis of the Plan of Action. To provide direction to the interviews, the initial memo contained research questions and a description of possible activities for each element. The interviewees were asked the following questions:

- Do you miss any elements in the cycle?
- Do you miss any connections (arrows)?
- Do you miss any research questions in each element?
- Do you miss any activities in each element?
- Can you prioritise the activities?

Stage 3: Reporting

These discussions and additional literature were used to further complete the details of the initial memo and create the actual Plan of Action described in Chapters 3 and 4. The Dutch reports of these interviews will be released separately. As far as possible, this report includes the consensus from the interviews together with the unique insights possessed by some of the interviewees.

3 Consideration of the "HBC chain"

Chapter 4 of this Plan of Action presents a Stage Plan to improve the wave model. The improvement of this wave model cannot be considered separately from the other components of the entire chain from wave measurements to Hydraulic Boundary Conditions, as endorsed by most of the interviewees. Figure 1 contains a somewhat simplified schematic representation of this chain. This chain is currently applicable to the Holland Coast and the Zeeland Delta.

The chain starts at the top left with measurements of waves in relatively deep water, of water levels at coastal stations and of wind at onshore wind stations. These measurements are extrapolated into extreme values of the same quantities. The deep-water statistics for waves must be transformed to wave boundary conditions at the toe of the structure through the application of a transformation matrix for different combinations of wind, water level and wave height for each wind direction. This transformation matrix, the KustDB20XX database (whereby 20XX is currently 2006 but, for example, in the future will be 2011), is filled with calculations carried out using the SWAN wave transformation model (Booij et al., 1999; Zijlema en Van der Westhuijsen, 2005). The extreme values are therefore not input directly into SWAN but they are used to determine the range of combinations that must be calculated, which is why there is a dotted arrow. The diagram also indicates that the transformation is carried out using a wave model for extreme conditions, while it has been validated and accepted for storm situations. This last step requires an acceptance stage that is detailed below. The wave model that has been accepted for storm conditions (top right in Figure 1) is the product of the cycle described in Chapter 4.

The wave boundary conditions at the toe of the structure, together with the water level boundary conditions, the failure mechanisms and the properties of the structure, are included in the HYDRA-K calculation model, in the box with a thick outline. The statistics and the transformation matrix form the input for HYDRA-K. This module uses all this data to compute the normative, or most critical, combination of wave height, wave period, wave direction and water level: the Hydraulic Boundary Conditions. This combination of values is used in current practice by the managers to carry out a deterministic test to determine the safety of the coastal structures through the application of strength and loading modules. The last two stages of testing and acceptance are actually not part of the HBC chain but are specified in the Figure for completeness.

An analysis of this chain, both before and during the interviews in Stage 2, resulted in the following questions and activities.

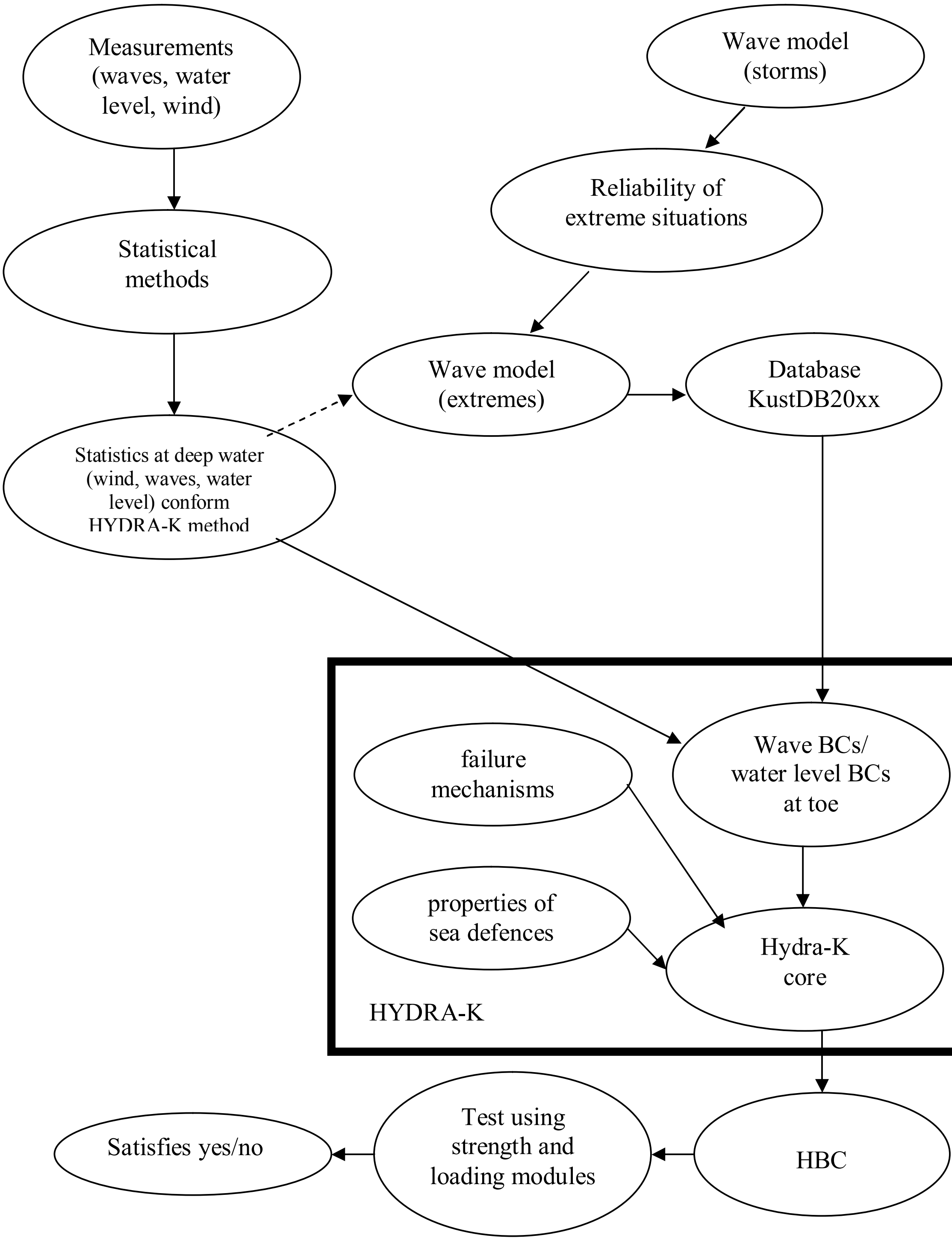

Figure 1: Schematic representation of the HBC chain

Uncertainty analysis

Virtually all interviewees endorsed the need for an integral consideration of the entire chain through an uncertainty analysis. This chain must first be specified unambiguously because there are currently different versions in circulation, with schematisations by RIKZ, RIZA and WL | Delft Hydraulics differing in their details. After this the elements must be analysed and the parameters must be determined. An estimate must be made of the uncertainty margin for each element and a specification provided of the degree to which this correlates with the uncertainty in other elements[1].

This method provides an understanding of the degree of uncertainty in the final answer (the HBC), which element provides the greatest contribution to the total uncertainty and how an improvement in one element affects the final error. But above all, the results from this analysis may be used to carry out a cost-benefit analysis to determine which element should be prioritised for action. It is possible that an element exists that has a high degree of uncertainty, but which cannot be reduced at a reasonable cost. In this case, this highest degree of uncertainty is normative and determines the need for improving the other elements.

The prioritising instrument being developed by the main SBW project is the most suitable instrument with which to perform this analysis. This is because this instrument answers the need for a chain approach whereby the effect of uncertainties in an element is visualised in other elements. However, this instrument is not yet ready and completion is expected in mid 2006. We recommend that an expert panel be used before this time to set up the chain and specify the uncertainty margins.

Activity

0.1 Performance of uncertainty analysis

This must be performed as soon as possible. For this, we recommend using the prioritisation instrument that will be completed in July 2006 in combination with an expert panel. The reliability per element is estimated on the basis of the understanding of the panel, which in a sense is subjective. The prioritising instrument links the elements and clarifies the effect of the uncertainties. The estimates can change because of changing knowledge and insights. The prioritisation instrument is only a tool, and not a goal in itself. If the prioritisation instrument is not completed by mid 2006, the best alternative would be to perform the study using an expert panel.

This uncertainty analysis must be supplemented by performing a risk analysis in which an inventory is made of the critical steps and scenarios are specified if certain goals prove to be unattainable. The details of this risk analysis should be completed in the Project Plan of the subproject SBW Boundary Conditions.

Statistical methods (extrapolation)

Several interviewed experts had doubts concerning the validity of the methods used to extrapolate up the measurements to extreme values. The physics are not sufficiently integrated into this method. There is, for example, a limit on the maximum wave height for a given depth. Physical limitations such as this influence the extreme values during low exceedance frequencies, as demonstrated in WL (2005b). In addition, there is insufficient understanding of the uncertainty of the statistical values.

[1] *One element of this chain is the wave model that also has an inherent uncertainty because the process formulations are an estimate of the (extreme) reality.*

There are also questions in respect of the water level as a result of the numerical simulations performed by Van den Brink from the KNMI, who arrived at much higher water levels (several metres more, personal communication C. Israel, RIKZ) when calculating extreme metrological scenarios than those produced by the extreme values analysis (see Chapter 4.3.6).

Activity

0.2 Research physical boundaries of extreme values

To determine whether statistical extrapolate to extreme values actually results in realistic values (for example: lower values for waves because of the depth limitation and higher values for water levels), this research, which builds on WL (2005b), should be carried out and completed in 2006 or 2007 before production computations are made within the framework of HBC2011.

0.3 Determining the reliability of extrapolating the physics

To map out the uncertainty of the statistics, the confidence bands should be determined for the derived distributions.

Probabilistic model (Hydra modules)

Hydraulic Boundary Conditions are calculated using different HYDRA modules for the different water systems. For example, Hydra-K(*ust*: coast), -B(*enedenrivieren*: tidal rivers), -VIJ (*Vecht-IJsseldelta*: Vecht-IJssel Delta), -M(*eren*: lakes) currently coexist. Uniformity is desired in this area, in particular because certain dike rings border on different water systems. The greatest problem to standardising these models is the “method of de Haan”, which is included in Hydra-K and of which the numerical integration may cause problems (personal communication R. Slomp, RIZA).

Activity

0.4 Formulating Operational Requirements to “Standardise Hydra modules”

Standardising the Hydra modules should start with the formulation of a set of Operational Requirements whereby the current modules and the theory at their foundation, such as the “method of de Haan”, should be evaluated. This activity does not have a high priority. Different modules will suffice for 2011. This activity could be taken up within the HBC framework.

Reliability in extreme situations

Chapter 4 describes a cycle in which the wave model, including input and control, is improved to the extent that it would be acceptable for storm conditions. However, these storm conditions are not the same as extreme conditions for which the wave model is used in the HBC chain. The acceptance of the wave model for extreme situations could occur in a number of ways:

- Laboratory measurements

  For the HBC for the Holland Coast, the SWAN wave model was calibrated (Alkyon, 2003) using wave conditions that were measured at the Petten Sea Defence (Wolf, 1998) and, on scale, in the Scheldt Flume (WL, 1999 and Van Gent en Doorn, 2001). SWAN was then validated using (scaled) extreme conditions in the Scheldt Flume. This gave confidence that the model can also be applied for extreme conditions in 1-D situations. It is almost impossible to carry out laboratory measurements for 2-DH situations that cover an entire tidal inlet system. A model for a tidal inlet system requires a very large basin or a very small scale, so laboratory or scaling effects would overshadow the results. However, laboratory tests for partial aspects, such as diffraction, depth-limited breaking and surfbeat, are possible on a smaller spatial scale.

- Field measurements
  The wave model can also be validated for measured storms that most resemble extreme situations, such as a case of spring tide and a northwesterly storm with wind force 9 and higher. The comparison between measured storms and expected extreme situations can be made on the basis of dimensionless parameters. To do this, measurements must be made over a long period or existing foreign data must be used, such as that for hurricanes (see Chapter 4.3.4).

- Process knowledge
  If hindcasts show that the physical processes have been modelled with sufficient accuracy, this will also contribute towards the acceptance of the wave model under extreme conditions. For this it is sufficient to consider normal (storm) conditions. If the trend in the development of the wave parameters when the storm conditions intensify is logical – in other words, according to the understanding of the experts – then the wave model can be accepted for extreme conditions. This aspect of the acceptance is described in Chapter 4.3.2.

Just as there is extrapolation of the application of the wave model, there is also extrapolation of the assumptions concerning model input. This could include the assumptions related to the spatial and temporal variations in the wind, water level and current fields. The sensitivity of the results to variations in this model input has been detailed in the following chapter.

Failure mechanisms

The failure mechanisms are investigated in the SBW Failure Mechanisms subproject. It is important to the subproject SBW Boundary Conditions to know which wave parameters, such as which type of wave period, are used in these mechanisms so improvements to the wave model can also focus on them.

Activity

0.5 Wave parameter alignment between SBW-Failure Mechanisms and SBW-Boundary Conditions

The project leaders for SBW Failure Mechanisms and SBW Boundary Conditions should implement this alignment as soon as possible in 2006 to enable the acceptance of the wave model to focus on important parameters, such as the wave period. This could be set up in the form of a workshop with experts in the area of wave modelling and failure mechanisms under the direction of the Project Leaders for SBW Failure Mechanisms and SBW Boundary Conditions. The product of this workshop is an overview of linked wave parameters and load parameters, together with their dependence and their uncertainty margin. This section forms the basis of the acceptance criteria, as detailed in

Chapter 4.3.2. Results must be communicated back and forth during the implementation of activities within this subproject.

Properties of coastal structures

The strength is a major unknown factor that determines whether a structure will fail, or not. This aspect and in particular the residual strength and the strength of the inside (grass) slope was mentioned by several experts. This topic is picked up in the SBW Failure Mechanisms subproject. No further activities related to the analysis of the strength of the structures will be defined here.

4 Plan of action strategy as a basis for the wave boundary conditions in the Waddenzee

4.1 Introduction

The wave model in the HBC chain (Chapter 3) enables the transformation of offshore wave conditions to wave boundary conditions at the toe of the structure. The wave model is one of the greatest sources of uncertainty in this chain as is shown by the tender request and the opinions of the interviewees. As previously stated in the demarcation of this assignment (Section 1.3), the foundations of the wave boundary conditions in the Waddenzee focus on improving the quality of the wave model.

In this chapter we describe a Plan of Action that is designed to arrive at a wave model that can determine sufficiently accurate wave conditions for storm conditions and reliable wave conditions for extreme conditions in the Waddenzee. In addition, the emphasis is on wave conditions near the solid structures as the sea dikes in Friesland, Groningen and Noord-Holland, the IJsselmeer Dam and on the Waddenzee side of the islands[2]. The Plan of Action is built around a Stage Plan, which is comprised of a number of elements. An inventory has been made within these elements of the unknown issues, how they can or should be elaborated and with which priority to arrive at a wave model that can derive reliable wave conditions for the Waddenzee. The associated timetable should also be taken into consideration.

4.2 Stage Plan

The strategy that needs to be determined focuses on a Stage Plan for model predictions, measurement data, calibration and validation, and model improvement with the ultimate goal of determining a reliable wave model. A schematic representation of the Stage Plan is presented in Figure 2.

The following section deals in detail with the elements of the Stage Plan. A brief description is provided below of how it should be applied. The Stage Plan begins with a <u>wave model</u>. In the first instance, a <u>hindcast</u> will be carried out on the basis of existing measurement data and using the latest version of the model, which at the time of writing was SWAN 40.41AB (see http://fluidmechanics.tudelft.nl/swan). The new white-capping formulation has not yet been included in this version. If the <u>acceptance</u> shows that the wave boundary conditions are sufficiently accurate for storms, the model can be accepted for these conditions. The model then forms the input for the HR chain (Figure 1, top right). The process of accepting a wave model that is suitable for storms as a wave model that is suitable for more extreme conditions has yet to be made (see the previous chapter and Chapter 4.3.2).

[2] *As mentioned in Chapter 1.3, care should be taken here to ensure that choices made for the Waddenzee are not in conflict with choices made for other water systems.*

If the model cannot be accepted for storm conditions, then an analysis will have to be performed to determine the origin of the greatest uncertainties in the wave boundary conditions determination. Assuming the measurements have been carried out with sufficient accuracy, the cause must be sought in the model itself (physics, numerical aspects) or in the input for the model (the environmental conditions). The analysis can also show that sufficiently accurate wave boundary conditions can be obtained with only limited corrections to the wave parameters that have been determined. One of the results of the analysis could be that there is a lack of suitable measurement data and that it is necessary to carry out new field measurements. The new measurement data will be used together with existing measurement data, whether or not from the Waddenzee, in a new calibration and validation of the existing model. This study produces the model results with an optimum set of calibration coefficients, whereby the parameter uncertainties are also taken into account.

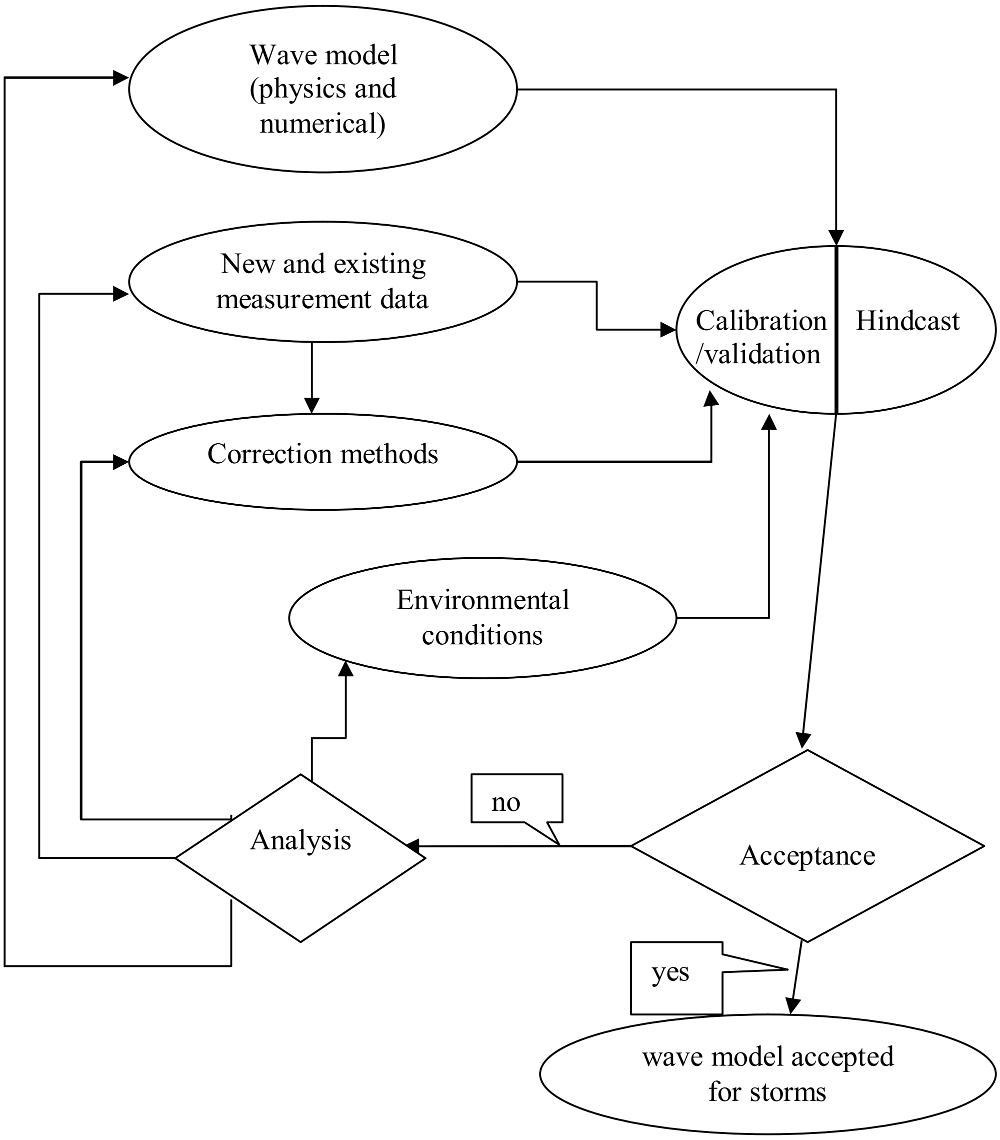

Figure 2: Schematic representation of the Stage Plan

In the Figure, the hindcasts and the calibration/validation are specified in the same element because they occur in the same place in the cycle. However, they do have different functions and are carried out at different times: the hindcasts are performed first and are intended to determine the reliability by using the limited, specific data set for storms. The calibration/validation takes place for the first time after the cycle has been performed once and is intended to adjust the free parameters on the basis of a much broader data set.

Wave boundary conditions can be released if the model results satisfy the acceptance test. If this is not the case, an analysis must be carried out to determine which following iteration step must be carried out to arrive at accurate wave boundary conditions.

The purpose of these steps is to arrive as efficiently as possible at a wave model that is suitable for the derivation of reliable wave boundary conditions along the coastal structures in the Waddenzee. It is not essential to complete all the elements, as long as the goal is achieved, namely reliable HBC at the coastal structures.

4.3 Detailing per element

The advantage of this diagram is that it shows the elements that must be considered in the medium term strategy, initially until 2011 and then to 2016. A consideration must be made per activity and element of its degree of importance to the final goal. Perfecting each of the elements or its constituent components, such as the perfect wave model or the perfect set of measurements, is not the goal of the strategy. With the ultimate goal in view, the analysis per element results in a prioritisation of the timetable for the essential activities that must be detailed for the first year.

The SWAN wave transformation model (Booij et al., 1999; Van der Westhuijsen et al., 2004) is currently the best operational model for determining wave conditions in areas the size of the Waddenzee under extreme conditions. It is unlikely that this will change before 2011. Other spectral models, such as ST-WAVE and Ref-Dif-S, are at best equal to SWAN, and time domain models that are based on Boussinesq equations or the non-linear, shallow-water equations require too much calculation work for an area the size of the Waddenzee. The models based on shallow-water equations also lack essential physics. In addition, SWAN is used along the rest of the Dutch coast. The Plan of Action is therefore based on SWAN as the applicable wave model. However, the above time domain models can be used for sub-areas and sub-processes.

A description is given of what must be carried out per element. This is information that can be included in a tender request. This Plan does not specify how it must be carried out; this is the task of the contractor.

4.3.1 Hindcast

The SWAN wave model must eventually be able to determine sufficiently reliable wave conditions near the coastal structures. To achieve this, there must be sufficient confidence in the physics. This will be achieved by carrying out hindcast studies under normal conditions and under storm conditions.

The accuracy of the model results cannot only be translated in terms of bias. Systematic errors can be extremely small, but if the uncertainty (dispersion) is large, the model results will be unreliable. This means that the degree of reliability or accuracy of the results must include an estimate of the model uncertainty.

Goal

The goal of this section is to increase confidence in the physical formulations in SWAN by using hindcast studies.

Description

The performance of the most recent SWAN version in the Waddenzee under normal conditions and under storm conditions must be determined using a number of hindcasts. Because it is not clear a priori how many hindcasts have to be carried out, it would be wise to set this up in a structured manner. Alkyon/WL (2002) developed a generic method for hindcasting-measured storms using SWAN. This method indicated which model input and model control should be used, the possible model uncertainties and how the model results can be quantified. This method has already been used in hindcast studies by Haskoning (2003) and WL/Alkyon (2003a).

As there are many processes that influence the wave conditions in the Waddenzee, we cannot limit ourselves to considering just a single data set. However, the available measurement data is scarce and as a result we shall for now consider the following data sets. The model can change during the process leading up to 2011. Additional hindcasts must be carried out to increase confidence in the model. The type of hindcasts this should be, will depend on the type of model adjustments.

The hindcasts should be properly calibrated runs to prevent differences between the measurement data and the model predictions being caused by the imperfect calibration of the wave model.

<u>Norderney data</u>
The first step towards determining the precise reasons for the mediocre performance of the model in the Waddenzee is to carry out a hindcast on the Norderney data (see Kaiser en Niemeyer, 2001), preceded by a model calibration using a subset of the data. If available, the calibration instrument described in section 4.3.8. can be used. We expect the old formulation of white-capping to be one of the most important sources of the underestimation of swell penetration by SWAN. This can be investigated by repeating the hindcast using a version of the SWAN model that has improved wave-breaking formulation (Van der Westhuysen et al., 2005).

<u>Amelander tidal inlet data</u>
In addition to the hindcast using Norderney data, a hindcast must be performed using SWAN on the storms that were measured recently in the Amelander tidal inlet (RIKZ, 2004; Svasek, 2005). The most landward-located buoy is actually located in a channel and not in the coastal structures or on the tidal flats. On the basis of a number of validation runs, it should be determined whether the calibration parameters that were derived from the Norderney case are suitable for the calculations for the Amelander tidal inlet.

Existing data on wave penetration (over banks) up to the coastal structures

The Amelander tidal inlet data does not contain any measurement data and the Norderneyer tidal inlet data contains only a limited amount of measurement data (SBW-Veldmetingen Internationaal, 2006, personal communication J. Dekker) close to the coastal structures, however wave boundary conditions must be produced for this area. It would therefore appear important to gather additional measurement data close to the coastal structures. However, this would not be useful as even during storm situations these locations can on occasion remain dry. It is perhaps better to select a location on the lower tidal flats and to pretend this is where the coastal structures are located. An additional hindcast must be carried out to determine the performance of SWAN in relation to swell penetration over shallow forelands such as banks. The first step is to make an inventory of the appropriate measurement data, such as the Westerschelde, the IJsselmeer Dam or a foreign tidal basin (activity 4.2.). This must be followed by the actual implementation of this hindcast.

Activities

1.1 Setting up a generic instrument to carry out hindcast studies

The initial study by Alkyon/WL (2002) and its application by Haskoning (2003) and WL/Alkyon (2003a) can be used for this. The details of this must be further elaborated to make it suitable for all the hindcasts that must be carried out.

1.2 Setting up and calibrating a model to carry out hindcasts for the Norderney and Amelander tidal inlets

If the calculation is performed in stationary mode, the points in time must be chosen during the storm. As not every physical process has the same degree of effect at every moment during the storm, multiple times during the storm should be considered and not solely the peak. This will enable different physical processes to be validated within the duration of the storm (see recommendations from the International Review Team, 2005). A representative set of times must be chosen for the Norderney data, which can then be used to calibrate the model for Norderney. This set of calibration parameters should be validated before the hindcast is performed on the storms in the Amerlander tidal inlet.

1.3 Inventory of additional measurement data for wave propagation over shallow banks

This data inventory must be related to relevant domestic data, such as the Westerschelde data from RWS and recently NIOO/WL, as well as foreign data. This activity can be placed under Activity 4.2.

1.4 Setting up models for additional hindcasts

To be able to hindcast the (storm) data, models must be set up for the data in the inventory of 1.3 and for the measurement data acquired during the project.

1.5 Performance of hindcasts

1.6 Analysis of hindcasts

This activity concerns the analysis of the subset, as described above. (The hindcast on a larger set is described in Activity 3.3.) To take a first step towards improving the model, a thorough analysis must be performed of the possible causes of any differences found after the measured and calculated wave parameters have been compared.

Prioritisation and timetable

The results of the first hindcasts will provide an understanding of the current state of affairs and provide direction for the subsequent strategy. These activities therefore have a high priority. Hindcast studies should be carried out throughout the entire process to increase confidence in the model. Table 2 presents the timetable, which includes a specification for each activity of the dependence within this element. The activities for 2006 are divided into "pre summer", which is therefore high priority, and "post summer".

	Activity	dep.	2006		2007	2008	2009
1.1	Set up generic hindcast instruments						
1.2	Set up, calibrate and validate Amld/Nrdney						
1.3	Inventory of measuring data for shallow banks						
1.4	Model setup for additional hindcasts	1.3					
1.5	Performance of hindcasts, including Amld/Nrdney	1.2, 1.4					
1.6	Analysis of hindcasts, including Amld/Nrdney	1.5					

Table 2: Timetable for hindcasts. NB: The dependence of 1.5 on 1.4 is only applicable for additional hindcasts

4.3.2 Acceptance criteria

Model results will be produced by the hindcasts or the calibration and validation stage, possibly including a newly determined, optimised set of calibration coefficients. These results will either satisfy the acceptance criteria or not. These acceptance criteria have not yet been specified.

The acceptance criteria that have yet to be set up include both quantitative (objective) and qualitative (subjective) aspects. The quantitative component is that the wave model must be able to produce sufficiently accurate wave parameters, with yet to be determined tolerance limits, to be able to determine the loading on the coastal structures in terms of aspects such as rock stability and wave overtopping. This means that we calculate backwards from the loading side to the wave model. A consideration of the storm conditions is sufficient for this component.

The qualitative component is that there is sufficient technical confidence in the results produced by SWAN: all the relevant physics is sufficiently well modelled and the trends in the results correspond with expectations based on physical knowledge. In addition to technical confidence, there must also be political and operational confidence: it must be possible to explain the results and they must be sufficiently well founded to justify possible major infrastructure interventions. The qualitative component is primarily of importance for scaling up the acceptance of the wave model for storms to acceptance for extreme conditions (see previous chapter).

Goal

To arrive at widely supported criteria on the basis of which model results would be accepted as wave boundary conditions for the coastal structures.

Description

The activities that must be carried out can be defined as follows:

2.1 Quantitative acceptance criteria
Inventory of the effect of uncertainty margins in the wave parameters on the loading of coastal structures and the conversion back from the tolerance margins in the loading to the requirements for uncertainty margins in the wave parameters. This section must be carried out in close consultation with the Failure Mechanisms subproject, where the conversion of wave parameters to load is made.

2.2 Qualitative acceptance criteria
Inventory in cooperation with policymakers, dike administrators and ENW (formerly TAW) to determine the qualitative acceptance limit for the wave model.

2.3 Development of a method to determine the uncertainty in the results produced by SWAN
It is the goal of this activity to provide confidence bands around the deterministic results from SWAN. These bands must be comprised of the cumulative uncertainty from SWAN on the basis of the individual sensitivities to input data and calibration parameters. One method of doing this is via adjoint modelling, in which not the quantity such as wave height is propagated in the model, but instead the error in the quantity. An adjoint was made for SWAN by Walker (2001). Alternatives include first order approximation via model linearisation and Markov Chain Monte Carlo. A well considered choice should be made, depending on the exact wishes and possibilities.

If improvement or correction in the iterative stage plan no longer leads to further improvement in the wave boundary conditions at the coastal structures and the imposed acceptance criteria have not yet been satisfied, then a fall-back option must be defined.

2.4 Determine fall-back option for determining boundary conditions
A number of possibilities can be considered when determining a fall-back option:
- Use the results acquired so far and provide them with uncertainty margins.
- Use the local water level (fixed H/d ratio) to help determine the wave height at the coastal structures.
- Calculate the wave parameters using simpler 1-D models along particular routes.
- Apply correction methods (see Section 4.3.6.).
- Use combinations of these.

Prioritisation and timetable

To know which model results are acceptable and which are not, an inventory and implementation of the acceptance criteria must be carried out in the short term. The activities for the “acceptance” element are therefore concentrated in 2006 (see Table 3) and have a high priority.

	Activity	2006	2007	2008	2009
2.1	Quantitative acceptance criteria				
2.2	Qualitative acceptance criteria				
2.3	Develop an uncertainty determination method				
2.4	Determine a fall-back option				

Table 3: Timetable for acceptance activities

4.3.3 Analysis

If the model results cannot yet be accepted, an analysis will have to be made to determine the primary cause of the lack of accuracy in the model predictions. The model results can be improved in different ways (see Figure 2):

- Improve the physics and the numerical implementation in the model.
- Increase the accuracy of the environmental conditions (input and wave boundary conditions).
- Apply the correction methods (see Chapter 4.3.5.).

The analysis step therefore includes a choice, which is why it is presented as a diamond in Figure 2.

Goal

Use analyses of hindcast studies and studies that have already been carried out into the shortcomings in SWAN to determine where and how the model predictions can be improved.

Description

It requires specialised knowledge to study the possible shortcomings in SWAN related to the wave boundary conditions in the Waddenzee. Various shortcomings in SWAN have been revealed in previous studies, such as WL/Alkyon, 2002; WL/Alkyon, 2003b. These have been summarised in Alkyon (2005) insofar as they apply to the Netherlands inland waterways. However, these physical and numeric shortcomings also apply to the Waddenzee, in particular the wind input modelling. However, wave penetration, surfbeat (generation of long waves), wave-current interaction (including the 3D effect of current on waves) and wave-induced setup also play a role in the Waddenzee. The environmental conditions (bathymetry, wind, water level, current, bed roughness and wave boundary conditions) are also a source of error. Of these environmental conditions, the bathymetry has an important effect on the wave conditions in the shallower parts of the Waddenzee and in particular for the defence structures. The transformation of wind statistics that have been measured at a number of locations on land, into spatial and temporal wind fields on open water is a source of error in the local sea growth. The spatial and temporal variations in current and water level also play a role, but to a lesser degree. The temporal and spatial variations in wind in particular, are a reason for carrying out instationary calculations.

As the analysis is very specific, we can only outline the activities that have to be carried out to determine how model predictions with increased accuracy can be obtained.

3.1 Sensitivity analysis of numeric aspects

Qualitatively better wave boundary conditions can be obtained not only through improved physics but also through better model schematisation that focuses on inland seas such as the Waddenzee. This could include:

- Schematisation of the grid, resulting in instructions:
  - Curvilinear versus rectilinear, nested or non-nested: A critical consideration is required of the curvilinear grids in current use that were designed for current calculations.
  - Geographic resolution: studies into the grid resolution required because of variations in the bathymetric profiles, geometry, and water level, current and wind fields. An extended analysis was provided by Witteveen and Bos (2004).
  - Spectral resolution: studies into the effect of the choice of resolution in directional space and frequency space, as well as cut-off frequencies and spectral tail. This has not yet been carried out. There are some indications of model sensitivity to these settings (projects in Hamma, Algeria and Dubai, VAE, personal communication J. Dekker).

  The derivation of instructions to arrive at a grid that is suitable for the implementation of accurate SWAN results in general and the Waddenzee in particular.
- Convergence behaviour:
  Consideration of the convergence speed and in particular the convergence criterion (see Van der Westhuijsen et al., 2004) that could lead to a non-converging solution. The convergence behaviour has always been a thorny issue and should therefore been closely scrutinised.
- Discretisations in geographic and spectral space:
  Witteveen and Bos (2004) carried out a comprehensive analysis of discretisations errors on a regularly nested grid. A study should be performed to determine whether these errors are comparable on a curvilinear grid. However, an additional analysis into the discretisations errors in spectral space is also desirable but is perhaps of lesser importance.

3.2 Accurate analysis of hindcast results

You should be aware of the complete or partial lack of physical processes in SWAN, such as a mechanism to generate long waves:

- Detailed comparison of measured and calculated wave conditions in different storm stages, not necessarily heavy.
- Analysis of spatial distributions of calculated wave parameters, as well as calculated 1D and 2D spectra over a number of wisely chosen cross sections, such as a cross section through the throat of a tidal inlet around an island to the rear of the island, a cross section through the throat of the tidal channel to the mainland and a cross section via the throat of a shallow bank to the mainland, as proposed by WL (2002b) and endorsed by the International Review Team

(2003). This involves a form of path control. However to be able to implement this, points must be measured along the paths (see Chapter 4.3.4).

This hindcast is supplementary to the initial hindcasts that were discussed in Activity 1.6.

3.3 Sensitivity analysis of physics and environmental conditions on wave conditions near coastal structures for the prioritisation of the different processes

Sensitivity studies have already been carried out in previous studies. For example, WL/Alkyon (2003b) determined that the greatest effect on wave conditions is caused by bottom friction across the entire domain, shallow water bathymetry and depth-induced breaking near the coastal structures. However, in relation to aspects such as wind input, it will hardly be possible to model depth induced breaking more accurately. This is why WL/Alkyon (2003b) prioritised the processes and environmental conditions that not only have a large effect on wave conditions near the coastal structures but also for which improvement is required and possible. This prioritisation is specified in Table 4, together with the models that were used to investigate the influence of the processes, or can be investigated in this activity. For the most part, the SWAN model was used. Results from the sensitivity studies should be supplemented with additional sensitivity studies in which consideration is given to the effect of the missing physics in SWAN. This could be carried out with the assistance of other numeric models. The Ref/Dif model can be used to study the effects of refraction and diffraction around island heads. There is no mechanism in SWAN for the generation of long waves that result of non-linear interaction. Delft3D-Surfbeat can be applied to the generation of long waves through variations in the wave field on the wave group scale. Finally, Delft-FLS is suitable for determining the swell penetration, for a comparison of results using the new white-capping formulation in SWAN, and the breaking of long waves on the banks.

Process	Study model
Bathymetry	SWAN
Bottom friction	SWAN
Wind input	SWAN
Long wave generation	Delft3D-Surfbeat / laboratory
Quadruplet interaction	SWAN
Depth breaking	SWAN
White-capping	SWAN (supplemented by Delft-FLS)
Effect of current on waves	WAQUA / Delft3D linked with SWAN
Refraction	RefDif / Delft-FLS

Table 4: Prioritisation of processes and environmental conditions in the Waddenzee that are eligible for improvement with respect to wave conditions near coastal structures (source: WL/Alkyon, 2003b)

3.4 Scenario calculations for instationary calculation

The sizes and complexity of the Waddenzee means that the environmental conditions of wave boundary conditions, water levels and wind are not stationary in time or uniform in space. A study must therefore be carried out to determine whether instationary calculation can improve the model results. An understanding of this can be obtained by performing a comparison of stationary and instationary SWAN model results for a storm scenario, using measured storms as a benchmark. However to perform proper instationary calculations, more information is required than is currently available, in particular in the area of the spatial and temporal distribution of wind fields. This should be further investigated within this activity, for example in consultation with KNMI.

Prioritisation and timetable

The sensitivity analyses must first be carried out to determine the proper prioritisation of the approach to physics and the numeric aspects in the model and the model input. We should also note that the model must be numerically in order and calibrated hindcasts should be carried out before improving the physics in the model. The analysis of different hindcasts will take place continuously during the entire process (see Table 5).

	Activity	2006		2007	2008	2009
3.1	Sensitivity analysis of numeric aspects					
3.2	Analysis hindcasts					
3.3	Sensitivity analysis of physics and model input					
3.4	Scenario calculations for instationary calculation					

Table 5: Timetable for analysis of activities

4.3.4 New and existing measurement data

Good measurement data is essential for the validation, calibration and improvement of the wave model. This data is facilitatory, in part to the verification process of obtaining sufficiently accurate environmental conditions, and in part to the validation of wave boundary conditions. In the development process, it is important to include a maximum of existing data and data that is relevant to the Waddenzee.

Goal

To make an inventory of relevant, available measurement data and determine the need for measurement data for the verification of processes in the wave model and the validation of results obtained using the wave model.

Description

The purpose of any measurements should be clear before carrying out an inventory into the suitability of the measurements and/or initiating new measurements. The activities can be defined as follows:

4.1 Determine the purpose of the measurements
The need for measurements is an important activity that must be dealt with as a priority. This question must be answered jointly by the SBW Field Measurements and the SBW Boundary Conditions for the Natural Environment subprojects. This could

be done in the form of a workshop with experts in the areas of wave modelling and field measurements, in the same form as Activity 0.5. If the goal of the measurements is to build the statistics of wave conditions, then the measurements must be made using different instruments, at different locations and for a longer duration than when it involves the verification of the processes to obtain a better physical model or to derive correction factors. For the former issue, the total duration available for the measurement of data until 2011 is too short to be able to perform a reliable extrapolation to extreme conditions. Measurements will certainly have to be continued beyond 2011. The International Review Team (2003) has already indicated that it is difficult to take process measurements in the field and that measurements should better be taken using different regimes. This corresponds with the proposal from WL (2002b) to measure along three routes: along a cross section through the throat of a tidal inlet around an island to the back of the island, along a cross section through the throat of the tidal channel to the mainland and along a cross section via the throat over a shallow bank to the mainland. It is possible to isolate physical aspects by examining different periods of time during a storm (see Activity 1.2).

4.2 Inventory of existing measurement data that is relevant to the Waddenzee or current measurement campaigns in the laboratory or the field

As soon as a determination has been made in 4.1 with respect to which measurements must be made, an inventory can be made of existing measurement data, and its quality and suitability can be assessed. Wave data is available form a number of measurement campaigns, obtained both in the Netherlands (Westerschelde, Petten, Amelander tidal inlet, IJsselmeer, Slotermeer) and abroad (including Norderney, Sleeswijk-Holstein, Denmark, Gulf van Tehuantepec in Mexico, Tai-Hu lake in China and various coastal locations in the US and Australia). In the case of the US and Australia, it could include data obtained during hurricanes or typhoons, from tidal inlet systems and from oil rigs in shallow water. The foreign data in particular must be assessed on its merits for the determination of wave boundary conditions in the Waddenzee. From a brief consideration, it appears that the principle omission is a measuring route over a bank to the coastal structures. This indicates a need to acquire this data in the Waddenzee.

4.3 Initiating new measurement programmes

The need to perform new measurements can be concluded from the results of Activities 4.1 and 4.2. The conditions for measurement locations in the Waddenzee have already been detailed during different studies, in particular three reports about what, where and how to measure: WL (2002b), Hoekstra and Hoitink (2002) and Stelwagen (2002). An initial monitoring network has already been placed in the Amelander tidal inlet on the basis of this literature. The first measurements have been described in RIKZ (2004) and Svasek (2005). On the basis of the need for measurements to improve the wave model, work will have to continue throughout the entire process to set up the measurement programme. The abovementioned three reports also dealt with the conditions for these measurements in detail.

As already mentioned, there is currently a lack of measurement data near to coastal structures in the Waddenzee in the Netherlands. However, it would not appear useful to perform these field measurements at the toe of the structure because even during storm situations these locations (at +2.0m N.A.P.) can occasionally remain dry. It is perhaps better to select a location on the lower tidal flats (at for example +0.5 m N.A.P.) and to pretend this is where the coastal structures are located, or to perform laboratory measurements.

The actual organisation of the measurement campaign is part of the SBW Field Measurements subproject. Despite this, the following aspects must be considered in close consultation with SBW Boundary Conditions for the Natural Environment:

- Which quantities must be measured?
- For the validation of the wave model, which required boundary conditions must be acquired simultaneously using a different method?
- Which measuring instruments must be applied for the process that must be measured? What is the required duration and accuracy of the measurements?
- What is the required duration of the measuring campaign?
- How must the data be processed and stored?

4.4 Increasing the statistical reliability of Waddenzee data

To prevent the short duration of the measurement period from resulting in data that is insufficiently reliable for the validation of the wave boundary conditions, we may well have to search for methods of obtaining reliable estimates. This could include things such as model simulations, laboratory tests for extreme conditions and measurement data from other areas.

Prioritisation and timetable

An inventory of the measurement goal on the one hand and existing measurement data on the other, should be carried out as quickly as possible to be able to perform the hindcasts and sensitivity analyses. The increase in the statistical reliability does not have to be carried out in the short term. The timetable is presented in Table 6.

	Activity	dep.	2006	2007	2008	2009
4.1	Determine measurement goal					
4.2	Inventory of existing measurement data					
4.3	Initiate new measurement campaigns	4.1				
4.4	Increase statistical reliability					

Table 6: Timetable for measurement data activities

4.3.5 Correction methods

The long circuit to obtain better wave boundary conditions proceeds via model improvements. This is perhaps not always necessary and sufficiently accurate values for the wave boundary conditions in the Waddenzee can be achieved by applying correction methods. However, one disadvantage of this approach is that it is not clear beforehand whether this will lead to qualitative acceptance for extreme conditions. After all, there is still the question of whether there is sufficient confidence in the SWAN wave model that is used. Another disadvantage is that additional measurements will have to be made to be able to determine the correction methods. For these reasons, it would be most obvious to first try to improve essential aspects of SWAN and only at a later stage to determine correction methods (personal communication C. Israel, RIKZ), and then only in cases of absolute necessity.

In fact the correction will be related to the missing processes in SWAN. Correction methods can only correct systematic errors ("bias") and not the dispersion of the results. To reduce the latter, it still remains necessary to improve the model or environmental conditions.

4.3.6 Environmental conditions

To calculate the wave transformation, SWAN requires input, which is called "environmental conditions" here. This involves:

- Bathymetry and topography (above and below water).
- Wind fields.
- Water levels.
- Currents driven by wave, wind and tide.
- Offshore wave boundary conditions obtained using other coarser grained models or extrapolated measurement data.
- Bed roughness.

The specified environmental conditions influence the accuracy of the wave conditions near to the coastal structures. The scale of these effects can also be concluded from the sensitivity analysis in Section 4.3.3. The input is based on measured data from a number of measurement locations, if necessary scaled up using extreme values analysis. To serve as input for SWAN, this local information must be converted to global information. In this section we focus on the specified conversion and we consider the measurements that were obtained via the SBW Field Measurements subproject as the starting point.

Goal

To acquire sufficiently accurate SWAN input from local measurement data to obtain accurate wave predictions near the coastal structures.

Description

Bathymetry

Bathymetric (under water) and topographic (above water) data has been gathered on a relatively fine mesh grid using depth soundings, laser altimeter measurements from aircrafts and GPS measurements from a vehicle. As far as this is concerned, the spatial aspect of the bathymetry is better known than the other environmental conditions, which are only known at certain locations. It is a policy decision that the current bathymetry is used and that for the tests no account has to be taken of long-term morphological changes. However, the measured bathymetry has an inherent inaccuracy and is subject to change. Roughly three time scales can be distinguished: bathymetry changes over a number of years, between measurement moments and during a storm. These last two changes must be included.

6.1 Effect of bathymetry changes during storms

Conclusions can be drawn about the effect of bathymetry changes that occur during a storm on the basis of the sensitivity analysis performed in respect of the bathymetry in Section 4.3.3. The extent of the bathymetry changes must be known to be able to determine this. This can be determined using measurements before and after a storm or morphological studies using an advanced model such as Delft3. However, this has not often been applied to morphological studies in the inner area of the Waddenzee, but it has been for tidal inlets and in the Westerschelde.

Wind

Wind data is only acquired at a number of locations on land. The point measurements must first be extrapolated via extreme values statistics to normative wind conditions before they can be used in production runs. At a given level of probability, this extrapolation currently produces higher wind speeds at inland locations than for coastal locations. The reason for this is the “curvature” in the point cloud (RIZA, 2003). These point statistics must then be converted to spatial wind fields about which little is currently known, in particular when it concerns the spatial patterns of a depression that is associated with an extreme value. In addition to the conversion from point to field, the transition from land to water (roughness differences), and the wind drag formulation (C_d value) are not well understood. There is no univocal wind model currently available that can be used to perform this (personal communication, De Waal, RIZA). The improved wind drag modelling, the transition from wind to water, is a model improvement to SWAN (see next section). All these elements contribute towards inaccuracies in the wind field, which causes inaccuracies in the local wave growth. This local wave growth is particularly important for the western Waddenzee.

6.2 Development of a wind model

The model that is to be developed will be able to convert wind data in a limited number of locations to a wind field, while taking into account the abovementioned aspects that occur in a complex area such as the Waddenzee. A comprehensive study by RIZA (2003) could serve as a starting point. However, this method is based on interpolation at the meso level. The KNMI advises interpolation at the macro level.

Current

The existing current models such as WAQUA and Delft3D-Flow enable us to determine the current and water level at an apparently sufficiently accurate manner. However, there is a difference between the behaviour of currents during storm conditions and during extreme conditions. During storm conditions the current is lead through the tidal inlets via the channels and maintains a more or less north-south direction. However, under extreme conditions during high tide the Waddenzee appears to fill from the Marsdiep thereby creating a west-east current (Alkyon, 2001). In the latter case, the dominant sea waves are at right angles to the current direction, which will reduce the effect of the current on waves. However, this report only examined one condition and this type of scenario will have to be further investigated in the future. The effect of 3D current, in particular depth-dependence ones, on the wave field will have to be investigated because SWAN currently does not take into account a depth-averaged current.

6.3 Use numeric model studies to determine the extent to which the current during storm situations differs from that during extreme situations

This study could be performed on the basis of extreme storm scenarios in cooperation with the KNMI and on the basis of Alkyon (2001).

6.4 Investigate the effect on wave propagation of vertical variation in the current patterns

This study could be performed using model studies with SWAN in combination with Delft3D for the specific case of the Waddenzee. This issue also plays a role in other foreign estuaries for which Delft3D was used.

Water level

The water level during extreme conditions is currently obtained from the extrapolation of water level measurements at coastal stations. These measurements contain both the effect of the tide and the wind swell, which results in a certain degree of “data contamination”. Recent studies by Van Den Brink from the KNMI (personal communication C. Israel, RIKZ) have shown that scenarios with extreme wind conditions and depressions cause much higher water levels than are obtained from the extrapolation of measurements.

In the SWAN calculations, the water level determined using measurements is accepted uniformly throughout space. As the measurements have been made at the coast, the water levels at these locations are “good” but the water levels at offshore locations are overestimated because the wind swell effect there is lower that at the coast. This effect will be small before the Holland coast, but it is precisely in the Waddenzee that the effects of a slightly lower water level at the outer delta and on the banks will not be negligible, which would be favourable to the HBC.

6.5 Studying the effect of non-uniform water levels

Instead of applying uniform water level fields on the basis of measurements, a water level model such as WAQUA or Delft3D could be used to sound out the sensitivity of the HBC to variation.

Prioritisation and timetable

Because in all probability both the bathymetry and the wind have a major effect on the accuracy of the wave conditions in the Waddenzee in general and near the coastal structures in particular, it is important to initiate the early development of an accurate determination of wind fields and to obtain timely knowledge of the effect of bathymetry changes. We propose that these activities should be carried out in 2006 and 2007 (see Table 7). Determining the difference between storm conditions and extreme conditions can be investigated at a later stage because these problems are less important than the other activities and because performing studies in parallel that build on each other can result in alignment problems.

	Activity	2006	2007	2008	2009
6.1	Determine effect of bathymetry changes				
6.2	Develop wind model				
6.3	Current differences of storm versus extreme				
6.4	Investigate effect of current profiles				
6.5	Studying the effect of non-uniform water levels				

Table 7: Timetable for environmental condition activities

4.3.7 Wave model

Complex processes play an important role in complex systems such as the Waddenzee. These include wave-current interaction, non-linear wave-wave interaction, diffraction and refraction. Kaiser en Niemeyer (2001) also demonstrated that SWAN produces unreliable results for the area around Norderney, an area that is comparable to the tidal basins in the Dutch Waddenzee. The imperfect swell penetration was regarded as the major culprit. As described earlier in this Plan, this validation must be repeated using the latest version of the model.

Goal

The modification and addition of essential physics and numeric aspects in SWAN to obtain accurate wave predictions near the coastal structures using this modified model.

Description

The analyses of hindcasts (Activity 1.6) and further analyses (Activity 3.3) could show that improvement is required in the model physics. This could include the following processes:

- Wind-generated waves.
- Wave-wave interaction.
- Wave-current interaction.
- Wave breaking and bottom friction.
- Refraction and diffraction.

These processes have already been modelled in SWAN but could be improved if is shown that the environmental conditions of wind, water level, currents and bathymetry have a small or large influence. If the wind proves to be important, the wind formulation in SWAN must be modified, in particular for extreme conditions. There are indications (Makin, KNMI) that the wind drag coefficient reduces with increasing wind velocity: the wave crests are blown off and the increasing wind has less of a “grip” on the waves. If the bathymetry proves to be important, then the processes that are dependent on the bottom level (friction, breaking) must be dealt with. If the current has a major effect in extreme scenarios, then the wave-current interaction term in SWAN must be reformulated, such as on the basis of Dingemans, 1997, p. 86/87.

The generation of low-frequency energy, whether bound or not, is not modelled in SWAN, but it can play a role in an area like the Waddenzee. This low-frequency energy can be calculated by another model, in addition to SWAN, or be added to SWAN parametrically on the basis of model calculations.

The shortcomings of SWAN that were observed in previous studies and insofar as they are related to the Dutch inland waters, have been summarised in Alkyon (2005). These shortcomings also apply to the Waddenzee. Wave penetration, surfbeat (generation of long waves), wave-current interaction and wave-induced setup also play a role in the Waddenzee.

A role is also played by numeric aspects such as discretisations, convergence behaviour and the choice of grid. A comprehensive description of possible physical and numeric model shortcomings has been given in Alkyon (2005).

It is not possible to specify in advance which activities have to be carried out to realise model improvements. To do this hindcast studies and further analysis must first determine the primary weaknesses of the model (see Section 4.3.1). However, the following activity can certainly be carried out:

7.1 Inventory of ongoing model improvements
Make an inventory of ongoing model improvements and determine their relevance for SBW HBC: Map out the ongoing model improvements that are currently being implemented or which must be worked on in the future, such as TU, NRL-Stennis and RIKZ.

Prioritisation and timetable

To prioritise the components that have to be improved, it is important to first draw up an inventory of the ongoing developments. Activity 7.1 should therefore be carried out in the short term (autumn 2006). The improvement of the wave model will probably not take place in 2006, but instead from 2007 to 2009, whereby it is not unthinkable that the model improvements will not be fully implemented for the determination of the HBC in 2011. The SBW project must therefore produce a state-of-the-art product by 2009 at the latest, in terms of the best model that can be used with confidence, to enable the calculations to be carried out to determine this HBC during the HR2011 project. In a worst case scenario, this product could be one of the fall-back options (Activity 2.4). It is quite possible that activities will be continuing in 2009 that cannot be completed in time for use in the HBC2011. These activities will continue after 2009 and contribute towards the product that can be used for the HBC2016. Subsequent HBC projects will therefore use increasingly improved models.

4.3.8 Calibration and validation

Modifications in the model could make it necessary for the calibration constants to be determined anew. These parameters must be adjusted anew on the basis of a suitable dataset. A supplementary part of the dataset will then be used to validate the modified model.

Goal

The goal of this component is to calibrate and validate the SWAN model after modifications in the formulations of existing processes or after the addition of new physical processes, such as better wave-current formulations or better wind input terms.

Description

The following activities are expected to be necessary to satisfy the above objective:

- Develop calibration instrument.
- Develop validation instrument (test bank).
- Perform calibration and validation.

The first two activities can be carried out in parallel.

Develop calibration instrument

If a modification is introduced into SWAN, a number of calibration parameters will have to be readjusted that occur in physical formulations for aspects such as wind-driving, dissipation and non-linear interaction. A sensitivity study such as that performed by Alkyon (2003) will indicate how these could be carried out for SWAN. In addition, a set of parameters has been determined by comparing the iteration behaviour, scatter plots of integral wave parameters and 1D model results, with measurements during storm conditions at relevant locations before the Dutch coast and Dutch inland waters. This was also carried out for extreme conditions on the basis of laboratory tests. Ruessink (2005) recently developed an automated search algorithm to determine calibration coefficients. There are many different calibration methods, but only a few main groups. Each method has is strong and its weak points. A literature study, supplemented by a feasibility study, should clarify this situation.

The following activities have been provided for the development of the calibration instrument:

8.1 Definition of a set of Operational Requirements
The wishes and requirements must be defined to which the calibration instrument must comply. The sensitivity study by Alkyon (2003) provides sufficient starting points for this. An understanding of the error area, such as wide plateaus or deep valleys, in SWAN is important to be able to determine the extent to which certain requirements are realistic. It should be noted that a calibration must not focus solely on minimising the bias in the model results. An estimate of the parameter uncertainty, and with this the model uncertainty, is at least as important. As stated in section 4.3.2, there are a wide range of methods for estimating the uncertainty, such as adjoint modelling, first order method and Markov Chain Monte Carlo.

8.2 Literature study and feasibility study into the applicability of different calibration methods as a calibration instrument for SWAN
A literature study should be used to gain an understanding of the available calibration methods. A study should be carried out on the methods that appear most suitable, to

determine how feasible it would be to use them as calibration instruments for SWAN. The Operation Requirements determined in Activity 8.1 is determinant in this. The methods of Ruessink (2005) en Alkyon (2003) are examples. The Arcadia tool that was developed by Nico Booij for Hiswa may even be suitable. However this is more labour intensive.

8.3 Setting up the calibration instrument

8.4 Operationalisation of the calibration instrument

Development of a validation instrument (test bank)

The validation instrument is a tool that can be used to validate new versions of the wave model. It includes a database containing metadata of field measurements, laboratory measurements and analytical solutions, modules to link a new version of the wave model to entities such as grids and boundary conditions, to run the model, generate output at specific locations and for specific wave parameters and to perform statistical comparisons using a selection of the datasets. The storm data that must be subjected to hindcasts is part of the database, as is the data that must be used by the calibration instrument (see below). The validation instrument is an extension to the test banks that have been developed so far.

In the past, test banks have been developed to facilitate model validation. The effect of a model modification can be investigated efficiently using a test bank, if the appropriate test cases are included in the test bank. The SWAN Testbank (2000) and the ONR Testbed (2002) were set up for this purpose. However, these test banks are slightly dated (Kieftenburg, 2004a, 2004b). These reports specify the flexibility of a test bank as an important requirement. It should be easy to add a test case (link to hindcast instrument), there should be simple access to the data, it should be possible to view a cross section of the data (analysis tool), and it should be easy to change the settings for the model input and model executables (link to calibration instrument). This section will continue to build on the insights obtained by Kieftenburg (2004a, 2004b).

A properly set-up validation instrument is particularly useful for the good implementation of the Stage Plan. This activity should therefore be initiated by SBW in cooperation with HBC. This instrument will ultimately be transferred to HBC and become the responsibility of HBC B&O (*Beheer en onderhoud*: Management and maintenance).

The following activities must be carried out to arrive at a manageable and maintainable test bank:

8.5 Defining the Operational Requirements and dynamic test bank structure

First, the details must be elaborated of the wishes and requirements for the test bank. This must then be processed into a set of Operational Requirements in respect of possible and necessary information for the test cases, model input and output, output units and locations, visualisation of the model output and statistical operations. The requirements will be elaborated into a structure for a dynamic system in which all the desired operations can be carried out. It should also be determined to which extent modules of the SWAN Testbank (2000) and the ONR Testbed (2002) can be used. Consideration should also be given to the organisation of the UCIT package (software for combining controlling parameters, data and morphological models) that was developed by WL | Delft Hydraulics and the hindcast tool WIS that was set up by CHL (Coastal Hydraulic Laboratory, Vicksburg, MS, USA).

8.6 Extension and modification of test cases
The test case must contain both general and problem-specific (for the Waddenzee) test cases. The general test cases are related to the processes that are already contained in SWAN for general situations, such as wave growth curves. These test cases are often already contained in the current test banks. The problem-specific test cases are related to the different physical process and environmental conditions that are relevant to the Waddenzee, such as wave-current interaction, the penetration of long waves in combination with local wind growth, propagation across shallow bank and the generation of long waves.

8.7 Setting up a test bank
The structure of the test bank that was elaborated in 8.5 must be implemented. The test cases must be added. The statistical operations must be integrated and the visualisation of wave data and statistical data must be implemented.

8.8 Operationalisation of the test bank
Test and validate all the facilities of the test bank.

8.9 Selection of test cases
Implementation of a routine that can be used to consider a subset of all the tests, for analytical purposes. This feature is already present for a part in the RIKZ test bank, but requires updating.

8.10 Bilateral links to the calibration instrument
Data must be read from the validation instrument database that is used for the calibration. It must also be possible for the new set of parameters that were obtained using the calibration instrument to be read back into the validation instrument. This must make it possible to carry out a validation or analysis of partial aspects of a user-specified set of test cases.

Perform calibration and validation

After the calibration and validation instruments have been developed and operationalised, it can also be put into actual operation on modified versions of the SWAN model. The following activities have been provided for this:

8.11 Selection of test cases in the test bank for calibration
Existing or new (combinations of) functionality can be calibrated using this selection. This must clearly characterise the process (what), the location (where) and the conditions (when).

8.12 Performance of actual calibration using the calibration instrument

8.13 Selection of test cases in the test bank for validation
The validation must be carried out on the basis of this selection. This must examine both general test cases for the entire model performance and problem-specific test cases for the performance of new or improved functionality.

8.14 Performance of validation using a test bank

Prioritisation and timetable

The prioritisation instrument and the test bank enable an effective and efficient approach to the entire project. The calibration and validation of SWAN takes place throughout the entire project because these activities are part of the cycle defined in the Stage Plan (Figure 2). It is possible to develop a calibration instrument and a test bank in parallel, but the activities are of such a size that they will have to be spread over two years. In addition, these activities will only be initiated if the hindcast studies (Section 4.3.1), which are preceded by the calibration and validation of the wave model using a less advanced method than that described in this section, shows that model improvement is actually required. Table 8 presents the timetable, which includes a specification for each activity of the activity upon which it is dependent. In itself, a validation instrument is also useful for the performance of hindcasts in the second round.

	Activity	dep.	2006		2007	2008	2009
8.1	Define a set of Operational Requirements for calibration instrument						
8.2	Literature and Feasibility study	8.1					
8.3	Set up calibration instrument	8.1-8.2					
8.4	Operationalise calibration instrument	8.3					
8.5	Set up Operational Requirements and test bank structure						
8.6	Extend and modify test cases						
8.7	Set up test bank	8.5-8.6					
8.8	Operationalise test bank	8.7					
8.9	Select test cases	8.8					
8.10	Link calibration instrument	8.4					
8.11	Select calibration test case	8.3-8.4					
8.12	Perform calibration	8.11					
8.13	Select validation test cases	8.8-8.9					
8.14	Perform validation	8.13					

Table 8: Timetable of calibration and validation activities

4.4 Quality assurance

This Plan of Action includes a large number of activities, that must sometimes be carried out in parallel and sometimes sequentially, with interfaces to other SBW subprojects and other projects within RWS, such as HBC. It goes without saying that this process and the products must be subject to good quality assurance. The internal quality assurance must take place at the level of the SBW project team (main project leaders and subproject leaders). This procedure should be elaborated in their respective Project Plans and is not part of this Plan of Action. The external quality assurance of this Plan of Action, the Project Plans and the results from each stage in the abovementioned cycle must be carried out by the existing Hydraulic Review Team. We recommend that the core of this Team assess the subprojects, whereby experts may need to be added for each subproject.

5 Summary and activities in 2006

This Plan of Action investigates which activities are required to be able to arrive at a better wave model for the Waddenzee in 2011, to be able to produce more reliable wave boundary conditions and Hydraulic Boundary Conditions. This investigation is carried using available literature and in particular through interviews with over twenty experts (see Table 1).

This plan was set up from the HBC chain, which describes the steps from deep water measurements to testing coastal structures, as described in Chapter 3 and schematically represented in Figure 1. The wave model, which is used to calculate the transformation of wave data from deep water to near the coastal structures, is an essential part of this. Any improvements must focus on aspects that improve the boundary conditions at the coastal structures, and not necessarily a general improvement of the entire wave model. The process of improving this wave model is presented schematically in the Stage Plan (Figure 2). This cycle contains the following elements:

- Hindcasts of storms (elaborated in Section 4.3.1)
- Acceptance criteria (4.3.2)
- Analysis (4.3.3)
- Measurement data (4.3.4)
- Correction methods (4.3.5)
- Environmental conditions (4.3.6)
- Wave model (4.3.7)
- Calibration and validation (4.3.8)

The activities and the sequence in which they must be carried out are detailed per element. For this summary, these tables are reproduced again below and include the activities that must be started as a priority.

	Activity	2006		2007	2008	2009
0.1	Perform uncertainty analysis					
0.2	Research physical boundaries of extreme values					
0.3	Determine confidence bands for extreme values					
0.4	Formulate Operational Requirements to “Standardisation of Hydra modules”					
0.5	Align wave parameters					

1.1	**Set up generic instruments for hindcasts**					
1.2	Set up model for Amelander tidal inlet and Norderney					
1.3	Inventory of measuring data for shallow banks					
1.4	Set up model for additional hindcasts					
1.5	Perform hindcasts, including Amld/Nrdney					
1.6	Analyse hindcasts, including Amld/Nrdney					

	Activity	2006		2007	2008	2009
2.1	Quantitative acceptance criteria					
2.2	Qualitative acceptance criteria					
2.3	Develop an uncertainty determination method					
2.4	Determine a fall-back option					

3.1	**Sensitivity analysis of numeric aspects**					
3.2	Analysis hindcasts					
3.3	Sensitivity analysis of physics and model input					
3.4	Scenario calculations for instationary calculation					

4.1	**Determine measurement goal**					
4.2	Inventory of existing measurement data					
4.3	Initiate new measurement campaigns					
4.4	Increase statistical reliability					

5.1	**Develop correction methods**				
5.2	Determine correction factors				

6.1	**Determine effect of bathymetry changes**					
6.2	Develop wind model					
6.3	Current differences of storm versus extreme					
6.4	Investigate effect of current profiles					
6.5	Studying the effect of non-uniform water levels					

7.1	**Inventory of ongoing research**					

8.1	**Define a set of Operational Requirements for calibration instrument**					
8.2	Literature and Feasibility study					
8.3	Set up calibration instrument					
8.4	Operationalise calibration instrument					
8.5	Set up Operational Requirements and test bank structure					
8.6	Extend and modify test cases					
8.7	Set up test bank					
8.8	Operationalise test bank					
8.9	Select test cases					
8.10	Link calibration instrument					
8.11	Select calibration test case					
8.12	Perform calibration					
8.13	Select validation test cases					
8.14	Perform validation					

Table 9: Overview of Activities.

The activities that must be carried out during the next six months are described again below:

0.1 Perform uncertainty analysis

This must be performed as soon as possible. For this, we recommend using the prioritisation instrument that will be completed in July 2006 in combination with an expert panel. If it is not completed before this time, the best alternative would be to perform the study using an expert panel. This uncertainty analysis must be supplemented by performing a risk analysis in which an inventory is made of the critical steps and scenarios are specified if certain goals prove to be unattainable. The details of this risk analysis should be completed in the SBW (Boundary Conditions for the Natural Environment) Project Plan.

0.5 Wave parameter alignment between SBW Failure Mechanisms and SBW Boundary Conditions for the Natural Environment

The project leaders for SBW Failure Mechanisms and SBW Boundary Conditions for the Natural Environment should implement this alignment as soon as possible in 2006 to enable the acceptance of the wave model to focus on important parameters, such as the type of period. This could be set up in the form of a workshop with experts in the area of wave modelling and failure mechanisms under the direction of the Project Leaders for SBW Failure Mechanisms and SBW Boundary Conditions for the Natural Environment. The product of this workshop is an overview of linked wave parameters and load parameters, together with their dependence and their uncertainty margin. This section forms the basis of the acceptance criteria, as detailed in Chapter 4.3.2. Results must be communicated back and forth during the implementation of activities within this subproject.

1.1 Setting up a generic instrument to carry out hindcast studies

The initial study by Alkyon/WL (2002) and its application by Haskoning (2003) and WL/Alkyon (2003a) can be used for this. The details of this must be further elaborated to make it suitable for all the hindcasts that must be carried out.

1.2 Setting up a model to carry out hindcasts for the Norderney and Amelander tidal inlets

If the calculation is performed in stationary mode, the points in time must be chosen during the storm. As not every physical process has the same degree of effect at every moment during the storm, multiple times during the storm should be considered and not solely the peak. This will enable different physical processes to be validated within the duration of the storm (see recommendations from the International Review Team, 2005).

1.3 Inventory of additional measurement data for wave propagation over shallow banks

This data inventory must be related to relevant domestic data, such as the Westerschelde data from RWS and recently NIOO/WL, as well as foreign data. This activity can be placed under Activity 4.2.

1.5 Performance of hindcasts

2.1 Quantitative acceptance criteria

Inventory of the effect of uncertainty margins in the wave parameters on the loading of coastal structures and the conversion back from the tolerance margins in the loading to the requirements for uncertainty margins in the wave parameters. This section must be carried out in close consultation with the Failure Mechanisms subproject, where the conversion of wave parameters to load is made.

2.2 Qualitative acceptance criteria

Inventory in cooperation with policymakers, dike administrators and ENW (formerly TAW) to determine the qualitative acceptance limit for the wave model.

4.1 Determine the purpose of the measurements

The need for measurements is an important activity that must be dealt with as a priority. This question must be answered jointly by the SBW Field Measurements and the SBW Boundary Conditions for the Natural Environment subprojects. This could be done in the form of a workshop with experts in the areas of wave modelling and field measurements, in the same form as Activity 0.4. If the goal of the measurements is to build the statistics of wave conditions, then the measurements must be made using different instruments, at different locations and for a longer duration than when it involves the verification of the processes to obtain a better physical model or to derive correction factors. For the former issue, the total duration available for the measurement of data until 2011 is too short to be able to perform a reliable extrapolation to extreme conditions. Measurements will certainly have to be continued beyond 2011. The International Review Team (2003) has already indicated that it is difficult to take process measurements in the field and that measurements should better be taken using different regimes. This corresponds with the proposal from WL (2002b) to measure along three routes: along a cross section through the throat of a tidal inlet around an island to the back of the island, along a cross section through the throat of the tidal channel to the mainland and along a cross section via the throat over a shallow bank to the mainland. It is possible to isolate physical aspects by examining different periods of time during a storm (see Activity 1.2).

4.2 Inventory of existing measurement data that is relevant to the Waddenzee and current measurement campaigns in the laboratory or the field

As soon as a determination has been made in 4.1 with respect to which measurements must be made, an inventory can be made of existing measurement data, and its quality and suitability can be assessed. Wave data is available form a number of measurement campaigns, obtained both in the Netherlands (Westerschelde, Petten, Amelander tidal inlet, IJsselmeer, Slotermeer) and abroad (including Norderney, Sleeswijk-Holstein, Denmark, Gulf van Tehuantepec in Mexico, Tai-Hu lake in China and various coastal locations in the US and Australia). In the case of the US and Australia, it could include data obtained during hurricanes or typhoons, from tidal inlet systems and from oil rigs in shallow water. The foreign data in particular must be assessed on its merits for the determination of wave boundary conditions in the Waddenzee. From a brief consideration, it appears that the principle omission is a measuring route over a bank to the coastal structures. This indicates a need to acquire this data in the Waddenzee.

6.2 Development of a wind model

The model that is to be developed will be able to convert wind data in a limited number of locations to a wind field, while taking into account the abovementioned aspects that occur in a complex area such as the Waddenzee. A comprehensive study by RIZA (2003) could serve as a starting point. However, this method is based on interpolation at the meso level. The KNMI advises interpolation at the macro level.

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