

Synthesis of SBW Belastingen

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Summary

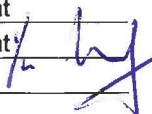
The Dutch Water Act (in Dutch: 'Waterwet 2009') stipulates that water boards must assess the quality of their primary water defences every six years. The Statutory Safety Assessment Suite (in Dutch: 'Wettelijk Toetsinstrumentarium', or shortly WTI) prescribes the rules to be applied. The WTI mainly comprises of the Safety Test Regulations (VTV), the Hydraulic Boundary Conditions (HBC) and the underlying Technical Reports and Guidelines. The HBC must be determined and established by the Minister of Transport, Public Works and Water Management every six years.

The scope of the SBW-Belastingen project concerns the filling in of the main knowledge gaps in the determination of the HBC, insofar as they fall under one of the four pillars of SBW-Belastingen: statistics, physics, probabilistics, uncertainty analysis. This new knowledge is obtained by means of site measurements, laboratory research, models and desk studies. A significant amount of research, covering all four pillars of SBW-Belastingen, has been performed in the period 2008-2010.

This synthesis report summarises the main results from the research performed within the framework of SBW-Belastingen during the years 2008-2010. The report will give a general overview of all research topics addressed before the start of SBW-Belastingen as well as a more detailed description of the progress: conclusions and recommendations of the research topics addressed within the framework of SBW-Belastingen in the period 2008-2011. The result of this synthesis is a statement of the performed research so far and a recommendation for research to be performed in the period 2011-2016.

References

Projectplan SBW-Belastingen 2010. Deltares Report 1202120-000-HYE-0001, A.J. van der Westhuysen. February 2010 (in Dutch)

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1 Introduction

1.1 Framework

The Dutch Water Act (in Dutch: 'Waterwet 2009') stipulates that water boards must assess the quality of their primary water defences every six years. The Statutory Safety Assessment Suite (in Dutch: 'Wettelijk Toetsinstrumentarium', or shortly WTI) prescribes the rules to be applied. The WTI mainly comprises of the Safety Test Regulations (VTV), the Hydraulic Boundary Conditions (HBC) and the underlying Technical Reports and Guidelines. The HBC must be determined and subsequently approved by the Minister of Infrastructure and Environment every six years.

When testing the water defences, dike managers are often confronted with a lack of knowledge. This lack of knowledge sometimes leads to an assessment "no judgement" due to the fact that essential information and process knowledge for a safety assessment process is not available. This may lead to a 'no judgement' assessment result, which is socially and politically undesirable. It may also lead to flood defences being wrongly approved or rejected. Such situations are also undesirable. A lack of practical knowledge is often connected with the restrictions in the area of application, or the accuracy of the HBC available or the assessment calculation rules. By filling in the knowledge gaps, the assessment tools are expanded and improved. As such, the objective of the SBW (Strength and Loading of Water Defences, in Dutch: 'Sterkte en Belastingen Waterkeringen') programme has been defined as follows:

Filling in the most important knowledge gaps in order to obtain a better estimate of the safety against flooding of the primary flood defences.

The SBW programme focuses on filling in the most important knowledge gaps in order to be able to better assess the safety of the primary water defences. This filling of the knowledge gaps should lead to a reduction of the percentage of water defences assessed "no judgement" or "insufficient". SBW provides system knowledge, expertise and instruments for, among other things, the WTI project (formerly known as HBC&VTV). SBW aims at the year 2011, but also at subsequent safety assessment rounds.

The overall SBW programme 2006-2010 comprised of nine projects, seven of which focused on strength aspects and two on hydraulic loads. One of those is the SBW-Waddenzee project, which in 2006 was the first SBW project to commence. During this project, the quality of the models and methods is established and improved, if necessary, making it possible to issue improved HBC for the Wadden Sea region in 2011 and beyond. The primary focus was on the wave model, as this was one of the chain's first weak points to be identified in 2006. An uncertainty analysis confirmed this (Deltares, 2009n) and also demonstrated that certain aspects such as water levels and wind, both in terms of statistics and spatial coherence, play an important role in the uncertainty in the HBC.

1.2 The SBW-Belastingen project

Whereas SBW-Waddenzee focused on the Wadden Sea, and the (establishment of new) HBC of 2011 in particular, the SBW-Belastingen project went beyond that. In principle, all freshwater and saltwater systems are included, and a research programme is set up on the basis of an inventory of knowledge gaps (Deltares, 2009a). The programme focused on the

HBC of all primary water defences. The time horizon of SBW-Belastingen reached beyond 2011 and focused on establishment of new HBC in 2016.

The objective of the SBW-Belastingen project was:

To fill in the main knowledge gaps in the field of hydraulic loads, making it possible to issue improved HBC for the Dutch primary water defences in 2016 and, if possible 2011.

The reduction of knowledge gaps will lead to new insights, theories or information. Were SBW to end there, we would still be without practical applicable methods or techniques that are robust and validated. SBW must develop these methods or techniques and, if applicable, implement it in an existing or a new model (= second step), for the WTI project to apply this. For these applications, WTI will provide up-to-date information for the model schematisation and other required input. This is shown in Figure 1.1. As long as improvements of models arise from knowledge gained, it forms part of SBW. However, improving model schematizations on the basis of existing knowledge does not necessarily fall within the scope of SBW, but should (partially) be addressed in projects such as Atlantis, B&O Hydra and WTI (see Appendix A for list of abbreviations).

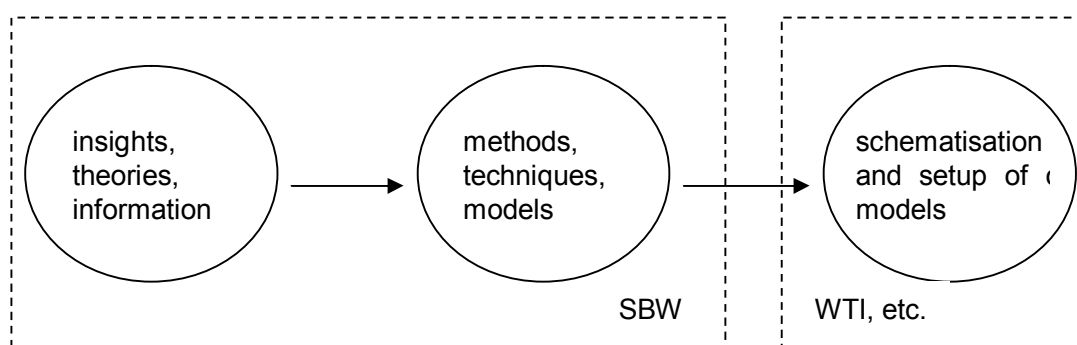


Figure 1.1 Diagram of SBW and WTI field (and other projects such as Atlantis, B&O Hydra)

The 2008 SBW Programme Plan (Deltares, 2007) laid the foundations for the SBW programme and the way in which the programme is incorporated in the management contract. The Programme Plan gives a brief description of the background, objectives and activities of SBW-Belastingen before 2008. As a part of the activities for SBW-Belastingen 2008, an Action Plan (Deltares, 2009a) has been prepared for the entire SBW-Belastingen project (and follow-ups), covering the period to 2011 and beyond. The Action Plan, in turn, forms the basis for the preparation of the 2008, 2009 and 2010 project plans (Deltares, 2008b, Deltares, 2009k and Deltares, 2010k) and those of subsequent years. New developments may subsequently give rise to adjustments to the Action Plan, which should thus be regarded as a living document.

1.3 Setup of the SBW-Belastingen project

The SBW-Belastingen project aimed to improve the determination of the HBC. Figure 1.2 is a diagram of the existing determination of the HBC. Statistics on waves, wind and water levels form the input for the probabilistic calculation methods that determine the critical wave conditions and water levels at the toe of the sea defence (primary dikes, damming structures and connecting primary defences, with the exception of dunes). In the translation of statistical

data into useable information near the sea defence, simulation models for waves, wind and water levels (such as SWAN, WAQUA) are used. A probabilistic model is used to determine the loading on the water defence for all combinations of hydraulic conditions. This loading is then compared to the results of the strength model. For all conditions on which the water defence scores a near-fail, the probabilistic shell determines the combination of normative variables that are most likely to occur. This combination is referred to as the illustration point of the HBC. In e.g. the lower-river areas the probabilistic model is also used as an assessment tool. This means that the probabilistic model does more than determining the illustration point alone.

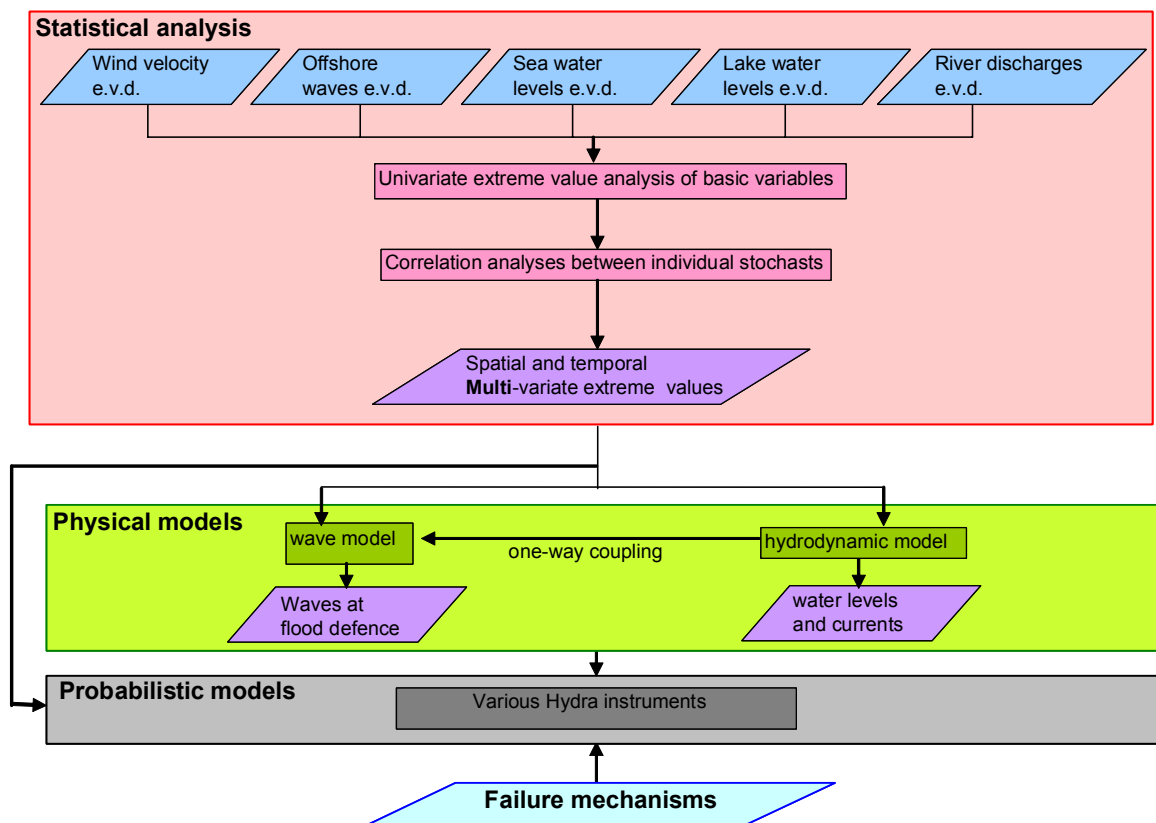


Figure 1.2 Diagram of probabilistic model used to determine HBC

In order to be able to determine the HBC, three pillars can be distinguished in Figure 1.2:

- 1 Statistical methods
- 2 Probabilistic models
- 3 Modelling of physics (wind, waves and water levels)

The topic of *uncertainty analysis* is added as a fourth pillar, in order to assess the degree of uncertainty in the investigated models and methods, and how this uncertainty is reduced during the course of the project. The details of the Action Plan (Deltares, 2009a) are derived from these four pillars.

1.4 Scope of the SBW-Belastingen project

The scope of the SBW-Belastingen project concerns the filling in of the main knowledge gaps in the determination of the HBC, insofar as they fall under one of the four aforementioned pillars. We must make two asides: firstly, the primary objective of SBW is not the improvement of the model schematisation used for HBC as such, but the improvement or development of the knowledge and the translation into methods and techniques in order to realise improved HBC. SBW does not stop at generating missing knowledge. Making this knowledge applicable is inextricably bound up with the development thereof, and can therefore not be allocated to a different project, such as WTI, but must be addressed within SBW too. The intended knowledge can be obtained by means of site measurements, laboratory research, models and desk studies.

Secondly, aspects that do not fall under said pillars fall outside the scope of SBW-Belastingen. In determining the HBC, the bathymetry plays an important role. In the present tools, the bathymetry information is taken as a starting point, and its dynamic character is not considered to be a part of the scope of work of SBW-Belastingen. This means that mapping out the effects of (changes to) the bathymetry on the hydrodynamic loading on water defences is regarded as an integral part of SBW-Belastingen, but that the underlying morphological aspects that are needed in order to determine the (changes to the) bathymetry fall outside the scope of the SBW-Belastingen. The same applies to failure mechanisms. They are taken as a starting point in the 'probabilistic' pillar. The development of expertise in order to improve failure mechanisms takes place in other SBW projects (SBW-Duinen and SBW-Reststerkte for respectively dunes and residual strength of primary sea defences), not in SBW-Belastingen.

1.5 Objective of this report

The objective of this synthesis report is to summarise the main results from research performed within the framework of SBW-Belastingen during the years 2008-2010. The report will give a general overview of all research topics as well as a more detailed description, conclusions and recommendations of the research topics. The result of this synthesis is a statement of the performed research and the recommended research for the period 2011-2016.

1.6 Outline of this report

This report is set-up as follows: Chapter 2 describes the identification and clustering of knowledge gaps. It includes an overview of the knowledge gaps identified during the start of the SBW-Belastingen project and a prioritisation of these knowledge gaps.

Chapter 3 presents an overview of actions and results from the SBW-Belastingen project for the period 2008-2010. The chapter also includes an overview of transferred knowledge to methods within SBW-Belastingen or schematisation and model setup within WTI (see arrows in Figure 1.1). Chapters 4, 5 and 6 present a more detailed description of the activities and results for respectively the short-, mid- and long-term activities. For each knowledge gap a summary of the results is presented as well as (if possible) the implication of the results for SBW-Belastingen. Chapter 7 presents an overview of the recommended activities for the SBW-Belastingen 2011-2016, taking the gained insight of SBW-Belastingen 2008-2010 into account.

2 Identification of knowledge gaps and research themes

2.1 Introduction

The primary aim of the SBW programme is to resolve knowledge gaps and sources of major uncertainty in the HBC. First, as part of the development of the Action Plan for SBW-Belastingen (Deltares, 2009a), an overview of uncertainties and knowledge gaps is created based on (i) available literature, (ii) requirements/actions of WTI (Deltares, 2008a) and (iii) an uncertainty analysis of the hydra-models as performed within the framework of SBW-Belastingen (Deltares, 2009n). The resulting overview is clustered based on the pillars introduced in section 1.3. With the uncertainty analysis added to this, we make a distinction between the four following research themes:

1. Statistical methods
2. Probabilistic models (load models and calculation techniques)
3. Modelling of physics (hydrodynamics, wind, waves)
4. Uncertainty analysis and dealing with uncertainty analysis

This chapter briefly describes the knowledge gaps and sources of major uncertainty as found during the preparation of the SBW-Belastingen Action Plan (Deltares, 2009a).

A number of aspects which are mentioned in underlying documents may be addressed in other projects. We only mention the aspects that fall within the scope of the SBW-Belastingen project.

2.2 Identification and clustering of knowledge gaps

Deltares (2009a) presents the knowledge gaps following from the investigation of the literature. The general impression from the literature review is that there is a broad diversity in the approach and applied methods/models. The established bottlenecks and knowledge gaps and further knowledge requirements relate to all elements in the chain for the HBC determination (Figure 1.2). The type and extend of the knowledge gaps do however vary strongly per element of the chain and per water system.

Taking all this into consideration and listing all points, the theme classification as presented in section 2.1 covers all knowledge gaps. The knowledge gaps are therefore clustered into the mentioned research themes (section 2.1). In addition, the knowledge gaps are categorised into short-, mid- and longterm activities, partly based on their urgency for WTI in 2011. The categorisation is based on a combination of the uncertainty analysis presented in Deltares (2009n) and criteria for prioritisation presented in Haskoning (2007). Table 2.1 presents the resulting clustering and categorisation. The references to the knowledge gaps elaborated further in the sections 4, 5 and 6 are given between brackets. Deltares (2009a) presents a detailed background of this table.

Theme	Short-term	Medium-term	Long-term
Extreme Value Statistics	Storm (surge) duration (KG1a)	Considerations of statistical distributions (KG3c)	Integration of physics (KG4a)
	Inventory of currently used methods (KG3a)	Alternative methods (KG3d)	Integration of model data (KG5a)
	Vrijling method (KG3b)	Guidelines EVA ¹ basis variables (KG3e)	
Probabilistic models		Time/space scale problems (KG6a)	New safety approach (KG9a-c)
		HBC suite for Eastern Scheldt (KG7a)	
		Reliability functions for other failure mechanisms (KG8a)	
Modelling of Physics – Wind	Point Statistics (KG10a)	Conversion point statistics to field information (KG10b)	Transfer to field information using model data (KG10d)
		Collection and analysis of measurement data (KG10c)	Further analyses of bottlenecks and solution directions (KG10d)
		Standardisation and improvement of wind drag modelling (KG11a-b)	
Modelling of Physics – Hydrodynamics	Analysis of seiches (KG12a)	Wave-induced motion (KG13a)	Seiches modelling (KG12b-c)
	Evaluation of hydrodynamic modelling (KG14a)		Further research into hydrodynamic modelling (KG14b)
Modelling of Physics – Waves	Verification of SWAN model (KG15ai, 16a)	Effects of bed changes (KG15b)	Analysis and validation of relevant wave aspects (KG15aii-iv)
		Analysis wave measurements / model prediction Lake IJssel (KG16b)	
		Wave models on rivers (KG17a)	

1. EVA = Extreme Value Analysis

Modelling of Physics – Coupled models			Development and validation of model train
Uncertainty analysis	Workshop dealing with uncertainties		Quantitative uncertainty analyses
Feedback to vision	Further analysis quality aspects and translation into criteria		
	Viability test and verifying implications for technical activities		

Table 2.1 Overview of activities per research theme, separated in short-, medium- and long-term duration activities (taken from Deltares, 2009a)

3 Overview of progression SBW-Belastingen 2008-2010

3.1 Introduction

A large number of research studies have been performed within the SBW-Belastingen project in the period 2008-2010. The research studies followed from an analysis of knowledge gaps and an uncertainty analysis (Deltares, 2009a). The studies aimed at contributing to the solution of the knowledge gaps and reducing the uncertainties. In order to determine the progress of the SBW-Belastingen project, an overview of knowledge gaps and corresponding research studies is required. This chapter presents an overview of the knowledge gaps and performed research studies for the period 2008-2010 sorted by short-, mid- and longterm activities.

The objective of the SBW-Belastingen project is to fill the most important knowledge gaps and to reduce uncertainties in the Hydraulic Boundary Conditions (see Chapter 1). The performed activities should thus (partly) fill the associated knowledge gap. In addition, the activity should, if possible, provide insight in (and possibly reduce) the contribution of the knowledge gap to the uncertainty in the design water level or crest height.

As a part of the preparation of the Action Plan for SBW-Belastingen, a qualitative uncertainty analysis has been carried out. This analysis resulted in an overview of the uncertainties and an estimate of the magnitude of these uncertainties², see Appendix C of Deltares (2009n). Amongst other aspects, the presented uncertainties are used for the prioritisation of the knowledge gaps. As part of a verification of these qualitative uncertainties, these uncertainties are (if possible) compared with the newly established uncertainties following from the research performed within SBW-Belastingen. This information is presented within tables (Table 3.2, Table 3.4 and Table 3.6) consisting of the following seven columns:

- 1 Knowledge gap identification number as used in Deltares (2009a).
- 2 Title of the knowledge gap.
- 3 Expected effect on HBC according to Deltares (2009n).
- 4 Whether or not the activity is completed.
- 5 Effect of the activity (in metres) on the design water level or crest height (if possible).
- 6 Remaining uncertainty (in metres) on the design water level or crest height due to the investigated knowledge gap. The uncertainty before SBW-Belastingen (if available) is presented between brackets.
- 7 Immediate recommendations or follow-up actions for SBW-Belastingen.

3.2 Short term activities

Deltares (2009a) identified seven knowledge gaps (resulting in 10 activities) that needed to be addressed on short term. Table 3.1 shows the short-term knowledge gaps identified in Deltares (2009a), the action taken within SBW-Belastingen 2008-2010 and a brief description of the result. A detailed description of the activities and results is presented in Chapter 4.

2. The magnitude of the uncertainties is defined as the uncertainty in metres on the design water level or crest elevation

Table 3.1 shows that nine out of the twelve short term knowledge gaps are (partly) addressed. Most of the activities already have results, which are described in detail in sections 4.1 to 4.12.

KG	Description	Action undertaken	Result
1a	Storm (surge) duration Section (4.1)	Statistical analysis of storm (surge) durations for locations within lower-river area.	Newly derived statistics on storm (surge) duration.
3a	Inventory of currently used statistical methods (section 4.2)	The presently applied methods are investigated.	Main observation is that the methods vary strongly between water systems. There does not appear to be a sound justification for the applied methods.
3b	Vrijling method (section 4.3)	Investigate feasibility, reliability and applicability of Vrijling Method as an alternative for method De Haan for the probabilistic approach for coasts.	Feasibility and reliability haven been investigated. Practical applicability has not yet been investigated. Present probabilistic approach within Hydra-K will possibly be abandoned in order to be able to facilitate time domain. Since the Vrijling method does not include time domain, the Vrijling method will, for the time being, not investigated further.
10a	Point statistics wind (section 4.4)	Update the individual steps resulting in extreme (point) wind statistics	Newly derived exposure correction factors leading to adjusted time series of potential wind speeds. New extreme wind statistics are derived from the adjusted potential wind speeds.
12a	Analysis of seiches (section 4.5)	Evaluation of present seiche allowances and (if possible) to update the allowances for the harbour areas.	Analysis of methods and measurements showed that there is no short term solution presently available. Additional analyses are carried out within the framework of WTI. The latter resulted in new seiche allowances.
14a	Evaluation of hydrodynamic modelling Section (4.6)	no action yet	-
15ai	Verification of SWAN model "Open coast" (section 4.7)	Verification of the SWAN model for the inlet of the Eastern Scheldt and Western Scheldt by means of hindcasts.	A verification study for the Western Scheldt has been performed. Based on the results of this verification study, an additional study into wave-current interaction has been performed. The inlet of the Eastern Scheldt is included in calibration SWAN (WTI): The performance of SWAN in the entrance of the Eastern Scheldt does not differ significantly in

			performance from ebb-tidal deltas in the Wadden Sea.
16a	Verification of SWAN model "Lakes" (section 4.8)	Verification of the SWAN model for Lake IJssel	The SWAN model has been verified for Lake IJssel by means of a calibration and validation study (including amongst others cases for Lake IJssel).
-	workshop dealing with uncertainties (section 4.9)	Organisation of workshop on uncertainties: held at October 8 th , 2009	Main conclusions: (i) improve the interface between HBC and VTV and (ii) publish available research on uncertainties. The latter has been initiated.
-	qualitative uncertainty analysis (section 4.10)	Perform a qualitative uncertainty analysis on the HBC chain (Hydra programs)	Analysis is performed and translated to knowledge gaps or transferred to alternate programs (e.g. GRADE, WTI or TOI)
-	Further analysis quality aspects and translation into criteria (section 4.11)	no action yet	-
-	Viability test and verifying implications for technical activities (section 4.12)	no action yet	-

Table 3.1 Activities and results for short term knowledge gaps during SBW-Belastingen period 2008-2010

Table 3.2 presents the results of the short-term activities on the HBC itself as well as the resulting change in uncertainty (or gain in insight of uncertainty if no previous information was available). Please note that '-' in Table 3.2 means that the activity did not (yet) provide any information regarding a change of the HBC or uncertainty in HBC.

The table shows that activities for knowledge gaps 1a, 10a and 12a have led to additional knowledge which has been transferred to the Hydraulic Boundary Conditions. The effect of the obtained knowledge on the Hydraulic Boundary Conditions (HBC) is investigated and the remaining uncertainty due to the investigated knowledge gap has been assessed.

An example:

The activities for the knowledge gap regarding storm (surge) duration led to a (limited) increase of the Hydraulic Boundary Conditions with a maximum of 0.25 metres compared to the previous values. Before the start of the activity, the uncertainty in the HBC due to uncertainty in the storm (surge) duration was unknown. After completion of the activities for KG1a, the uncertainty was determined to be 0.02 metres. Thus, In this case, the research led to a trade of between offset and uncertainty in the HBC.

Table 3.2 also shows immediate follow-up activities for a number of knowledge gaps. For example, the workshop "Dealing with uncertainties" has led to the construction of a Wikipedia presenting the available research on uncertainties.

By observing the large amount of '-' in Table 3.2, the general conclusion that can be drawn for the short-term knowledge gaps is that most of them are being addressed (according to the left and middle part of Figure 1.1), but that the transfer to the HBC (right part of Figure 1.1) still needs some attention. This holds especially for the knowledge gaps regarding the SWAN model: the verification studies have been performed, but the translation towards the HBC still needs attention (and possibly additional research).

		Action plan	Result of/for SBW-Belastingen			
KG	Description	Effect (ΔHBC)	Completed	ΔHBC³	σHBC³	Recommendation/ follow-up activities
1a	Storm (surge) duration	10 cm	yes	Max. +0.25	0.02 (-)	-
3a	Inventory of current statistical methods	unknown	yes	-	-	-
3b	Vrijling method	unknown	no	-	-	-
10a	Point statistics wind	several dm	yes	0.00	3.0 (3.3)	-
12a	Analysis of seiches	20 cm	yes	-0.25	0.2 (>0.4)	-
14a	Evaluation of hydrodynamic modelling	several dm	no	-	-	-
15ai	Verification of SWAN model "Open Coast"	several dm	partly	-	-	Investigate uncertainties in model input and verify for Eastern Scheldt and Holland Coast
16a	Verification of SWAN model "Lakes"	several dm	partly	-	-	Determine effect on HBC and corresponding uncertainty
-	workshop dealing with uncertainties	NA	yes	-	-	Set-up a Wikipedia ⁴ with existing research on uncertainties (presently in preparation).
-	qualitative uncertainty analysis	NA	yes	-	-	-
-	Further analysis quality aspects and translation into criteria	NA	no	-	-	-
-	Viability test and verifying implications for technical activities	NA	no	-	-	-

Table 3.2 Progression short-term activities SBW-Belastingen 2008-2010

3. HBC= Design water level or required crest height

4. At the time of writing of this report, it is not yet clear whether the Wikipedia will be publicly accessible due to confidentiality of the included documents.

3.3 Mid term activities

Similar to the short term activities, Table 3.3 presents the actions and results for the mid-term activities. Six mid-term actions are already executed and finalised, two mid-term actions are partly finalised and five mid-term actions have not started yet. A detailed description of the activities and results is presented in sections 5.1 to 5.13.

KG	Description	Action undertaken	Result
3c	Considerations of statistical distributions (section 5.1)	Different approaches for determination of extreme values have been evaluated (e.g. AM/GEV and POT/GPD). In addition, procedures for choosing a threshold for POT analysis are evaluated.	It is concluded that the best approach is a Peak over Threshold in combination with a Generalised Pareto Distribution. The fit should be based on a Weighted Moments (PWM) method. A formal procedure for determining the threshold in a POT analysis is investigated. It is concluded that a formal procedure should be applied for samples with less than 20 years of data, whilst the ad hoc procedure can be used for samples with more than 20 years of data.
3d	Alternative methods (section 5.2)	Investigation of alternative methods: a) Conditional and multivariate extreme value analysis, b) Bayesian statistics; for the analysis of extreme values, c) Regional frequency analysis, d) Use of covariates, e) Tail of extreme wave distributions and f) Applicability of RFA for wave periods	The alternative methods have been investigated and recommendations have been made regarding application of these methods. RFA can be applied within the HBC chain, but should be based on time series resulting from a more sophisticated wave model than applied for NEXTRA.
3e	Guidelines EVA basis variables (section 5.3)	no action	-
6a	Time/space scale problems (section 5.4)	Investigate time and spatial variability of stochastic variables, especially in estuaries and Wadden Sea. Experts are asked to present suggestions for including time and space scales in the probabilistic models.	The analysis of storms in the Wadden Sea resulted in a definition of a standard model for time dependency of wind speed and direction in the Wadden Sea. A preliminary correlation analysis did not reveal pronounced correlations. Expert provided suggestions for implementation of time and space scales
7a	HBC suite for Eastern Scheldt (section 5.5)	no action	-

8a	Reliability functions for other failure mechanisms (section 5.6)	Investigate the application of alternate reliability function within Hydra-K (different failure mechanisms)	A preliminary study has been performed on methods to include additional failure mechanism in Hydra-K. A recommendation is made regarding a uniform short term measure to avoid irregular failure domains for all water systems.
10b	Wind modelling: Conversion point wind statistics to field information (section 5.7)	Improvement and standardisation of conversion of point statistics to space dependent wind fields as well as an overall assessment of the quality of the applied wind fields for HR2011.	Present approaches are not always reproducible, but approaches to approximate them are proposed. No available alternative approaches are identified that are better and still practically applicable. It is recommended to use the reproduced approaches for the re-calculation of the Hydraulic Boundary Conditions. The overall quality assessment of the WTI wind fields for HR2011 showed that the applied wind fields are in the lower limit of values obtained by different approaches.
10c	Collection and analysis of measurement data (section 5.8)	Plan of Approach and preliminary investigations into spatial wind fields	The extreme wind speeds used for the HBC above water are compared with various alternative extreme wind speeds above water (derived with different methods). It was concluded that the used extreme wind speeds above water are at the lower limit of the values obtained by alternative methods, which is undesirable. A Scope of Work has been defined to improve the extreme wind speeds.
11a-b	Standardisation and improvement of wind drag modelling (section 5.9)	no action, foreseen for 2011-2016	-
13a	Wave-induced motion (section 5.10)	Coupling of WAQUA and SWAN to include wave induced setup in WAQUA	An offline link has been implemented in WAQUA, this is however not extensively tested. Remainder of this activity has been put on hold.
15b	Effects of bed changes (section 5.11)	Sensitivity analysis into the effect of bed changes on wave conditions	The sensitivity analysis showed that the influence of morphological changes during an extreme storm on the wave height near the toe of the dike are in the order of centimetres to one decimetre.
16b	Analysis wave measurements / model prediction Lake IJssel	no action, foreseen for 2011-2016	-

	(section 5.12)		
17a	Wave models on rivers (section 5.13)	no action, foreseen for 2011-2016	-

Table 3.3 Activities and results for mid term knowledge gaps during SBW-Belastingen period 2008-2010

Table 3.4 shows the results of the mid-term activities on the HBC itself as well as the resulting change in uncertainty (or gain in insight of uncertainty if no previous information was available). A description of each of the columns is presented in section 3.2. Please note that “-” in Table 3.2 means that the activity did not (yet) provide any information regarding a change of the HBC or uncertainty in HBC. In some cases the activity confirmed the present HBC and/or uncertainty (resulting in ‘no change’ in Table 3.4).

The table shows that activities for knowledge gaps 3c, 3d and 10b have led to additional knowledge which is transferred to the Hydraulic Boundary Conditions. The activities for KG3c have led to a decrease of the uncertainty in wind speed of 30%, which is yet to be transferred to a reduction in uncertainty of the HBC. The activities for KG3d and KG10b did not reduce the uncertainty, but eliminated questions regarding applicability of the presently applied approaches. It was concluded that the present approaches are considered to be reasonable: alternative methods would not reduce the uncertainty. It was also found that the applied wind fields for HR2011, based on the present approaches, are at the lower limit of the uncertainty range.

Analysis of the wave induced motion has revealed that including this physical process would lead to an increase of the HBC by approximately 0.20 metres. The effects of bed changes on the uncertainty of the HBC appeared to be in the order of 0.10 meters.

		Action plan	Result for SBW-Belastingen			
KG	Description	Effect	Completed?	ΔHBC	σHBC	Recommendation/follow-up activities
3c	Considerations of statistical distributions	unknown	yes	-	30% reduction on wind	Apply proposed POT/GPD method to all statistical variables.
3d	Alternative methods	unknown	yes	no change	no change	-
3e	Guidelines EVA basis variables	NA	no	-	-	-
6a	Time/space scale problems	NA	partly	-	-	-
7a	HBC suite for Eastern Scheldt	NA	no	-	-	-
8a	Reliability functions for other failure mechanisms	Unknown	yes	-	-	-
10b	Conversion wind point	several dm	Partly	no change	no change	(i) implement generic approaches in WTI 2011

	statistics to field information					and (ii) thereafter explore sound model-based alternatives
10c	Collection and analysis of measurement data	NA	No	-	-	-
11a-b	Standardisation and improvement of wind drag modelling	50 cm	No	-	-	-
13a	Wave-induced motion	unknown	partly	+0.20	-	Decide whether or not WAQUA-SWAN will be the tool used for subsequent recalculations of Hydraulic Boundary Conditions
15b	Effects of bed changes	unknown	Yes	0.00	0.1 (-)	-
16b	Analysis wave measurements / model prediction Lake IJssel	several dm	No	-	-	-
17a	Wave models on rivers	several dm	No	-	-	-

Table 3.4 Progression mid-term activities SBW-Belastingen 2008-2010

3.4 Long term activities

Table 3.5 shows an overview of the long term knowledge gaps, actions and results. As can be seen in the table, only the activities KG4a, KG9-a-c and the quantitative uncertainty analysis have some results. The remainder of activities have not been started yet.

KG	Description	Action undertaken	Result
4a	Integration of physics statistics in (section 6.2)	Organise Workshop on the application of climate models for determination of HBC.	The advantages and disadvantages of applying climate models in the HBC chain are investigated. General conclusion is that the present state of the climate models and specifically the interfaces between climate and hydrodynamic models require attention before application can be considered.
5a	Integration of model data in statistics	no action	-
9a-c	New safety approach (section 6.3)	Workshop "Probabilistic modelling" and testing of a method for including irregular failure domains.	Workshop resulted in an adjustment of the projectplan: testing of a method for dealing with irregular failure domains in the probabilistic models. The method has been tested for application in Hydra's.

10d	Transfer to field information using model data	no action	-
10d	Further analyses of bottlenecks and solution directions	no action	-
12b-c	Seiches modelling	no action	-
14b	Further research into hydrodynamic modelling	no action	-
15aii-iv	Analysis and validation of relevant wave aspects	no action	-
-	Development and validation of model train	no action	-
-	Quantitative uncertainty analyses (section 6.4)	Perform uncertainty analysis on all relevant aspects within the HBC chain.	Quantitative uncertainty analysis on wind statistics, storm surge duration, seiches and dune erosion.

Table 3.5 Activities and results for long term knowledge gaps during SBW-Belastingen period 2008-2010

Table 3.6 shows the progress of the long term activities within SBW-Belastingen. None of the activities have already transferred knowledge to the Hydraulic Boundary Conditions. This is to be expected, since the long-term activities are either not yet started or are not yet completed. Sections 6.2 through 6.4 present the intermediate results of the activities that have already started.

KG	Description	Action plan	Result for SBW-Belastingen			Recommendation/ follow-up activities
		Effect	Completed?	Δ HBC	σ HBC	
4a	Integration of physics in statistics	NA	partly	-	-	-
5a	Integration of model data in statistics	NA	no		-	-
9a-c	New safety approach	NA	partly		-	-
10d	Transfer to field information using model data	NA	no		-	-
10d	Further analyses of bottlenecks	NA	no		-	-

	and solution directions					
12b-c	Seiches modelling	0.20 cm	no		-	-
14b	Further research into hydrodynamic modelling	several dm	no		-	-
15aii-iv	Analysis and validation of relevant wave aspects	several dm	no		-	-
-	Development and validation of model train	NA	no		-	-
-	Quantitative uncertainty analyses	NA	partly	0.00	various	-

Table 3.6 Progression long-term activities SBW-Belastingen 2008-2010

3.5 Overall progression SBW-Belastingen 2008-2010

The sections 3.2 to 3.5 present the progression for the short-, mid- and long-term. Integrating these results into overall progression of the SBW-Belastingen project leads to the following main conclusions:

- A large number of activities have been started, resulting a significant gain of information and knowledge (left part of Figure 1.1). Part of this knowledge has resulted in new or improved methods, techniques and models (middle part of Figure 1.1). Only a limited amount of knowledge has already provided practical feedback to the WTI-project (right part of Figure 1.1). It is recommended to put additional effort in transferring the gained knowledge to techniques/models and providing feedback to the WTI-project.
- Most of the short-term and mid-term activities have been initiated. The remainder of the activities has not been started yet due to prioritisation and financial issues. It is expected that these activities will be initiated within the 2011-2016 activities for SBW.
- The long-term activities have mainly been put on hold. An exception is the quantitative uncertainty analysis: this should be performed parallel to the investigations into the knowledge gaps.

Regarding the developed knowledge, the following conclusions can be drawn (presented by theme):

- A lot of effort has been put into the subject *extreme value statistics*. At present, a lot of different methods for extreme value analysis are used within the HBC chain. There appeared to be a lack of sound justification of the applied methods. The activities performed within the SBW-Belastingen project have lead to recommendations for a uniform approach for extreme value analyses. The results of these analyses have not yet been (fully) transferred to the Hydraulic boundary Conditions. It is however expected that the proposed methods will not change the HBC themselves (no change in the mean values is expected), but they will probably reduce the uncertainty resulting from the

extreme statistics. Application of these proposed methods in the HBC chain recommended, because a reduction in uncertainty is highly preferred.

- An analysis of the *probabilistic models* has shown that these are not able to produce (reliable) Hydraulic Boundary Conditions in case of irregular failure domains which appear in cases for which an increase in water level or wave height does not lead to an increase in load on the sea defence: e.g. when the stability of the lower part of the structure is considered. A pragmatic approach has been developed to overcome this problem, which is to be applied for all water systems. The development of sophisticated changes to overcome the problems with irregular failure domains are put on hold because: (i) insight into the contribution of the pragmatic approach to the overall uncertainty needs to be obtained and (ii) perhaps the entire probabilistic approach will be changed, automatically solving the problem with irregular failure domains.
- Within the research theme *physics*, a lot of research has been performed regarding the *wind*. Major steps in the analysis of wind measurements (in combination with the proposed methods for extreme value statistics) have led to improvement of the time series of potential wind speeds and the extreme (point) wind statistics based on those time series. The resulting extreme (point) wind speeds do not differ significantly from the previously used values, but are more scientifically sound and reproducible. Two large knowledge gaps still remain: (i) the so-called curvature problem (extrapolation of data to smaller probabilities of occurrence) and (ii) a method for deriving spatial wind fields for HBC calculations. The latter has the largest contribution to the uncertainty in HBC, but can not be resolved with the present knowledge. As long as there is no improvement in the mentioned spatial wind fields, resolving only the curvature problem will not significantly reduce the uncertainty in the HBC due to wind.
- The topic *hydrodynamics* within the theme *physics* resulted in (partly) solving two individual issues: (i) seiche allowance within HBC and (ii) wave-induced motion. A large element of the hydrodynamics is however not yet addressed: evaluation of hydrodynamic (surge and current) modelling. Given the potential effect on the HBC and its uncertainty, this topic should be addressed on short term.
- Within the framework of *physics-waves*, the wave model SWAN has been validated for the Western Scheldt, Eastern Scheldt (ebb-tidal delta), and Lake IJssel. The validation for the Western Scheldt was quite extensive and resulted into a specific validation of a formulation related to wave-current interaction in SWAN. The validations for the Eastern Scheldt (ebb-tidal delta) and Lake IJssel were less extensive (at least in terms of geographical coverage and number of hindcast moments). The conclusions of the validation studies, regarding the performance of SWAN with newly derived physics and settings, have been transferred to the HBC.
- The SBW-Belastingen project started with a qualitative *uncertainty* analysis, which was used for the prioritisation of the knowledge gaps. Later on, expert opinions are gathered as to how to deal with uncertainties. This led to the creation of a Wikipedia⁵, presenting the available knowledge on uncertainties. As part of the quantitative uncertainty analysis the influence of uncertainty in storm (surge) duration, seiches and wind statistics on the design water level has been evaluated. It is recommended to perform such an analysis on all the results of the research into the knowledge gaps.

5. At the time of writing of this report, it is not yet clear whether the Wikipedia will be publicly accessible due to confidentiality of the included documents.

4 Results short-term activities

4.1 Storm surge duration (KG1a)

The probabilistic model Hydra-B (“B” stands for Benedenrivieren or “Lower branch of the rivers”) is used to determine the design water levels for assessing dikes in the Rhine-Meuse estuary. Storm surge duration at Hoek van Holland and storm duration are two parameters (implemented as stochastic variables) that determine the design water level in Hydra-B. The first refers to the water level increase in addition to the astronomical tide, the second to the wind speed. Both are set at 29 hours in the current version of Hydra-B, but there do not appear to be sound reasons for this value. The provincial authority of South Holland, for one, considers it to be too short. This means that the design water levels determined for HR2001 and HR2006 may be too low. For instance, a storm surge duration of 40 hours rather than 29 hours will result in an increase in design water levels of some 25 cm at Haringvliet/Hollandsch Diep, where the effects are greatest (Waterdienst, 2007).

The determination of statistics of storm durations and the effects of the (adjusted) storm duration statistics on the load model are investigated and reported in several stages:

- a. No regret actions taken in 2008: Deltares (2009b) and Deltares (2009c)
- b. Actions performed within the framework of SBW-2009: reported in Deltares (2009d)
- c. Actions performed within the framework of SBW-2010: Deltares (2010e)

Storm surge duration

The schematized development of the storm surge (as applied within Hydra-B for HR2001 and HR2006) is presented in Figure 4.1. The storm surge duration (D , being defined as the period that the wind-induced setup of the water level is higher than 0 metres), applied in the computations for the HR2001 and HR2006, is 29 hours.

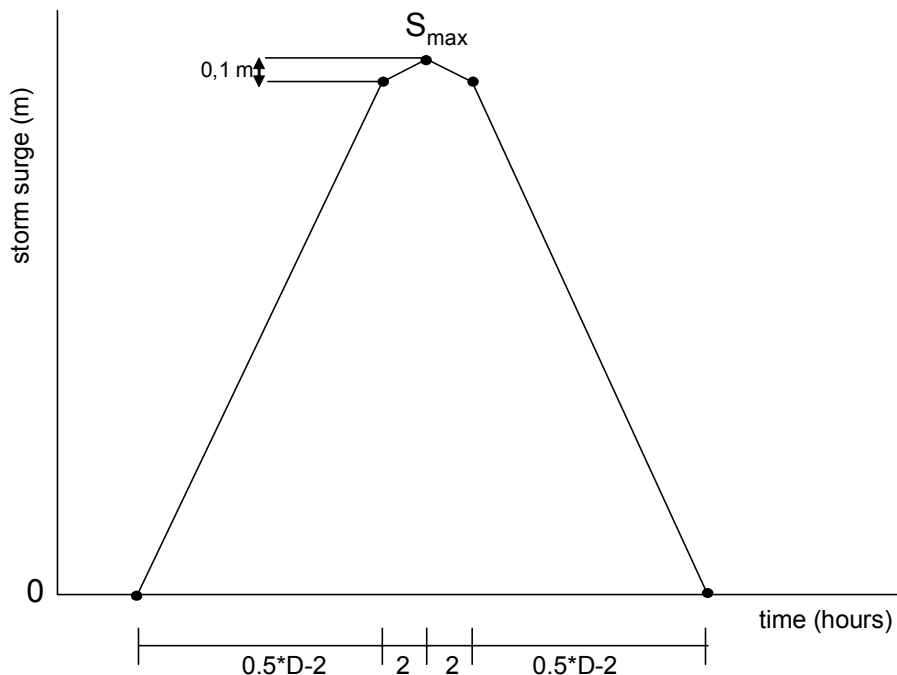


Figure 4.1 Storm surge hydrograph in Hydra-B Sobek simulations for HR2001/HR2006 (from: Deltares 2009d), with $D=29$ hours which implies a total storm surge duration of 29 hours

The re-determination of the storm surge duration resulted in a mean duration (D) of 46 hours, taking an increase of the water level (including astronomical tide) with 0 metres as the start of the storm surge. It should be noted that this duration is based on a derived duration for a surge elevation threshold of 0.5 metres, because surges in practice fluctuate around 0 metres which is not considered to be representative for a real storm event. The re-determined storm duration differs significantly from the duration applied in the HR2001 and HR2006 computations (46 hours versus 29 hours) and confirms the expected underestimation mentioned in Deltares (2009b). The application of a storm duration of 46 hours instead of 29 hours will lead to an increase of the water levels up to 0.25 metres at Haringvliet/Hollandsch Diep, where the effects are greatest (Waterdienst, 2007).

A more statistically/physically sound approach would be to base the storm surge duration on measured storm surge durations using a threshold value of 0.5 metres for the calculation of the storm surge. Such an approach would eliminate the need for extrapolation of the storm surge duration based on a threshold of 0.5 metres to a threshold of 0.0 metres, consequently reducing the added uncertainties due to this extrapolation. The storm surge duration based on threshold level of 0.5 metres is calculated to be 30 hours. This approach and the corresponding storm surge properties are already adopted by WTI and included in the new Hydraulic Boundary Conditions.

The current approach in Hydra-B, with a fixed surge duration, assumes that the surge duration is independent of the maximum surge. In Deltares (2009b) no indications have been found that maximum surge level and surge duration are interdependent. This means that the current assumption is acceptable.

Storm duration

The computations for HR2001 and HR2006 use a storm schematization as presented in Figure 4.2. The duration of the storm (D_w) is presently taken at 29 hours, defined as the

duration of a wind speed above 10 m/s. The applied duration of the peak of the storm is 5 hours.

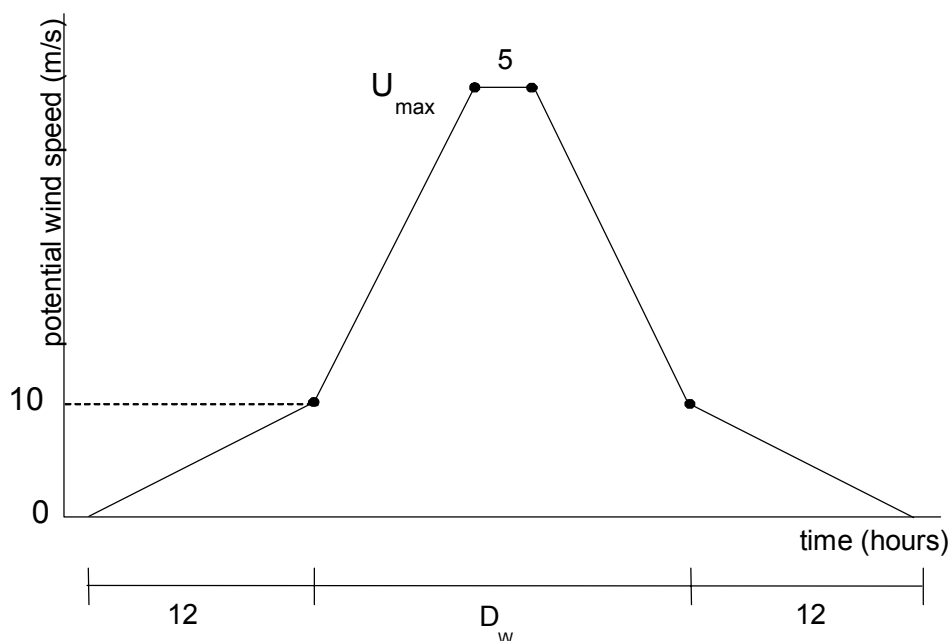


Figure 4.2 Evolution of wind speed in time for HR2001 and HR2006, as assumed in the Hydra-B Sobek simulations (from: Deltares 2009d), with $D_w = 29$ hours resulting in a total storm duration of 53 hours

The re-determined storm duration is 51 hours, starting from 0 m/s and using a peak duration of 1 hour. The basic level of 10 m/s was abandoned. The total duration slightly decreases compared to the total storm duration as applied in HR2001 and HR2006 (being 53 hours). The analysis showed that a peak duration of the storm of 1 hour (previously 5 hours) gives the best representation of the storm. An explanation for the significant decrease of the storm peak duration is not presented.

As an alternative, a trapezoidal shape as used in Hydra-VIJ, with a peak duration of 2 hours and a total duration of 48 hours, was also found to be an acceptable representation of the mean evolution of wind speed. For consistency with Hydra-VIJ, adopting this schematisation for wind speed in Hydra-B is therefore recommended.

More complex time graphs (multiple peaks) and dependency between the peak value and duration have been explored to a limited extent in these studies (e.g. Deltares 2009b), with a view to possible future modifications to Hydra-B. It is important to realise that design water levels at the river side of the Maeslantkering stormsurge barrier (in the Meuse river, protecting Rotterdam) are mainly determined by the duration of the closing of the barrier, rather than by the shape of the sea level hydrograph. The influence of storms with multiple peaks on this period is limited because, as a rule, it is possible to discharge water between two storms. For some applications however, such as studies into storage of excess water, multiple peaks may be a highly relevant phenomenon.

Deltares (2009b) further recommends an analysis of the time difference between the maximum storm surge residual and the astronomical tide peak. Hydra-B currently assumes a time difference of 4.5 hours for all simulated storm events.

A more realistic representation of this time difference seems appropriate and may significantly improve the estimates of design water levels. The proposed research should provide the necessary information for this adapted approach.

The investigations into the storm surge duration are finalised by the analysis presented in Deltares (2010e). In this study the remaining uncertainty in the storm surge duration is translated to uncertainty in design water level and crest height. The results of the uncertainty analysis show that the uncertainty in the storm surge durations leads to an uncertainty in the design water level of approximately 0.02 metres. Given other uncertainties within the HBC-chain, this uncertainty is considered to be acceptable.

4.2 Evaluation of the statistical methods currently (until 2006) used (KG3a)

The Hydraulic Boundary Conditions make use of extreme statistics for governing variables such as wind and water levels. The methods for deriving these extreme statistics (as well as other statistical properties of the variables) have been listed and discussed with several experts in Deltares (2009e). Different types of distributions have been applied for different water systems and for different basic variables. This is partly due to differences in the water systems and variables themselves, but also due to different development histories in handling these kinds of analyses, personal preferences and separate developments for the salt- and freshwater systems. It seems to be time to examine the possibility of arriving at a uniform approach for all Dutch water systems and basic parameters used.

An assessment of the statistical methods used in the calculation of the HR2006 (Deltares 2010b) was made, based on the outcomes of the aforementioned workshop and on the basic principles of modern extreme value theory.

It is concluded that many (extreme value) distributions currently applied to Dutch water systems have no sound theoretical foundation according to the extreme value theory. It is therefore not advisable to use them, unless physical arguments can be given. The POT/GPD approach is regarded as the best choice for all basic variables in all water systems, see section 5.1. Applying the POT/GPD approach yields relatively large confidence intervals, especially when data series are short. However, generally those intervals are realistic.

The performed analyses result in the recommendation to adjust the presently applied statistical methods. It is however questionable whether or not the statistical methods should be implemented. The transition to another extreme value approach yields lower calculated boundary conditions, but there are two reasons why it is not always necessary to adjust the current, last published, boundary conditions. The first (technical) reason may be the large confidence intervals, that is the uncertainty in the estimates of the parameter quantiles, in relation to the difference between existing and new estimates. The second (policy) consideration may be the possibility of other results after six more years of data, new insights, consistency of policy (no yo-yo effect) and robust design (so no sharp assessment of safety) of water defences.

4.3 Vrijling method (KG3b)

Storm events along the Dutch coast are characterised by the combination of high water levels and severe wave conditions. This is caused by the fact that storms in the North Sea cause an upsurge, while the same storm also generates the severe wave conditions. The resulting water levels and waves can not be treated as statistically independent variables (e.g. for determining the hydraulic load on water defences) because they result from the same meteorological conditions.

The joint probability of hydraulic conditions without any correlation can easily be determined using marginal statistics. The same techniques can unfortunately not be used to derive the joint probability in cases with a correlation between variables. The underlying marginal statistics and correlations can often be determined, but combining these to create a single joint probability is often a problem. Presently, two approaches are available for solving this problem for hydraulic conditions at deep water: (i) fully statistical and (ii) using a combination of statistics and physics.

The present method for determining the Hydraulic Boundary Conditions (Hydra-K approach) uses the fully statistical approach: the so-called method of “De Haan” (Haan and De Ronde, 1998). An alternative for this approach is the method of Vrijling & Bruinsma (1980), which is considered an example of a combined statistical and physical approach.

Deltares (2008d) investigated the method of Vrijling & Bruinsma (1980). Deltares (2008d) found that the results from the Vrijling & Bruinsma approach differ from both measured marginal statistics and the results from the Hydra-K approach. The Vrijling & Bruinsma approach therefore needs further investigations. The main recommendation of Deltares (2008d) is to extend the Vrijling & Bruinsma method with more advanced physics (e.g. SWAN) and verify the results of the more advanced approach. However, since the present approach of Hydra-K will possibly be abandoned in order to be able to introduce time domain, the Vrijling method (which does not include time domain) will not be investigated further for the time being.

4.4 Point statistics wind (KG10a)

An important part of the HBC chain is the derivation of point statistics for wind, since this is used as input for the probabilistic models. Within the framework of "Point statistics wind" a number of research topics are covered. Firstly, the transformation of measured wind speeds to potential wind speeds is investigated (section 4.4.1). This research led to an additional investigation into the origin of the so-called curvature problem (section 4.4.2). The gained insights are used to derive new extreme wind statistics to be used in the probabilistic models (section 4.4.3). Finally, the obtained knowledge regarding the uncertainties in the extreme wind statistics are translated to uncertainties in the design water levels (section 4.4.4).

4.4.1 Improving potential wind for extreme wind statistics

The Hydraulic Boundary Conditions are determined with use of the probabilistic Hydra-models. These models presently use, amongst others, the hourly averaged wind statistics based on Wieringa & Rijkoort (1983). Wieringa & Rijkoort (1983) used timeseries from 1962 to 1976. The KNMI HYDRA-project (1998-2005) aimed at extending these time series whilst improving the methods to estimate wind extremes. However, the HYDRA-results were not accepted for the HBC as it yielded an implausible result according to the used wind modelling concept: estimates of land-based wind extremes were higher than those over the sea, referred to as the curvature problem.

It has been postulated that part of the curvature problems may be caused by the way in which the exposure correction factors (ECF) are derived. Wieringa & Rijkoort (1983) used an hourly gustiness analysis to derive the exposure correction factors. It is however recommended by Wieringa & Rijkoort (1983) and KNMI (2009) to instead base the exposure correction factors on 10-minute data with direct use of standard deviation and average wind, the so-called σ_u -analysis. Starting from 2003, most KNMI stations record the 10-minute samples in combination with the standard deviation. This allows for a recalculation of the exposure correction factors, based on more appropriate assumptions.

KNMI (2009) recalculated the exposure correction factors, leading to newly derived potential wind time-series covering the period 1993-2007. The newly derived exposure correction factors reduce the uncertainty in the contribution of the exposure correction factors to the curvature problem. The correction of the exposure correction factors has led to a reduction of 15-20% on individual measurements with large upstream roughness (see figure below), but large upstream roughnesses are not common, especially not in the station data considered for the extreme value analysis. Typically, the improved exposure correction factors led to 1-5% downward revision of exposure corrected winds over land. Nevertheless, the newly derived exposure correction factors reduce the uncertainty in the contribution of the exposure correction factors to the curvature problem.

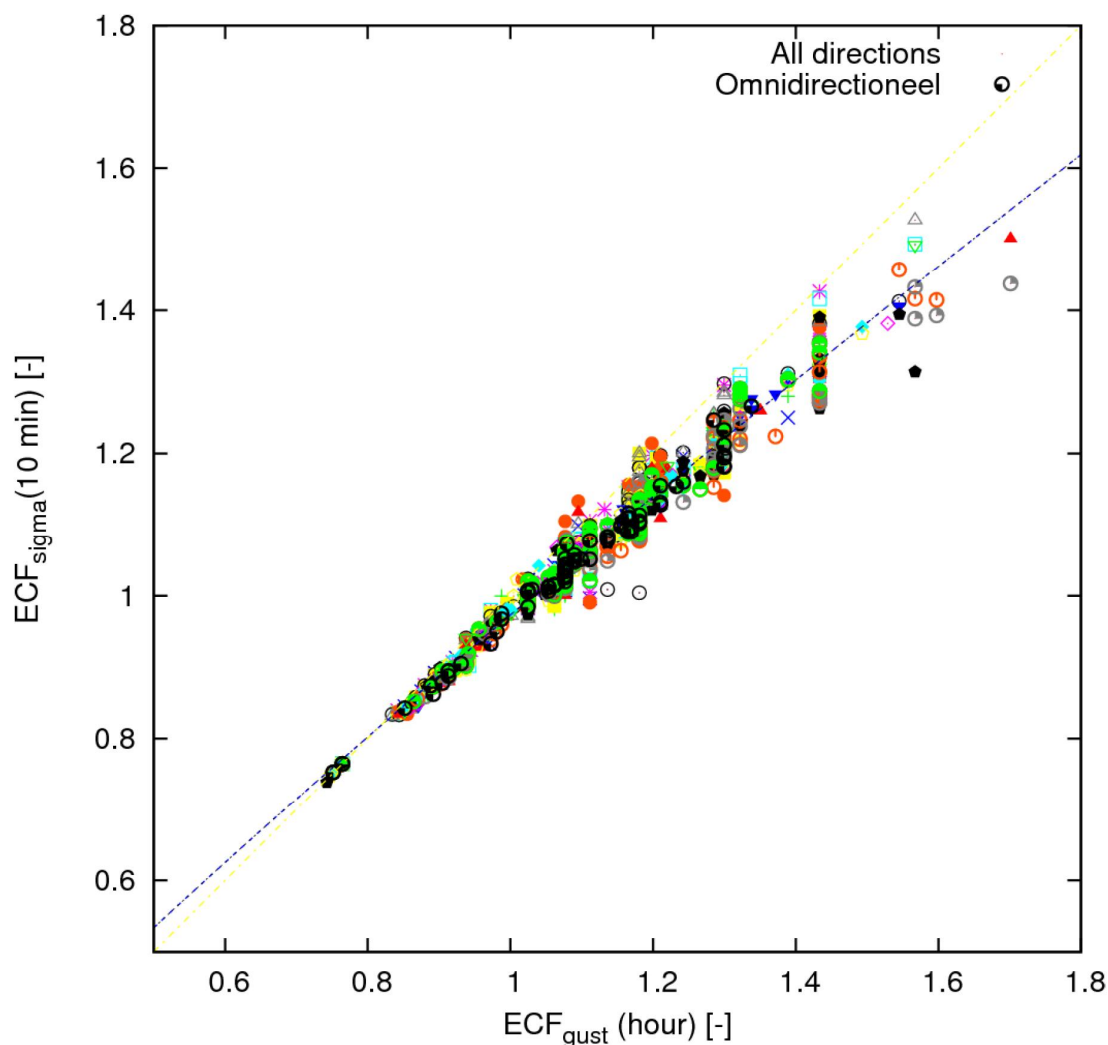


Figure 4.3 Omni-directional relation between exposure correction factors from gustiness analysis and σ_u analysis for 109 wind sites in the period 2003-2008. Each dot represents an exposure correction factor for a wind direction sector for a station; each colour dot represents a 20 degree wind direction sector. The blue line denotes a fit, based on all directions and stations together. Source: Wever and Groen, 2009, Figure 4.5.1.

4.4.2 Additional investigations into the curvature problem

For the assessment of the Hydraulic Boundary Conditions (HBC), information is required on wind conditions over open water areas, pertaining to return periods up to thousands of years. In earlier assessments of the HBC, a wind modelling concept was developed to provide adequate estimates of the required information. This modelling concept is based on wind measurement data at KNMI stations and some assumptions pertaining to the physics and the statistics of wind over the Netherlands and its water areas. During the KNMI-Hydra project (not to be confused with the software package), it was noticed that the observed variation in shape (curvature) of the extreme wind statistics at the KNMI stations does not fit within the developed wind modelling concept. This disagreement between the data and the modelling concept has become known as the curvature problem. It was clear that the curvature problem needed to be solved in order to derive reliable estimates for the required wind information (for the assessment of the HBC).

Deltares en KNMI (2009) gained more insight in the curvature problem by means of brief analyses into some physical and statistical assumptions in the wind modelling concept that is applied in the determination of potential wind series and in the earlier assessments of the HBC. The following major factors have been identified as contributing to the curvature problem:

- Non-neutral atmospheric stability: The assumption of a neutral atmospheric stability for all conditions in which the wind speed exceeds 6 m/s appears to be invalid (at sea and coastal stations). This implies that the (shape of the) wind speed profile is not guaranteed "logarithmic and governed by surface roughness only", complicating the use and interpretation of the concept of 'potential wind'.
- Wind-speed-dependent water roughness: The roughness of water increases with increasing wind speed, whereas the roughness at inland sites does not depend on the wind speed. Furthermore, in the homogenisation of the series of measurement data, a "constant" (wind-speed-independent) exposure correction factor is applied. In case of advection over water, the actual roughness, which the factor is supposed to correct for, does depend on the wind speed. Neglecting the wind speed dependence in water roughness and in the determination of the potential wind series, both enhance the difference in curvature of wind speed statistics at inland sites versus coastal sites.
- Non-stationary anemometer height: Certain coastal stations, such as at Hoek van Holland and IJmuiden, are exposed to the sea. It is expected that when high surges accompany extreme sea wind, a rather common situation, that the considered height of anemometer relatively to the mean sea level is an overestimation of the effective measuring height and the computed potential wind an underestimation.

The identified causes are located in both the available data and rather fundamental aspects of present wind modelling concept. Based on the findings in this study it is recommended to follow a systematic approach of analysing all hypothetical curvature problem causes. It is further strongly recommended to reconsider the fundamental aspects of the data and modelling concept. It should also be kept in mind that, apart from the curvature problem, the present wind modelling concept within the framework of the HBC assessment also has other weaknesses, e.g. the very crude schematisation of a storm in time and space. Putting all effort into solving the curvature problem is therefore not recommended.

4.4.3 Extreme wind statistics for the HBC

Deltares (2009m) updated the extreme potential wind statistics for 21 KNMI wind stations with long time series available using the newly derived exposure correction factors derived in KNMI (2009). Data over the period 1970-2008 were considered in the analysis. Both omnidirectional and directional estimates were obtained. The sensitivity of the results to different periods was also analysed and found to be reasonable, i.e. the differences found do not exceed the uncertainty associated with the estimates. The data was analysed using the standard AM/GEV and a POT/GPD approaches. The hypothesis of a Type I tail for the potential wind data was extensively tested. Power 2 and power k data transformations, with k being the shape parameter of the Weibull fit to the whole dataset, were considered in order to accelerate the convergence to a Type I tail. However, in the cases considered, the transformations do not appear to improve the convergence to a Type I tail, nor do they seem to be needed.

The assumption of a Type I tail seems to be valid for the potential wind data considered. Furthermore, the estimates obtained from exponential fits to the POT data were found to be realistic and reliable and are given as final/best estimates.

Mainly due to the Type I tail assumption, the curvature problem (discussed above) does not seem to strongly affect the computed estimates. Furthermore, these new estimates do not differ much from the currently used estimates of Wieringa and Rijkoort (1983). More precisely, the 10,000 yr return value estimates of this study differ by less than 3% from those of Wieringa and Rijkoort (1983) in 10 of the 13 stations considered by them. The two stations for which the differences are larger - about 10% - the estimates were adjusted 'by hand' by Wieringa and Rijkoort (1983) and discrepancies would even be larger if they had not been adjusted.

The updated wind statistics are made available for computing the Hydraulic Boundary Conditions for the Dutch primary water defences within the project WTI.

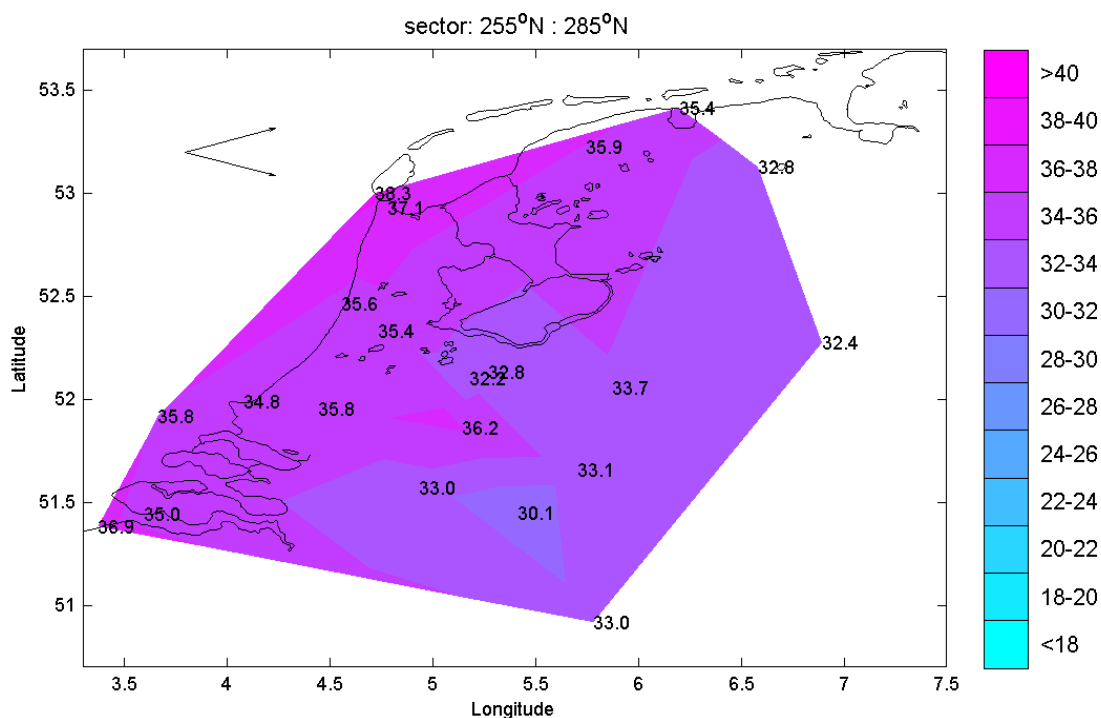


Figure 4.4 Potential wind speed 10,000-yr return value estimates in m/s. Exponential fit to POT data to the specified sector. Source: Deltares (2009m).

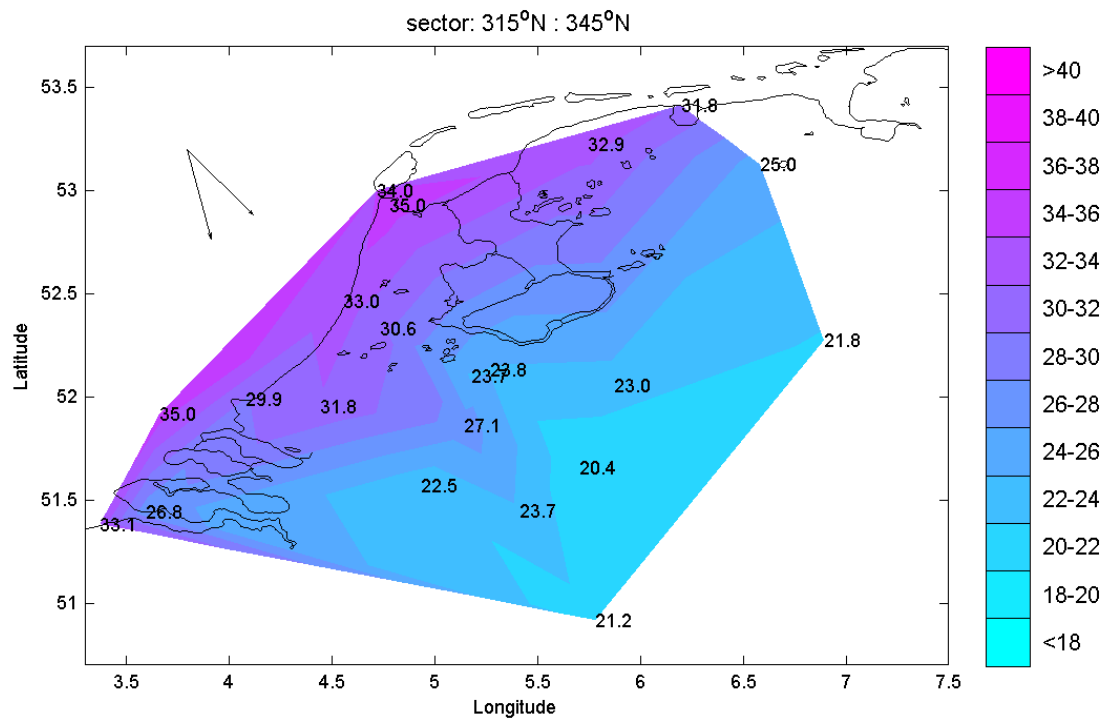


Figure 4.5 Potential wind speed 10,000-yr return value estimates in m/s. Exponential fit to POT data to the specified sector. Source: Deltares (2009m).

4.4.4 Effect of uncertainty in extreme wind statistics on the design water levels

As part of the uncertainty analysis, Deltares (2010e) has investigated the effect of uncertainty in extreme wind statistics on the design water levels. Experts were asked to make an inventory of the important sources of uncertainty, and to provide uncertainty bands on the extreme wind speed (1/10,000-year frequency) at measurement station Hoek van Holland, both precluding and including knowledge of the 2009 research. The width of the 95% confidence interval reduced by 1.6 m/s (from 12.5 m/s to 10.9 m/s), based on expert interviews. The principal reasons for reduction were: reduction in statistical uncertainty, consistency in regional extreme wind patterns based on two different methods of analysis (1983 analysis and 2009 analysis), and comparability of extreme estimates (1983 and 2009) despite different series lengths and different methods. The latter two reasons concern the confidence in the method(s), and are therefore a very important, but very subjective source of uncertainty reduction.

The impact that such a reduction in uncertainty has on the required dike height was investigated at three coastal locations: Katwijk, Maasmond, and Scheveningen. The reduction in the uncertainty bands at these locations was found to be 13 cm, 39 cm, and 27 cm, respectively. The limitation of these values was discussed, such as use of the model Hydra-K, which is only applicable for the coast, and the uncertainty estimation at a coastal measurement station. The impact on lake dikes is expected to be more substantial due to the use of the wind speed statistics in the calculation of the water level in lakes. The uncertainty at a land station will differ due to a number of uncertainties that are only applicable for open water locations.

4.5 Analysis of seiches (KG 12a)

The motivation for investigating the importance of seiches originates from insights and hypotheses on the generation of seiches in the Port of Rotterdam that were developed by De Jong (2004). When confirmed, those findings could influence the Hydraulic Boundary Conditions (HBC) in the Europoort Area.

As a first step in the evaluation of the validity and relevance of those insights, a study (Deltares, 2009p) was initiated with the aim to evaluate the present seiche allowances used in the Hydraulic Boundary Conditions (HBC) for the Europoort area and to determine the actions possibly required to update them. The study approach consisted of two main parts. First, a preliminary evaluation was made of the existing methods for calculating seiche allowances in the Europoort area to serve as input for WTI. The second step analysed the hypothesis from De Jong (2004) on the expected seiche characteristics in extreme conditions: less extreme seiches during extreme wind speeds due to the fact that the forcing weather cells do not occur in combination with high wind speeds. This latter step showed that confirming this hypothesis is a (recommended) long term action, which has so far not been included in SBW-Belastingen.

The results from Deltares (2009p) served as input to a study within the framework of WTI (Deltares, 2010h) for re-evaluation of the seiche allowances in the Europoort area of Rotterdam. This additional study started after Deltares (2009p) was finished. According to Deltares (2009q), Deltares (2009p) describes a comparison of seiche statistics as applied within the Hydraulic Boundary Conditions (HBC) and those derived with the method originally applied for the Storm Surge Barrier in the Nieuwe Waterweg (SVKW) that should be re-considered before final interpretation for WTI. This was also taken up as part of Deltares (2010h).

Deltares (2010h) describes new net seiche effects, i.e. the net influence of seiches on high water levels, for extreme events. These values have been derived from statistical analyses of long term measurements. Also the translation of these reference results from the measurement location to other locations in the port, based on post processing of calculation results from the mild-slope model PHAROS, has been updated by applying a different, validated translation approach. The new reference seiche statistics at the measurement location turned out to be lower than the existing values. The update of the translation method to the other locations relevant for HBC resulted in a further lowering of the local values. However, in the course of the PHAROS calculations, it turned out that a correction (adjustment of reflection and transmission properties in the schematisation, see section 4.4.2 in Deltares, 2010h) was required in the applied model schematisations, originally setup for HR2006 (Alkyon, 2005), which had an increasing effect on the net seiche effect at most locations. The combined effect of these elements is that the new values for the net seiche effect at locations relevant for HBC are equal to or slightly below the existing values.

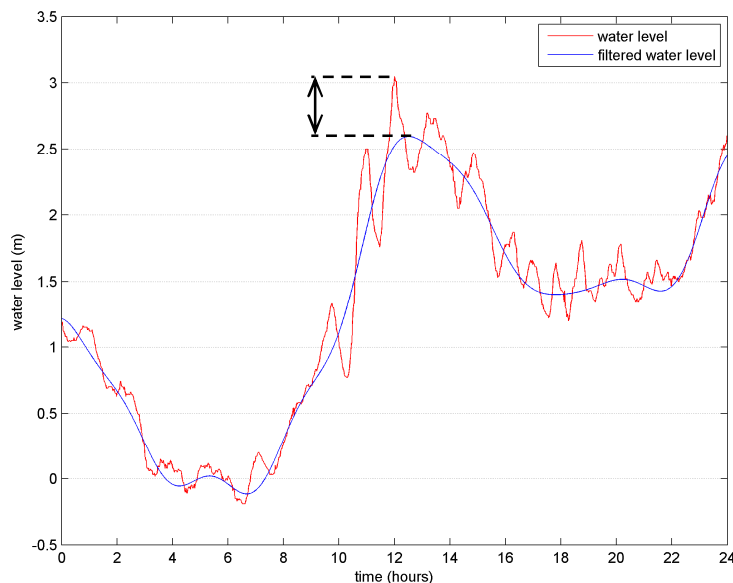


Figure 4.6 Time series measured signal and filtered water level signal. The net seiche effect on the high water level is indicated by the vector.

4.6 Evaluation of hydrodynamic modelling (KG14a)

At present, the activities foreseen within the framework of “Evaluation of hydrodynamic modelling” have not been started. It is expected that these activities will be addressed within the framework of SWB-Belastingen 2011-2016.

4.7 Verification of SWAN model “Open coast” (KG15ai)

The wave model SWAN has been improved within the framework of SBW-Wadden Sea (Deltares, 2009i and Dongeren et al, 2010): (i) the underestimation of wave height in depth limited wave growth situations has been improved by extending SWAN with a new depth induced wave breaking formulation, (ii) investigations of the underestimation of wave propagation through the basin has lead to the hypothesis that this may be caused by refraction and dissipation effects of low frequency waves and (iii) the overestimation of the wave height in the case of opposing currents has been improved by means of a new dissipation term (which unfortunately also has negative side effects).

The applicability of these improvements needs to be investigated/verified for the coastal regions for which new Hydraulic Boundary conditions will be determined. Besides for the Wadden Sea, new Hydraulic Boundary Conditions in salt water areas for HR2011, using the wave model SWAN, will only be determined for the Western Scheldt.

4.7.1 Western Scheldt

Witteveen+Bos (2010) has performed a verification study for the Western Scheldt in order to test the applicability of the (improved) wave model SWAN for the Western Scheldt. This work is performed within the framework of WTI and will be presented here briefly because it fills this knowledge gap (KG15ai). The study consisted of hindcasting 6 storms from the previous decennium and comparing the results with measurements taken at (i) the outer delta, (ii) central part and (iii) the most inner part of the Western Scheldt.

The results for the outer delta are in line with Svašek Hydraulics (2007): SWAN underestimates the penetration of North Sea waves over the outer delta. Application of a

refraction limiter, which resulted in a better performance of SWAN for the Eastern Wadden Sea, did not improve the performance for the Western Scheldt (Witteveen+Bos, 2010).

For the inner part of the Western Scheldt, the differences between measured and computed wave height and wave periods are small (in terms of bias) except for two locations situated at the edge of a tidal channel. The results show a large standard deviation. The uncertainty of the model input (wind, bathymetry and currents) is such that the performance of SWAN for the Western Scheldt can not be established. Reduction of the uncertainty in the model input is required. This will however require a more extensive measuring campaign (comparable with the Wadden Sea).

An important physical process for Dutch water systems (e.g. Scheldes, Wadden Sea and rivers) is wave-current interaction. The performed hindcasts for the Western Scheldt (Witteveen+Bos, 2010) formed a starting point for validating a newly-developed formulation for dissipation on opposing current gradients of Deltares (2010i). In addition to the available hindcasts for the Western Scheldt, a second field case is used to validate the newly developed formulation: Colombia River mouth, USA.

Deltares (2010j) shows that the formulation for enhanced dissipation proposed by Deltares (2010i) appears to perform well for the Western Scheldt, and that the formulation contributes towards the overall model accuracy. Wave heights with negative current gradients (that is increasing counter current or decreasing following current) are reduced by the enhanced dissipation, whereas waves in without current gradients are largely unaffected, (as expected). By contrast, in the Columbia River Mouth field case, the reduction of significant wave heights due to the enhanced dissipation results in an underestimation of the observations. The difference in performance of the enhanced dissipation formulation between these two field cases may be due to differing physical conditions, the location of the observation stations relative to the main wave-current interaction regions (Columbia River Mouth), or errors in the computed current fields.

Deltares (2010j) also showed that observed wind speeds in the middle and eastern parts of the Western Scheldt are about 15% lower on average than those in the outer delta, used by Witteveen+Bos (2010) to force SWAN. Reduction of the latter uniform wind speeds in the simulations by 15% significantly reduces the large positive bias in H_{m0} in the middle part of the estuary reported by Witteveen+Bos (2010). For all observation stations, a 15% reduction in the wind magnitude yields an overall reduction in the bias and scatter of H_{m0} , with a slight increase in the negative bias of $T_{m-1,0}$, bringing the model performance to a generally satisfactory level comparable to the performance level in the Wadden Sea. This sensitivity suggests that well validated spatially varying wind fields should be applied in future simulations in the Western Scheldt.

Further improvements to the model performance in the Western Scheldt are found by varying both model inputs and settings, within the range of their uncertainties (Deltares, 2010j). Increasing the coefficient for enhanced dissipation to $C_{ds3} = 1.6$ yields an improvement that surpasses that of the increased current magnitude. However, such an high parameter value is not supported by the laboratory flume tests presented in Deltares (2010i).

Deltares (2010j) recommends to apply the new formulation for enhanced dissipation to the Western Scheldt, because in the Western Scheldt field case, as seen for the Amelanders Zeegat (Deltares 2009i), the enhanced dissipation expression was found to improve model accuracy.

4.7.2 Eastern Scheldt

Svašek Hydraulics (2007) already validated SWAN for the outer delta of the Eastern Scheldt. In addition, several hindcast moments for the outer delta of the Eastern Scheldt are included within the calibration and validation study of SWAN (Deltares, 2010f). The results of this analysis have led to additional research within the framework of SBW-Waddenzee. The results of the validation of SWAN also show that the performance of SWAN falls within the range of all investigated hindcasts. Point of attention is, as for all inlets, the propagation of North Sea waves over the outer delta (which is underestimated by SWAN).

At present no validation studies for the inner part of the Eastern Scheldt have been performed.

4.8 Verification of SWAN model “Lakes” (KG16a)

The wave model SWAN has been improved within the framework of SBW-Wadden Sea (Deltares, 2009i and Dongeren et al, 2010). These improvements need to be verified for the lakes for which new Hydraulic Boundary conditions will be determined.

Deltares (2010f) presents the calibration and validation of the SWAN model for the cases available within the SWIVT database. This SWIVT database also contains cases for Lake IJssel. Results of the validation showed that the SWAN model performs better for the wave period after the calibration, this was however at the cost of the performance of the wave height. Overall, the performance of SWAN for Lake IJssel hardly changes with different settings. The study recommends to use the calibrated coefficients for the HR2011 computations for Markermeer and Lake IJssel.

4.9 Workshop dealing with uncertainties

Within the framework of SBW-Belastingen, theme “Uncertainty analysis”, a workshop was held at Deltares, Deltares (2009j). This workshop aimed at (i) obtaining insight into the (relevant) uncertainties within WTI2011, as well as how to deal with them, (ii) getting acquainted with the various elements of WTI2011, (iii) exchanging knowledge and (iv) generating ideas for investigating the uncertainties within WTI2011.

The workshop was limited to the uncertainties related to the present method for evaluation of water defences and the present approach within the Hydra-models (as to be used for WTI2011). The following recommendations are made based on the workshop:

- Improvement of the interface between the Hydraulic Boundary Conditions and the VTV (“Voorschrift Toetsen op Veiligheid”). On one hand, the strength side (“failure mechanisms”) of the VTV asks for hydraulic loads in order to perform a correct evaluation of the water defences. On the other hand, available information of the hydraulic load, such as temporal variation, can initiate improvements regarding the failure mechanisms. A strong interface allows for more interaction between the both. In addition, the uncertainties in failure mechanisms and hydraulic loads should be considered within one context.
- Keep the rules for evaluation of the sea defences simple, but make sure that the probabilistic models are capable of substantiating the required safety margins.

- A lot of research has already been done regarding uncertainties (e.g. ONIN, SPRINT and TAW reports). It is recommended to make this research more accessible, e.g. by means of a Wikipedia on uncertainties⁶.

4.10 Qualitative uncertainty analysis

A qualitative uncertainty analysis has already been executed within SBW-Belastingen (Deltares, 2009I). The results of this qualitative uncertainty analysis are included in the action plan for SBW-Belastingen (Deltares, 2009a) and form (a part of) the starting point for SBW-Belastingen. The results of the uncertainty analysis are presented in Appendix C of Deltares (2009I) and incorporated in the tables presented in Chapter 3.

However, the mentioned uncertainty analysis is a snapshot in the sense that it is executed for the situation at the start of SBW-Belastingen (2008) and based on existing Hydra programmes (2008). Aspects which are not incorporated in the Hydra's have not yet been considered. This applies in particular to failure mechanisms, other than overflow and overtopping, and strength parameters. A complete uncertainty analysis whereby all relevant load parameters and also strength parameters are considered in combination is highly desirable. There is also a requirement for insight into the uncertainties in the modelling of the physics. This also generates a complete overview.

Prior to each (part) investigation on the HBC tools, a quantitative uncertainty analysis is executed on the corresponding section of the tools. This provides insight into the anticipated effect of the investigation and the available room for improvement in respect of quality. If this potential improvement is significant, then the investigation will be executed. After completing the research, an uncertainty analysis is executed again. The effect on the accuracy (quality) of the executed research becomes measurable in this way.

The execution of these activities is to some extent dependant on other sections of SBW-Belastingen, Wadden Sea and the strength sections of SBW. The duration is also strongly dependant on the progress of those sections.

4.11 Further analysis quality aspects and translation into criteria

At present, the activities foreseen within the framework of "Further analysis quality aspects and translation into criteria" have not been started. It is expected that these activities will be addressed within the framework of SBW-Belastingen 2011-2016.

4.12 Viability test and verifying implications for technical activities

At present, the activities foreseen within the framework of "Viability test and verification implications for technical activities" have not been started. It is expected that these activities will be addressed within the framework of SBW-Belastingen 2011-2016.

6. At the time of writing this report, a Wikipedia on uncertainties is being developed, but it is unclear whether the Wikipedia will become publicly accessible.

5 Results mid-term activities

5.1 Considerations of statistical distributions (KG3c)

In order to assess their relative merits in the context of the determination of Hydraulic Boundary Conditions (HBC), the annual maxima / Generalized Extreme Value distribution (AM/GEV) and Peaks over Threshold / Generalized Pareto Distribution (POT/GPD) approaches were compared (Deltares, 2009h). The comparison was in terms of their accuracy (as measured by mean square errors) in estimating exceedance probabilities using time series with various lengths and with characteristics that mimic those of real time series, such as non-stationarity and serial dependence. Two types of simulation studies were carried out. Both took into account the characteristics of the data currently available on the so-called basic variables.

The first part of the Deltares (2009h) study focused on the finite-sample properties of the estimators of the GEV and GPD models based on independent and identically distributed data. For this, both the Maximum Likelihood (ML) and Probability Weighted Moments (PWM) estimation methods were considered. It is concluded that with POT samples having an average of two or more observations per year, the GPD estimates are more accurate than the corresponding GEV estimates. However, with more than 200 years of data, the accuracies of the two approaches are similar and rather good. Furthermore, it was concluded that if less than 50 years of data would be available, the method of PWM should, on the basis of its error characteristics and robustness, be preferred to the ML method. However, with longer data sets the two estimation methods have comparable accuracies.

The second part of the Deltares (2009h) study focused on the finite-sample properties of the AM/GEV and the POT/GPD approaches applied to non-stationary and serial dependent data and using the method of PWM. It was concluded that, given a time series of less than 100 years, the POT/GPD estimates of the shape parameter are more accurate than those of the AM/GEV approach. With 100-year long time series the performance of the two approaches is comparable, the accuracy of the AM/GEV approach being slightly greater with lighter tails and that of the POT/GPD approach being slightly greater with heavier tails. In terms of return value estimates (namely of the 4,000-yr and 10,000-yr return values), the POT/GPD approach is significantly more accurate. Only for time series of 200 years or more do the two approaches yield comparably small mean square errors. Still, even with 200-year long time series the relative root-mean square errors of the POT/GPD approach are about 2/3 of those of the AM/GEV approach whenever the underlying tail index exceeds -0.1.

Based on the results of the Deltares (2009h), it is recommended that, irrespective of the variable of interest, the POT/GPD approach be used for the extreme value analyses of the data required for the computation of HBCs. Furthermore, it is recommended that the parameters of the GPD be estimated using the method of PWM.

Deltares (2009h) recommended to investigate the methods for selecting the threshold to be used in extreme value analysis. At present, the threshold is selected by means of an informal method. Deltares (2010m) investigated the possible gains that can be obtained from using formal methods instead of the informal ones to derive the appropriate threshold for the extreme value analysis. The investigations showed that the most preferable formal method is the so-called “fixed p implementation”. In case of samples derived from a dataset of less than 20 years of data, the formal method should be used instead of the informal one.

In case of samples derived from a dataset of more than 20 years of data, the informal method is equally good if not better than the formal method.

5.2 Alternative methods (KG3d)

5.2.1 Approaches to extreme value statistics

According to the experts in extreme value statistics, who were consulted during the workshop (Deltares, 2009e), the usefulness of the following methods in determining the HBC should be investigated:

- a) Conditional and multivariate extreme value analysis
- b) Bayesian statistics; for the analysis of extreme values
- c) Regional frequency analysis
- d) Use of covariates

All methods were investigated (Deltares, 2009f, 2009g and 2010c), the results of which are presented below.

Regarding multivariate methods, item (a), the method of Zachary et al. (1998) was used to compute estimates of the joint density of the wave parameters H_{m0} and $T_{m-1,0}$, of conditional densities, and of the joint return value plot. The bivariate return value plot estimates were further compared with estimates obtained using the De Haan Method that is currently used. The bivariate return value estimates obtained using the De Haan Method (Haan and Resnick, 1977) coincide with those obtained with the method of Zachary et al. (see Figure 5.1), reflecting the similarity between the two methods. However, the method of Zachary et al. has the added value of also providing the conditional densities.

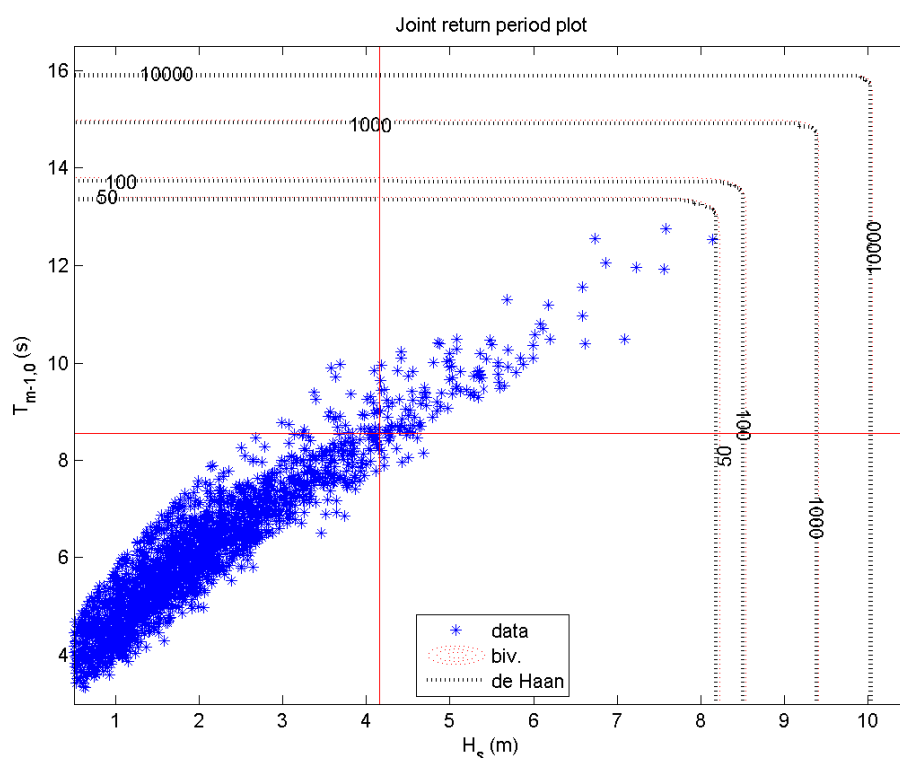


Figure 5.1 Joint return value plot of H_s and $T_{m-1,0}$. Source: Deltares (2009g)

Regarding the item (b), the possibility of using Bayesian methods in the estimation of return values of 'basic variables' was considered. Examples of Bayesian extreme value analysis of still water level data were worked out. The HKV and Rijkswaterstaat MATLAB tool for Bayesian extreme value analysis BAYES (see RWS-RIZA (2002) for a technical description of BAYES) was used, with a view towards identifying any shortcomings or desirable enhancements. The following shortcomings were identified:

- Lack of informative priors;
- Posterior densities of quantiles are not available;
- The tool targets the carrying out of Bayesian inference by combining percentiles from different distribution functions, which is incorrect in the context of extreme value analysis according to specialists.

The following enhancements are suggested:

- Inclusion of informative priors that allow knowledge about the tail type of the data and information from other relevant analysis to be included;
- Posterior densities of the percentiles/return values should also be made available.

In the investigation into method (c), the rationale for using a regional frequency analysis, in which the shape parameter (tail index) of the extreme value distribution of wave data is modelled as a function of water depth, was investigated using wave height data in Deltares (2009f), see Section 5.2.2 for more details, and further investigated by analysing mean wave period data and determining the correlation between the shape parameter estimates and water depth, see Section 5.2.3 for more details. The results show that the tail indices of the significant wave height and mean wave period data are strongly correlated with the water depth, justifying the application of regional frequency analysis. It should, however, be recognized that the regional frequency analysis estimates do not provide the best fits to the data at each location, and hence that, depending on the application, the 'local' parameter estimates may be preferable.

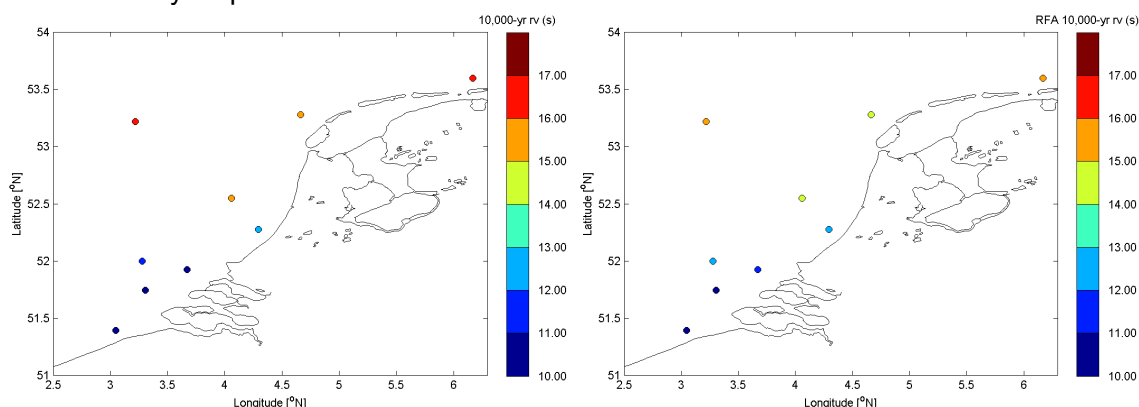


Figure 5.2 Estimates of the wind-sea 10,000-yr return values of $T_{m-1,0}$ based on local POT/GPD analyses (left) and on the RFA (right). Source: Deltares (2010c).

Regarding the item (d), the possibility of introducing a directional covariate in the distribution of extremes as a means to obtain return value estimates in terms of directional sectors was investigated, see Section 5.2.3 for more details. The results show that directional and omnidirectional return value estimates can be reliably obtained by resorting to models with directional covariates. However, the covariate-based models considered apply only to independent data, and efforts should be made to extend them to dependent data.

5.2.2 Tail of extreme value distributions: extreme wave heights (KG3d)

To determine the HBC2006, Weerts and Diermanse (2004) modelled the spatial correlations between the offshore wave extremes using a modified regional frequency analysis (MRFA). In the MRFA the estimates of the shape parameter of the conditional Weibull distribution of both significant wave height and mean wave period data are modelled as a function of the fetch, taken as the buoy's distance to the Doggersbank, and bottom depth (see Weerts and Diermanse, 2004, pp. 4-8, section 4.3, and Heijer et al., 2005).

The analyses of Weerts and Diermanse (2004) and Alkyon (2008a) are based on a conditional Weibull distribution. As noted in WL | Delft Hydraulics (2007b) the conditional Weibull distribution has a Type I tail, hence an infinite upper endpoint, and therefore does not allow the determination of eventual upper-limits in the extremes. The North Sea locations considered in the HBC are in finite depth and the significant wave height is supposed to be fetch- and/or depth-limited. Consequently, it is likely that the estimation of extreme values in those locations will benefit from the possibility of accounting for the existence of upper-limits of wave data and their estimation, which in particular may yield less over-cautious estimates.

Furthermore, the use of spatial information does not only allow a more accurate estimation of eventual upper-limits but also the modelling of the upper-limits as functions of spatially-varying variables such as fetch and depth. This can be done by basing the MRFA on the Generalised Pareto Distribution (GPD), which allows all types of tail behaviour, rather than on the conditional Weibull distribution. In fact, the results of WL | Delft Hydraulics (2007b) seem to suggest that the asymptotic distribution of the measurements of the 9 buoys offshore the Netherlands has a type III tail and hence that the significant wave height data have an upper bound.

The objective of Deltares (2009f) was to determine eventual upper-limits in the significant wave heights offshore the Netherlands, hence the distribution of the tail. Deltares (2009f) also investigated the correlations between the estimated upper-limits and the depth, as well as correlations between the shape parameter of the distributions of extremes and the depth. Both wave model hindcasts, the NEXTRA dataset, and measurements (with and without filling of gaps) of significant wave height data were considered and all analyses were omnidirectional.

Validation of the NEXTRA data against the raw measurements offshore the Netherlands has shown that the biases are low, the corresponding RMSEs generally below 40 cm, and that the data show some scatter and relatively high correlations. Furthermore, the NEXTRA data have the tendency to overestimate the extreme events and the error statistics are location dependent, which suggests that no simple data correction algorithm can be applied to them.

Upper-limits were estimated using both the GPD and a non-parametric method of Aarssen and De Haan (1994). No significant differences were found between the results of both methods.

The results based on the measurements show that there is a clear correlation between the bottom depth and the upper-limit estimates of H_{m0} . This correlation is stronger if based on the raw data than if based on the filled-in time series, which is not surprising since methods of filling-in missing values in time series are based on some sort of averaging and are not directly based on physics.

There are no significant correlations between the upper-limit estimates from the NEXTRA data and the associated bottom depth. The lack of depth-induced breaking in the wave model used to create the NEXTRA data seems to affect the characteristics of the H_{m0} extremes. The calibration of the model in terms of bottom friction does provide some depth related dissipation, but not enough to fully account for the depth induced breaking of the extreme wave heights. In fact, as noted by Enet (2007), the calibration of the NEXTRA wave model is not optimal for the area offshore the Netherlands, which limits the applicability of the NEXTRA dataset in an eventual regional frequency analysis.

Although the NEXTRA data compare reasonably well with the measurements (apart from some over-estimation of the most severe storms), the lack of association of their shape parameter estimates with depth suggests that the agreement between wave model and measurements does not hold in the tails. Consequently, we recommend that, regarding the determination of wave extremes along the Dutch coast, the NEXTRA dataset be ignored from now on, since it does not properly reproduce the tail behaviour of the measurements. It is still important, however, to complement the available measurements with more spatial information in order to better determine the spatial distribution of extremes and eventual upper limits. It would therefore be advisable to generate a long-term wave analysis dataset for the North Sea using a wave model in which all important shallow water physics (including depth induced breaking) are incorporated.

5.2.3 Spatial and directional extreme value analyses on wave period (KG3d)

The North Sea locations considered in the determination of HBC are finite depth locations, and the extreme waves there are supposed to be fetch- and/or depth-limited. Section 5.2.2 presents the results of an analysis of extreme significant wave heights using the Generalised Pareto Distribution (GPD) and correlations between the estimated upper-limits and water depth and between the tail index (the shape parameter of the GPD) estimates and water depth. The substantial correlations observed between the tail indices and depth justify the application of a Regional Frequency Analysis (RFA) in which data from different (depth) locations are used to smooth and reduce the uncertainty of the estimates. Since the mean wave period associated with a given extreme significant wave height is constrained by the wave steepness, we also expect the shape parameter of the mean wave period data to vary with water depth, and this begs for an analogous study on the mean wave period data.

Extremes of environmental variables are often associated with covariates such as direction, time (for instance when there is a trend or cycle in the data), depth, etc. In such cases, the extreme value analysis can be carried out by 'binning' or stratifying the data on the environmental variable of interest according to the values of the covariates. Thus, in the current determination of HBC for waves and wind the direction is taken as a covariate and accordingly the wave or wind data are divided into directional sectors and the parameters of the extreme value distributions determined separately for each sector. An alternative approach to this is to introduce the covariates directly into the parameters of the extreme value model and to estimate the model with the whole (as opposed to the 'binned') data. This approach may be advantageous because it involves fewer parameters and hence could yield more efficient (i.e. less variable) estimates.

Deltares (2010c) presents the following research activities:

- Analyses of the North Sea mean wave period measurements in the same way (using RFA) as the significant wave height data has been analysed in a previous study (Deltares, 2009f), determining estimates of eventual upper-limits and the correlation between the estimated tail indices and water depth.

- Analyses of extreme wave and wind data by means of extreme value models of varying complexity whose parameters are functions of direction.

The results of the analyses show that the tail index of mean wave period and the water depth have a high correlation, motivating the use of regional frequency analyses. However, it should be recognized that RFA estimates do not provide the best fits to the data at each location, and hence that, depending on the application, the best estimates may be those obtained separately by 'local' extreme value analyses. Therefore, if the goal is design/assessment at a particular location, our recommendation is that the local estimates be preferred. On the other hand, because the return value estimates enter into the HBC as offshore boundary conditions for the wave models, we recommend that for purposes of the determination of HBC the smoothed estimates provided by RFA over a region associated to a given depth be preferred.

The results also show that directional and omni-directional return value estimates can be reliably obtained by resorting to the models based on direction proposed here. However, the covariate-based models considered apply only to statistically independent (or uncorrelated) data, and efforts should be made to extend them to dependent data.

5.3 Guidelines EVA basis variables (KG3e)

At present, the activities foreseen within the framework of "Guidelines EVA basis variables" have been partially addressed in Deltares (2010b). It is expected that these activities will be further addressed within the framework of SBW-Belastingen 2011-2016.

5.4 Time/space scale problems (KG6a)

Deltares (2009a) identified potential problems with the present probabilistic approach. This approach does not seem to be able to handle so-called complex failure domains (see section 5.6) and complex water systems (e.g. Wadden Sea and Eastern Scheldt). Solving these problems, by means of a new safety approach, is not feasible for the HBC to be derived in 2011. Therefore, two actions are taken: (i) derivation of an ad-hoc short term solution and (ii) inventory of expert advice regarding a new safety approach. The results from these activities are presented in respectively section 5.4.1 and section 5.4.2.

5.4.1 Ad-hoc and short term solution

The SWAN model (used for deriving wave conditions inside the Wadden Sea) takes wind, water level and currents as input. In the HBC2006 setup as applied for the Holland Coast, the water level is assumed uniform over the area and the currents are neglected. The results of many SWAN simulations have been stored in a database and used as a transformation matrix by the probabilistic model Hydra-K to obtain nearshore wave conditions from wind and water level. The correlation between wind and water level has been derived from observed storms and extrapolated to extreme events.

There are, however, indications that this Hydra-K version is not equipped to efficiently model the physical processes leading to high water levels in the Wadden Sea. Alkyon (2008b) for instance, showed that a schematised storm with a constant wind speed and direction (over time) could not reproduce the observed water levels. Also, it is evident that currents have a great influence on wave characteristics in e.g. the Wadden Sea.

Taking into account the above, it is clear that there is a need for a new type of probabilistic model for the Wadden Sea. However, to develop such a model would take several years. For HR2011 this will be too late, so it is therefore necessary to keep on using Hydra-K. To take some of the above mentioned physical aspects into consideration for HR2011, a standard

storm profile can be used. In a new setup of SWAN calculations for Hydra-K, described in (Deltares, 2009r), the water level and current fields are calculated using the hydrodynamic model WAQUA, also taking wind as input. This model setup requires a typical storm profile (time evolution of wind speed and direction), which was the objective of Deltares (2010d). The following research topics are covered by Deltares (2010d):

- providing a standard model for the time dependency of wind speed and direction for usage in Hydra-K (WTI2011);
- investigating the correlations between the surge levels in the Wadden Sea and a number of meteorological variables, such as wind speed, wind direction, air pressure and temperature.

A selection of storms is used to derive a schematised profile for temporal variation of wind speed and direction. For the development of the wind direction distinction is made between westerly- and easterly-oriented storms.

The temporal variation of the wind speed is schematized with a trapezoidal profile with a base of 48 hours and a peak duration of 1 hour as suggested in Deltares (2009d). This schematization corresponds with results from a similar research for Hydra-B and Hydra-VIJ.

The temporal variation of the wind direction in the Wadden Sea is schematized with an error function. The analysis showed that the temporal variation differs significantly between peak storm directions. Therefore the temporal variation of the wind direction is derived for four directional bins. It is recommended to further analyse this directional dependency using methods that are more sophisticated. It should be noted that the found description for the temporal variation of the wind direction deviates from the temporal variation as applied for Lake IJssel and Markermeer. It is also recommended to analyse this difference in more detail.

The correlation analysis revealed that the wind speed is most strongly linear correlated with high surges. Several other weather conditions (cloud cover, temperature and wind direction) have weak linear correlations with the surge. The dependencies and correlations between the meteorological variables and surge that were found are not very pronounced, even for processes whose general physics is well understood. This suggests that their occurrence in the Wadden Sea is further complicated by other non-meteorological, say geographical, factors.

The results of the correlation analysis are only a preliminary step to a more advanced investigation of correlation between meteorology and surge. In order to be useful, the analysis should be extended to take into account more knowledge of physical relationships between the variables, non-linear relationships and spatial correlations of the variables. It is therefore recommended to perform further research in preparation for a new probabilistic model for Wadden Sea storm surges, which would resolve a number of limitations of the current Hydra-K model.

5.4.2 Expert advice

The current computations of the HBC rely mostly on the distribution of the basic variables at the peak of the storms. As a means of improving the quality of the numerical modelling with a view towards the 2017 assessment, it is envisaged that the numerical models (e.g. SWAN) will in the future use time and space varying wind fields and fields of the relevant variables (in the case of SWAN: offshore wave conditions, water levels and eventually currents) associated with extreme wind speeds. With these time and space varying fields the numerical

models will produce a set of time varying hydraulic loads along the water defences. The distributions of these loads are then to be used in probabilistic models in order to compute failure probabilities, enabling the evaluation of other failure mechanisms than overtopping (e.g. dune erosion, armour layer stability etc.). To fulfil this programme for the assessment round of 2017, the temporal and spatial evolution of the multivariate extreme events—the temporal and spatial evolution of wind, waves and water levels in a storm—need to be modelled somehow, up to a certain realistic level of detail and according to the needs and capabilities of the numerical and probabilistic models.

There are many possibilities as to how the temporal and spatial evolution of a (multivariate) extreme event can be described. There are also varying levels of detail in which this can be achieved. Given the many possible ways (including many ‘pragmatic’ ones) in which this could be done, it was deemed necessary to consult two leading experts in extreme value theory, Prof. Laurens de Haan and Prof. Richard L. Smith for their advice on how to approach such problem. I.e. how to model extreme time and space evolving multivariate extremes. Both experts have advised the use of max-stable processes. Prof. de Haan advises a method derived by him for this purpose. The method is both elegant and feasible and involves the extreme value analysis of the time series at each grid point, in order to determine the Generalized Pareto Distribution parameters for each grid point, and further a fully non-parametric approach to model the time and space evolution of each (say, 10,000 year) extreme event, by lifting the observed storms exceeding a certain threshold. Prof. Smith advises both a parametric and a non-parametric method. The non-parametric method shares some similarities with the method derived by Prof. de Haan, but differs in the way temporal and spatial evolution extreme events are selected. The proposed parametric method, although already applied to model spatial extremes, has not yet been applied to also model temporal evolutions and the mathematical theory of it is not yet complete. Some work needs therefore to be done in order to find appropriate models. Furthermore, it is also not clear whether such models, which use only a very limited number of parameters, will be able to realistically describe the complexity of storm fields.

5.5 HBC suite for Eastern Scheldt (KG7a)

At present, the activities foreseen within the framework of “HBC suite for Eastern Scheldt” have not been started. It is expected that these activities will be addressed within the framework of SBW-Belastingen 2011-2016.

5.6 Reliability functions for other failure mechanisms (KG8a)

The quality of the Hydraulic Boundary Conditions, as derived using the Hydra probabilistic models, is insufficient for a large number of cases. In some cases it is even not possible to derive the Hydraulic Boundary Conditions. BMT ARGOS & HKV (2008) give some examples for which the present version of Hydra-K can not derive hydraulic boundary conditions. The cause for a lot of the problems can be linked to the fact that the considered failure mechanisms result in irregular failure domains. An irregular failure domain is present when an increase in load variables does not increase the hydraulic load on the water defences, see Figure 5.3. The probabilistic concepts implemented in the Hydra-models are not always capable of handling these irregular failure domains because they implicitly assume regular failure domains.

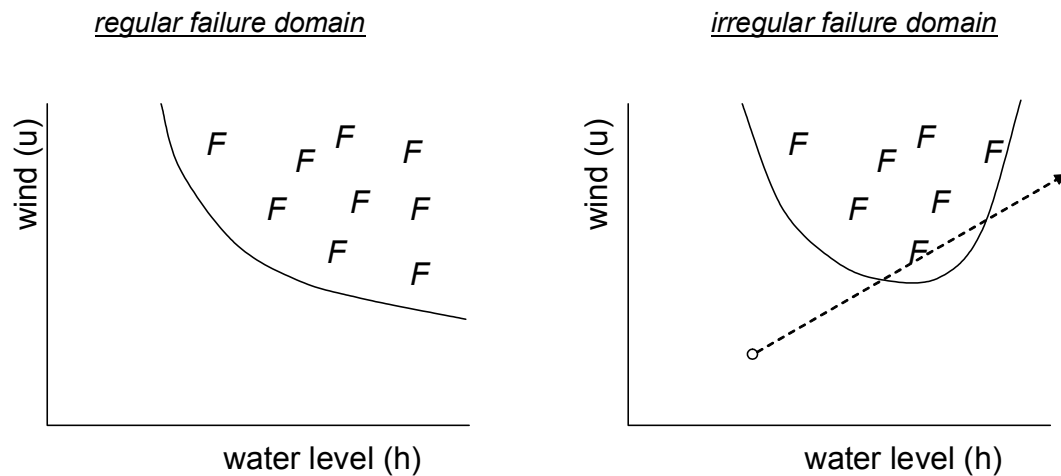


Figure 5.3 Regular and irregular failure domains, taken from HKV & BMT ARGOS (2009)

The development of Hydra-models that are capable of handling irregular failure domains will take a several years due to the complexity of the associated calculation methods. HKV & BMT ARGOS (2009) state the present problems with irregular failure domains as well as possible solutions and investigated the contribution of irregular failure domains to the problems with a number of failure mechanisms as implemented in the Hydra-models. The investigations showed that irregular failure domains are the main source of the problems for most failure mechanisms.

In addition to the failure mechanisms, time varying loads also contribute to the existence of irregular failure domains. The present approach of the Hydra-models uses one vector of loads (e.g. maximum water level and corresponding wind speed), whilst in reality the load varies over time during a threatening event. For reasons of simplicity, the hydraulic load is assumed to be one vector in the Hydra-models. However, the application of a single load may lead to an underestimation of the failure frequency. Adding time varying loads to the probabilistic approach will further increase the presence and extend of irregular failure domains.

The results from the investigations into occurrence of irregular failure domains are used to evaluate the applicability of alternative probabilistic approaches. This includes both alternative calculation methods as well as pragmatic corrections to the presently implemented probabilistic calculation methods (by means of adjusting the failure domain). The latter approach is somewhat unrealistic from a physical point of view, but is possibly easier to implement in the present Hydra-models and has a limited effect on the resulting failure frequency.

Within the framework of WTI, three options for short term inclusion of irregular failure domains have been investigated for implementation within the present Hydra-programs. These investigations led to a recommendation regarding the application of a Hydra-Q version that can be used for irregular failure domains (Deltares, 2010I).

5.7 Conversion point wind statistics to field information (KG10b)

Deltares (2010a) focused on the relation between the wind statistics at the individual measurement locations (KNMI stations) and the wind fields that are used as input in models that compute water levels, currents and waves as a part of the HBC assessment. The main goal of the study was, lacking a more fundamental approach, to retrieve the methods applied

for HR2006 to derive the wind fields from the point statistics for each water system, in order to be able to implement any update of the point statistics. In addition, the quality of the retrieved methods is discussed, by presenting an analysis of the newly derived data and - briefly - by discussing recently obtained wind measurement data near land water transitions.

The exact reproduction of the methods to derive wind fields for the HBC assessment from the point statistics at KNMI stations has not been achieved. However, where necessary, approximating approaches are proposed. The application of updated statistics (Deltares, 2009m) in these approaches may lead to differences with respect to the present wind fields that are not solely determined by the new statistics. However, given the uncertainties in extreme value analyses, these differences are relatively small. At present, lacking an immediately available validated alternative, spatial interpolation of potential wind speed return levels is advised, which fits in the present approach of the wind modelling for the HBC assessment. In this approach, however, pragmatic choices are still required, which may have a considerable impact on the resulting wind fields.

In the longer term, in order to develop well-substantiated wind fields over the water areas of interest, we need to understand the spatial variation in the wind statistics. However, especially the relationship between the wind statistics at inland sites and the wind statistics at sites near large water areas is unclear at present: the data do not support the modelling concept, see section 5.8. This problem, which has become known as the curvature problem in extreme wind statistics, must be addressed (see section 4.4.2).

There is no alternative available yet for the present modelling concept that is theoretically better and still practically applicable in terms of complexity. Therefore, the combination of the assumptions in the two-layer model and the schematization of the surface roughness of the Netherlands and its water areas are still basic components of the currently accepted modelling concept. Since these components have been implemented in the so-called Downscaling Model (Deltares 2010a), this model should play a key role in further modelling development and validation. The data from the dedicated measurement campaign in the Wadden Sea area are expected to contribute considerably to the modelling quality of spatial wind variations near land water transitions. This measurement campaign should become fully-operational as soon as possible. The same applies to the organisation of the validation activities.

5.8 Collection and analysis of measurement data (KG10c)

Section 5.7 describes the identification of the applied modelling concept for the conversion of point wind statistics to field information. It was concluded that no theoretically better, yet still practical, alternatives are presently available. This leads to large uncertainties associated with the wind fields used for HR2011. Nevertheless, there is a need for information regarding the position of the HR2011 wind conditions compared to alternative (but also plausible) approaches.

In order to assess the position of the applied wind fields used for HR2011 within the uncertainty range of extreme wind fields, the extreme wind conditions are determined by means of alternative statistics, reference stations and transformations via meso or macro level (Deltares 2010m). This analysis is performed for three water systems: Lake IJssel, Western Scheldt and Holland Coast. The effects of the wind statistics on the required crest heights are determined for a number of strategically chosen dike sections (e.g. dike sections for which wind has a large influence through water level and wave conditions).

The derived open water wind speed estimates obtained directly from the measurements are generally close to, although also generally higher than, those currently applied from HR2011. This is also the case for the estimates obtained via meso level. The estimates obtained via macro level are generally the highest. Thus, according to Deltares (2010m), the position of the HR2011 wind fields is at the lower limit of the values obtained by other approaches.

Application of the open water wind speeds derived through alternate methods for determination of the required crest heights showed that the resulting uncertainty in crest height is less than 7% (less than 1.2 metres) for all water systems except Lake IJssel. The latter is more sensitive to changes in wind speeds and shows an uncertainty of 25-35% (in excess of 2 metres, see figure below).

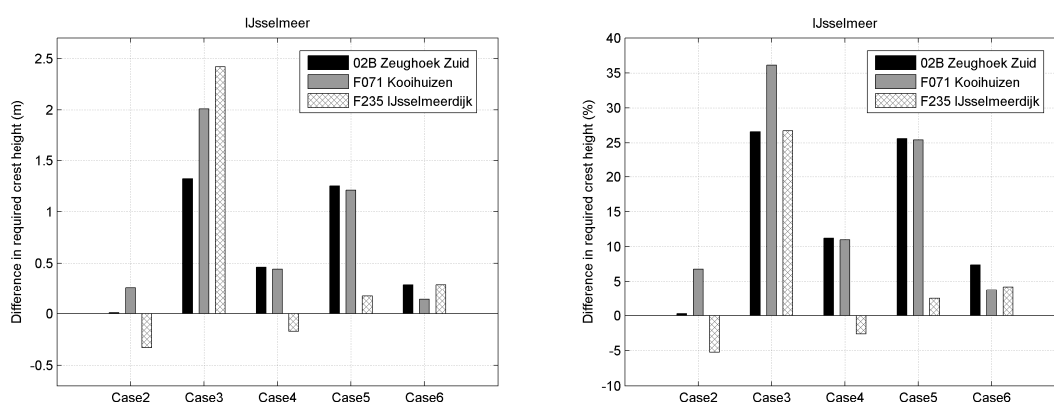


Figure 5.4 Absolute (left) and relative (right) difference in required dike crest heights for three locations along the IJsselmeer, relative to the reference case (Case 1, WTI). Source: Deltares (2010m)

The results from Deltares (2010m) showed that the applied open water wind speeds in the HR2011 are at the lower limit of the values obtained by other considered approaches. It is therefore recommended that all efforts are made to resolve the open water wind velocity knowledge gap so that the wind fields as applied in HR2011 can be improved. Based on this recommendation, a Scope of Work has been defined to investigate (and resolve) this knowledge gap.

The defined Scope of Work for obtaining more reliable time- and space varying wind fields consists of the following activities: (i) evaluation of applicability of present atmospheric models for deriving spatial wind fields, (ii) generation of a database with high resolution wind data to be used in the computations for the HBC and (iii) extreme value analysis on the extreme wind fields using the methods resulting from the activity described in section 5.3 (KG3e). The research will be performed by researchers from both KNMI as well as Deltares, ensuring maximum interaction between disciplines.

5.9 Standardisation and improvement wind drag modelling (KG11a-c)

At present, the activities foreseen within the framework of "Standardisation and improvement wind drag modelling" have not been started. It is expected that these activities will be addressed within the framework of SBW-Belastingen 2011-2016.

5.10 Wave-induced motion (KG13a)

Alkyon (2008b) performed hindcasts for the Eastern Wadden Sea and the Eems Dollard Estuary. A coupled hydrodynamic-wave model (modelled with Delft3D and SWAN) was used for the computations, allowing to include the effect of wave and wind-induced forcing.

The results showed that the contribution of the wave induced set-up ranges from 0.20 metres at Huibertgat to 0.45 metres at Lauwersoog. This contribution is considered to be significant and should be included in the calculation of the Hydraulic Boundary Conditions.

The presently used hydrodynamic and wave models in the HBC model suite are respectively WAQUA and SWAN. The present version of WAQUA does not allow for a (online) coupling with SWAN. Therefore WAQUA has been extended to allow for offline coupling between WAQUA and SWAN (Vortech Computing, 2009): SWAN results are included as forcing of the hydrodynamic model.

The offline coupling has been implemented and tested for one specific case. Further testing and implementation of online coupling may be realized after the calculation of the HR2011. Since it is unclear whether the combination of WAQUA and SWAN will be used for the next rounds of HR calculations (HR2017 and beyond), further testing and implementation has been put on hold.

5.11 Effects of bed changes (KG15b)

Morphological changes during a storm are not taken into account in the calculations of the HBC. Rather, the models are run with a recently measured bathymetry. However, the measured bed levels consist of inherent inaccuracies and are subject to changes due to morphological changes and/or policy changes. Three different time scales can be distinguished for changes in the bed levels: a period of several years, the period between bed loading and the actual storm event and the period during a single storm. At least the changes during the latter period should be included in the determination of the hydraulic boundary conditions at the primary coastal structures. In 2007 a study was carried out (WL | Delft Hydraulics, 2007a) investigate the effects of neglecting morphological changes during a yearly-averaged storm. One of the main conclusions of that study is that no significant impact of the short-term bed level changes during a yearly-averaged storm was found in the computed wave characteristics at the toe of the Frisian dikes. WL | Delft Hydraulics (2007a) recommends to perform a similar analysis for a more extreme (1:4000 year) storm.

Deltares (2008c) complies with the recommendation to perform a similar investigation to the impact of bed level changes during an extreme 1:4000 years storm, since the HBC are based on such an extreme condition. The study was performed within the framework of SBW-Wadden Sea. The results are presented in this synthesis report because it covers a specific knowledge gap (KG 15b) mentioned in the list of knowledge gaps for SBW-Belastingen.

Deltares (2008c) showed that the morphological activity due to a 1:4000 years storm can result in bed level changes of several meters. The largest bed level changes (> 5 m) occur at the outer delta of the Ameland Zeegat and in the tidal inlet (scour). Bed level changes of up to 1 m are computed inside the Wadden Sea from the Ameland Inlet to about 4 km off the Frisian sea dikes. Close to the Frisian sea dikes, the bed level changes are smaller (<2 dm).

Stationary wave computations have been performed (following the procedure for HBC-computations) on a bathymetry prior and after the 1:4000 years storm event. Differences in wave heights up to 1 m were found at the outer tidal area. Inside the Ameland Zeegat, the differences are less, but they may still be up to 0.5 m. From the tidal inlet towards the Frisian sea dikes, the impact of the short-term bed level changes that occur during a 1:4000 years storm on the wave characteristics is found to reduce. However, at the toe of the Frisian dikes the impact on the wave height is still observable; an increase in wave height has been predicted in the order of several cm's to one dm. At the Frisian sea dikes, the mean absolute

wave period is also affected by the changed bathymetry. A maximum increase of 0.2 s can be expected.

It is recommended to pay attention to the applied bathymetries in the various models used for the derivation of the HBC, because the present study shows that bed level changes during an extreme storm might influence the wave characteristics near the Frisian sea dikes. Such an effort does not fall within the SBW-Belastingen project, but should be assessed within WTI. It is however expected that the uncertainty in the applied bathymetry does not cause the largest part of uncertainty in the modelled wave height near the Frisian sea dikes. Other sources of uncertainties like the modelled water level will have a more significant impact on this.

5.12 Analysis of wave measurements / model prediction Lake IJssel (KG16b)

At present, the activities foreseen within the framework of “Analysis of wave measurements / model prediction Lake IJssel” have not been started. It is expected that these activities will be addressed within the framework of SBW-Belastingen 2011-2016.

5.13 Wave models on rivers (KG17a)

At present, the activities foreseen within the framework of “Wave models on rivers” have not been started. It is expected that these activities will be addressed within the framework of SBW-Belastingen 2011-2016.

6 Results long-term activities

6.1 General

Most of the long-term activities have not been started yet. The results of the activities that have already been initiated are presented in this chapter: (i) integration of physics in statistics, (ii) new safety approach and (iii) quantitative uncertainty analysis. Activities not mentioned in this chapter have not been initiated at the time of writing of this synthesis.

6.2 Integration of physics in statistics (KG4a)

The water levels used as Hydraulic Boundary Conditions are derived for return periods up to 10.000 years. The basis for these water levels is formed by a time-series of water levels of approximately 100 years. The extrapolation of the time series to the extremes assumes that the extremes follow the distribution of the highest observations. This approach neglects the available knowledge regarding the aspects that influence the distribution of extremes.

A possible alternative is the application of numerical models that describe the wind climate and corresponding extreme water levels (see Figure 6.1 for an example). This approach would allow for the simulation of 10.000 years of wind forcing and water levels along the Dutch coast. This will generate synthetic time-series that can be used for the determination of the extreme values, but now including the physics that influence the distribution of the extremes.

A workshop has been organized to investigate the possibilities for applying climate models for the determination of the Hydraulic Boundary Conditions. Deltares (2009o) presents the results from the workshop:

There are good arguments for the application of climate models:

- The present time-series are too short for the derivation of extreme values with the desired accuracy/confidence limits. Model simulations can produce extreme long time-series.
- The physics within the Wadden Sea are too complex to neglect dynamic storm behaviour. Simulation of extreme storms with numerical models is preferable above the present probabilistic approach of Hydra-K.
- Model simulation will implicitly take the spatial cohesion and correlation between individual parameters into account.
- Model simulations can take the effect of climate change into account, so that the effects of climate change on the Hydraulic Boundary Conditions can be investigated.

A potential problem with the application of climate models is the fact that these are based on observations (and thus processes) over the past 100 years, which may not be representative for a longer period. If the real extremes are governed by processes that are not present in our observations, then the model will not be able to predict these extremes. This holds for both the statistical and numerical approach, since both are based on measurements and knowledge obtained from measured events.

Another problem with the application of atmospheric models is the fact that processes can either not be modelled due to the coarse grid size or that processes are too complex to be modelled. In general, this is solved by applying a parametric description of the process. The effects of these parameterisations on the extreme conditions are not fully known.

One of the weakest points in the application of the model train is the coupling between the atmospheric and hydrodynamic model. The present formulations for energy transfer make use of a so-called drag coefficient, which is “basin dependent” since it is used as a calibration parameter. It would be better to use a wind shear stress, but this is still not realistic. Most important recommendation is to use identical definitions for the energy transfer for all atmospheric and hydrodynamic models.

A large advantage of the application of numerical models is the possibility to gain insight in the physics corresponding to extreme, not yet occurred, situations. Such insight can provide confidence in the results and possibly result in recommendations for further research.

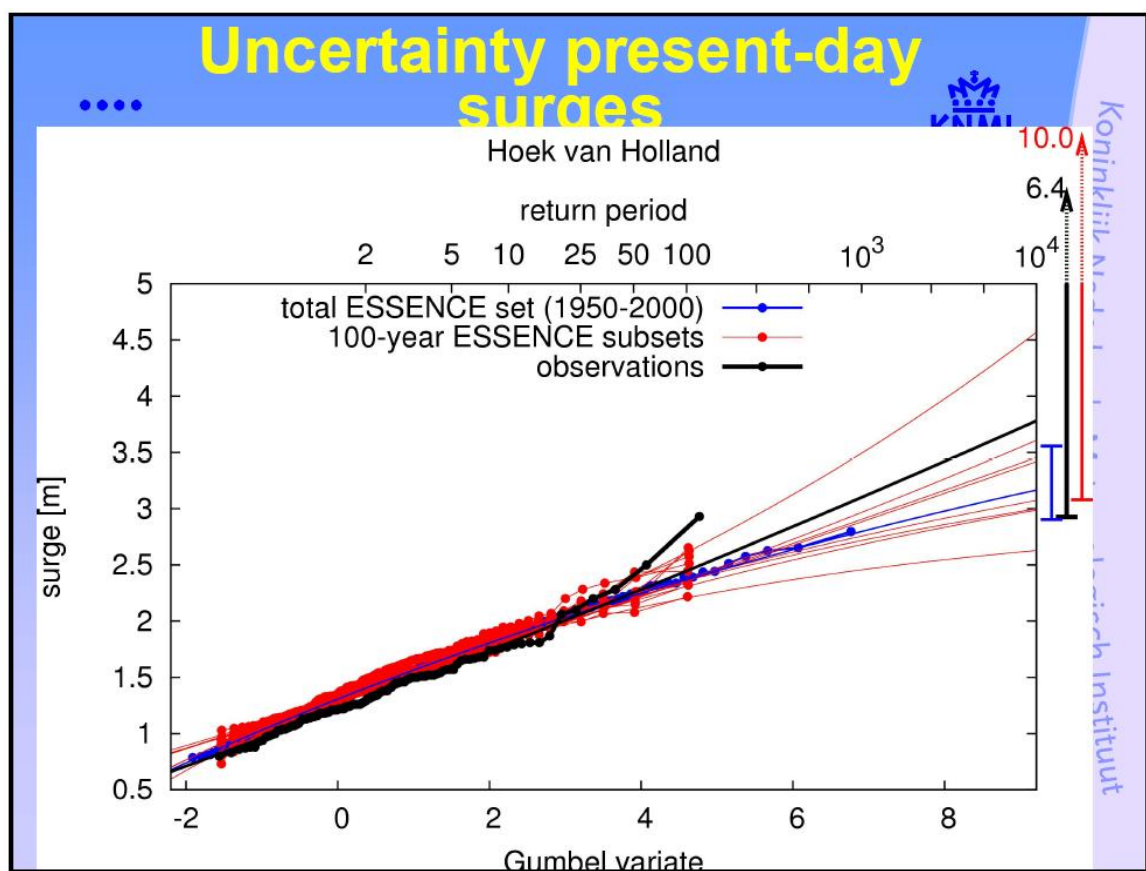


Figure 6.1 A straightforward example of the application of a coupled climate (ECHAM) and Hydraulic (WAQUA) model from the presentation of the KNMI (A. Sterl) during the workshop: A set of 17 simulations (ensemble) over the period 1950-2000 (present climate) from the ESSENCE-project were applied to create timeseries of the surge at Hook van Holland. Subsets of 100 years, comparable with the available time series of measurements, were created. The red dots and lines are GEV-fits (Generalized Extreme Value distribution on year maxima) on the 100 years subsets. The blue dots and line correspond with the year maxima of the total ESSENCE set (17 times 50 years). The black line was derived from the measurements over the period 1887-2004. On the right side the corresponding confidence intervals for the surge estimate with a return period of 10.000 years are shown.

The above mainly focuses on the integration of atmospheric and hydrodynamic physics in statistics. Aside from these aspects, there is also the morphological development during extreme conditions. This morphological development should also be integrated in the physics. However, it is expected that this will not be an easy task. It is therefore recommended to develop a method for including morphological developments in the statistics.

6.3 New safety approach (KG9a-c)

The determination of the Hydraulic Boundary Conditions makes use of various probabilistic models. A significant amount of knowledge and insights on these probabilistic models has been developed during the past years. Despite this fact, some questions still remain, amongst which:

- How do the present probabilistic models handle complex or irregular failure domains?
- How do the present probabilistic models handle hydraulic loads and failure mechanisms for which time dependency plays a significant role?

Deltares (2010g) describes results from a workshop held with experts in the field of probabilistic modelling during which, amongst others, the above questions are discussed. During the workshop it became clear that the present approach used in Hydra-Q does not meet the requirements. However, some of the participants of the workshop agree that the present approach is the best available approach at this moment. Most of the participants agree that accurate probabilistic models do exist (e.g. Crude Monte Carlo), but that achieving sufficient accuracy would require a significant computational effort.

The next step in improving the probabilistic models may be the inclusion of time dependent load and strength functions. Inclusion of the time dependency is however not a simple task and will most likely result in an increase of complexity and computational effort.

Deltares (2010g) concludes with recommending investigations into (i) the “error” introduced by the Hydra-Q approximation, (ii) whether or not Hydra-Q results in conservative hydraulic loads, (iii) the quality of the final hydraulic boundary conditions, (iv) inclusion of the time dependency of loads and failure mechanisms and (v) with less priority the development of new probabilistic approaches.

The main research question raised during the workshop was the “error” introduced by the present Hydra-Q approximation. This topic was considered relevant enough to investigate before starting research into a new prototype of the probabilistic model. The result of this investigation led to the implementation of a dedicated Hydra-Q variant (see section 5.6), which is considered to be adequate for the HBC of 2011. The development of a new probabilistic model should solve (or possibly obviate) the problems with irregular failure domains) more fundamentally for the HBC of 2017.

6.4 Quantitative uncertainty analysis

Within the framework of the project SBW Belastingen, several research projects were carried out in 2009 related to the estimation of hydraulic boundary conditions at primary water defences. Three of these research projects focussed on extreme wind speed statistics, storm surge duration, and the seiches effect. Deltares (2010e) assessed the effect that this research has had on uncertainty in both the quantities themselves and in the design water level. Results of these uncertainty analysis are included in the results of the investigated knowledge gap.

A fourth study, Deltares (2010o) focussed on the effect of uncertainty in the water level distribution on critical dune erosion (expressed in retreat distance with an exceedance frequency of 10^{-5} per year). A semi-probabilistic dune-erosion method was developed for the 2006-2011 round of assessments, within the project SBW-Duinen. This method uses probability distributions to capture the uncertainty in input variables (e.g. grain diameter). The extreme water level distribution is one of the inputs into the model; the uncertainty in the

distribution (while acknowledged to be large) is not considered in this semi-probabilistic method. It is however expected that the uncertainty in the water level distribution has a significant impact on the critical retreat distance.

In order to include the uncertainty of the water level distribution in the probabilistic model, this uncertainty had to be determined because it was not readily available. The effect of including the uncertainty in the water level distribution in the probabilistic dune-erosion model was determined for five locations along the Dutch Coast. The results showed that the influence of the uncertainty in the water level distribution on the critical retreat distance was significant: increased critical retreat distances ranged from 34% to 93% of the original estimate.

A second set of computations was performed with a reduced uncertainty in the water level distribution. This reduced uncertainty was implemented in a simple and pragmatic way, and was analysed to assess what impact reduction in uncertainty of the water level distribution has on the critical retreat distances. This was particularly considered relevant for two reasons: 1) the water level distribution includes information from physically-based numerical models, which should reduce the uncertainty in the distribution but was not taken into account in the uncertainty estimates, and 2) if the reduction in the uncertainty has a strong impact (i.e. a strong reduction in the retreat distance increases), then research into a (more) accurate determination of the uncertainty in the water level distribution can be prioritised. The effect was increases in retreat distance of 10% to 26% of the original estimates at the five locations, representing a strong decrease relative to the full-uncertainty case (see previous paragraph).

Finally, the probabilistic first order reliability method (FORM) was used to derive the relative importance of each of the input variables. This analysis showed that the relative contribution of the uncertainty in the water level distribution is of the order of 10 to 20%.

Deltares (2010o) concludes that the exclusion of the uncertainty in the water level in the semi-probabilistic model for dunes is unfounded and can result in a substantial underestimation of the critical retreat distance. The analysis also showed that the results are quite sensitive to the estimated uncertainty in the water level distribution. The uncertainty in the water level distribution as derived in this study does not take into account physical knowledge. Given the substantial contribution of the uncertainty in the water level distribution to the critical retreat distance, it is recommended to further investigate the reduction in the uncertainty caused by incorporation of physical knowledge.

Figure 6.2 shows the dune retreat frequency of exceedance (with critical retreat distance indicated) for the three cases of no uncertainty, (full) uncertainty, and reduced uncertainty at example location Den Helder.

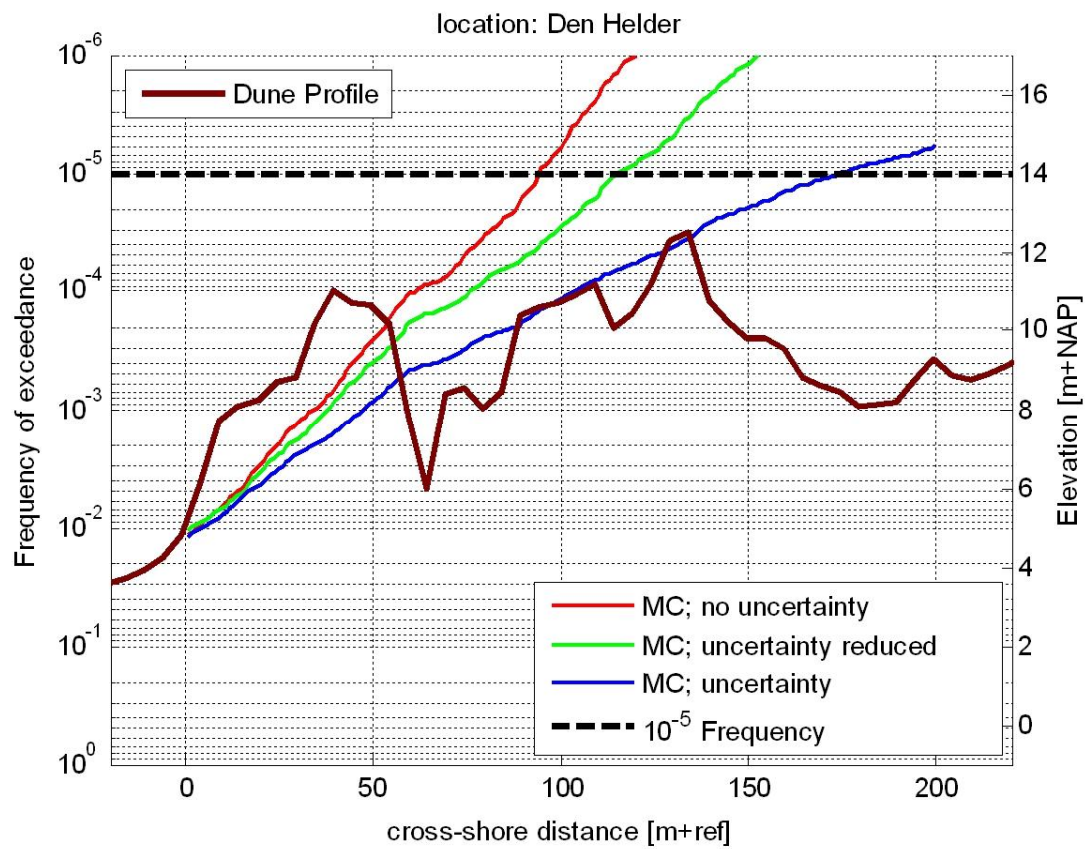


Figure 6.2

Critical dune retreat distance for three cases: no uncertainty, uncertainty, and reduced uncertainty at example location Den Helder. The dune profile is also shown (right axis).

7 Recommended activities for SBW-Belastingen 2011-2016

7.1 Introduction

The SBW programme for 2011-2016 should on one hand focus on the remaining knowledge gaps of Deltares (2009a) and on the other hand use the gained insight to adjust or add knowledge gaps mentioned in Deltares (2009a). This chapter presents the remaining activities (section 7.2) as well as the additional identified knowledge gaps (section 7.3).

7.2 Remaining knowledge gaps from Deltares (2009a)

7.2.1 Short-term activities

Mainly due to prioritization, a number of short term activities have not or partially been carried out within the period 2008-2010. These are:

- Evaluation of hydrodynamic modelling (KG14a)
- Verification of SWAN model "Open Coast" (KG15ai)
- Verification of SWAN model "Lakes" (KG16a)
- Further analysis quality aspects and translation into criteria (-)
- Viability test and verifying implications for technical activities (-)

The activities related to the verification of the SWAN model (KG15ai and KG16a) are partially carried out. In order to finalise these activities, the obtained knowledge has to be transferred to the Hydraulic Boundary Conditions. This holds especially for the estimation/determination of the expected uncertainty in crest elevation due to the uncertainty in the SWAN model for these regions.

The evaluation of the hydrodynamic modelling has not been started yet. Deltares (2009n) found that the uncertainty in the HBC could be up to several decimeters, which is the highest of all remaining short-term activities. Since the hydrodynamic modelling forms a major part of the HBC chain, it is recommended to give this knowledge gap a high priority in the SBW-Belastingen project for 2011-2016.

The last two remaining activities concern the transfer of knowledge developed within SBW-Belastingen to, for example, WTI. As already observed in section 3.5, this transfer of knowledge is not yet achieved for all activities. In addition, there are no specific criteria with respect to the form and quality of the transferred knowledge. The development of the criteria and verifying implications needs to be given a high priority, in order to ensure that the developed knowledge within SBW-Belastingen contributes to its maximum extend to the SBW project and other projects.

Activities with respect to the "Vrijling method" as an alternative for the presently applied probabilistic methods in Hydra-K have been put on hold because investigations into the probabilistic models have shown that the present approach may not be adequate at all for the future (HR2016). The activities should remain on hold until a decision is made regarding the probabilistic model to be used for future Hydraulic Boundary Conditions.

7.2.2 Mid-term activities

As expected, a larger number of mid-term knowledge gaps have not been investigated yet. It concerns the following knowledge gaps:

- Collection and analysis of measurement data (KG10c)
- Standardisation and improvement of wind drag modelling (KG11a-b)
- Analysis wave measurements / model prediction Lake IJssel (KG16b)
- Wave models on rivers (KG17a)
- Guidelines EVA basis variables (KG3e)
- Time/space scale problems (KG6a)
- HBC suite for Eastern Scheldt (KG7a)

During the period 2008-2010, a lot of knowledge gaps with respect to point statistics of wind are investigated. This resulted in state of the art extreme wind statistics at KNMI measurement locations which can be used in the HBC chain. The next step in the HBC chain is the transformation of these point statistics to spatial wind fields to be used in the models. Knowledge gap KG10c covers this aspect and, together with knowledge gap KG11a-b, prevent a substantial gain in uncertainty of the HBC. Activities related to knowledge gap KG10c and KG11a-b should therefore be given a higher priority.

The SBW-Wadden Sea project solved a large number of knowledge gaps related to the wave model SWAN⁷. These knowledge gaps, and their solutions, are mainly focused on the estuaries. However, waves and/or the wave model SWAN also play a role in the inland water systems like lakes and rivers. The applicability of SWAN for the lakes has already been investigated and is considered reasonable. There are however some uncertainties when applying SWAN for inland lakes, although probably not that large, that need to be investigated. The same holds for the determination of wave conditions on rivers: given the fact that wave conditions are often limited in rivers, the effect of uncertainty in the prediction of these waves are also limited. Especially since there is already an allowance for waves included in the rules for assessing the primary river defences. The activities related to knowledge gaps KG16b and KG17a should therefore probably have less priority than KG10c and KG11a-b.

The last remaining mid-term knowledge gaps concern the probabilistic approach of the various water systems. Within the framework of the long-term activities, investigations into a new safety approach have been started. The knowledge gaps KG6a and KG7a are strongly related to this new safety approach. It is therefore recommended to put the activities for these knowledge gaps on hold until decisions have been made regarding a new safety approach.

The knowledge gap with respect to wave-induced motion has been put on hold because it is not certain whether or not the combination WAQUA-SWAN will be used for the (possible) recalculation of the HBC in 2016. It is recommended to place this decision high on the priority list, because implementation and testing/validation of the combination WAQUA-SWAN will take some time. A decision to use WAQUA-SWAN for HR2016 should be made before 2012 in order to be sure that the coupling can be made operational.

7. *Not all knowledge gaps related to SWAN could be solved within the SBW-Wadden Sea project, amongst which the penetration of low frequency wave energy towards the primary sea defences in the Wadden Sea. This specific and other knowledge gaps are transferred to the successor of SBW-Belastingen and SBW-Wadden Sea and discussed in section 7.3.*

7.2.3 Long-term activities

Most of the long-term knowledge gaps have not been addressed within the 2008-2010 period of SBW-Belastingen. The remaining knowledge gaps are:

- Transfer to wind field information using model data (KG10d)
- Further analyses of bottlenecks and solution directions regarding the transformation of point to field wind statistics (KG10d)
- Seiches modelling (KG12b-c)
- Further research into hydrodynamic modelling (KG14b)
- Analysis and validation of relevant wave aspects (KG15a-iv)
- Integration of model data in statistics (KG5a)
- New safety approach (KG9a-c)

Most of the knowledge gaps specified above concern a further reduction of the uncertainties. The required effort for solving (if possible) these knowledge gaps is significant, obviously since they are considered to be long-term knowledge gaps. Because of the timescale for solving these knowledge gaps, it is recommended to start with these knowledge gaps by performing a preliminary analysis of potential improvements to the HBC by solving these knowledge gaps. This will help prioritising these knowledge gaps and obtain insight into the required information/measurements (which often takes time to acquire). This holds for knowledge gaps KG10d, KG12b-c, KG14b, KG15a-iv and KG5a.

Knowledge gap KG9a-c is a special case. The short- and mid-term investigations have shown that the present probabilistic approach has its limits. The implementation of other failure mechanisms than already implemented is not possible (pragmatic approaches are possible in some cases) within the present probabilistic approach. Since the development of a new safety approach will require a significant effort, it is recommended to investigate the error introduced by the pragmatic approach (and thus evaluating whether a pragmatic approach is feasible).

The investigations into the knowledge gap “Integration of physics into statistics” has been put on hold. A workshop was organised to investigate the possibilities of using a combination of climate models and hydrodynamic models to derive synthetic time series. It was however concluded during the workshop that (i) the present climate models are not yet able to provide the detailed information (time- and space scales) required for the hydrodynamic models and (ii) the interface between the climate and hydrodynamic models (e.g. shear stress at the surface) needs to be investigated first (which is part of KG 11a-b).

7.3 New insights: additional knowledge gaps

The research performed within the SBW-Belastingen project, SBW Wadden Sea (Deltares, 2009i and Dongeren et al, 2010) as well as WTI have led to new insights that subsequently led to additional knowledge gaps. The first (and largest) addition to the knowledge gaps is the time-dependency of the hydraulic loads. Up to now, the Hydraulic Boundary Conditions are derived for one moment during the storm (peak storm). This moment is chosen such that it represents the normative load for crest height. This is however not, by definition, the normative load for the revetments or dune erosion. Within the framework of WTI, this has led to the recommendation to include time dependency in the Hydraulic Boundary Conditions, which is subsequently being transferred to a knowledge gap for SBW-Belastingen. This time-dependency contains three main knowledge gaps: (i) can we derive marginal statistics for the time-dependent variables (theme “statistics”), (ii) are the present load models capable of deriving accurate time-dependent conditions (theme “physics”) and (iii) how do we derive/present the normative loads for the various failure mechanisms (theme “probabilistics”).

The present WTI-approach considers the failure of one dike section. A more sophisticated approach would be to consider the entire system of primary defences protecting a certain area (so-called “dikering-approach”). This approach is already available to some extent: it only considers wave overtopping and it assumes that the normative load is occurring simultaneously at each dike section. The WTI-project has identified this as a knowledge gap and transferred this to SBW-Belastingen. Within SBW-Belastingen this leads to the following knowledge gaps (partly corresponding to the knowledge gaps for the time-dependency): (i) can we derive marginal statistics for the time/space-dependent variables (theme “statistics”), (ii) are the present load models capable of deriving accurate time/space-dependent conditions (theme “physics”) and (iii) how do we derive/present the normative loads for the various failure mechanisms with a so-called “dijkring”-approach (theme “probabilistics”).

With respect to the physics, the SBW-Belastingen and SBW Wadden Sea projects recommend to further investigate (i) spatial and temporal extreme wind fields, (ii) the underestimation of the low-frequency wave energy penetrating from the North Sea towards the toe of the primary sea defence, (iii) wave-current interaction and (iv) wind induced water level and flow velocity/direction modelling by means of validation with measurements. Items (i) and (iv) are relatively new and have gained in priority, whilst items (ii and (iii) are mostly the result of further enhancement of the existing knowledge gaps.

8 References

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A List of Abbreviations

Abbreviation	Explanation
Atlantis	Project for the application and development of the SIMONA software suite and associated model setups. Successor to the RIKZ project Nautilus.
B&O Hydra	Hydra maintenance and development. Project for the maintenance and development of Hydra applications.
Delft3D	2D/3D modelling system to investigate hydrodynamics (module FLOW), sediment transport and morphology (module SED) and water quality (module WAQ) for fluvial, estuarine and coastal environments.
DG Water	Directorate-General for Water Affairs. Policy making part of the Ministry of Transport, Public Works and Water Management (in Dutch 'Ministerie van Verkeer en Waterstaat').
ENDEC	ENergy DECay. 1D Wave model (dated).
ENW	Expertise Network for Flood Protection. Platform bringing together specialists in the area of flood protection and address for guidelines and technical reports in this field.
ENW-Rand	ENW-Hydraulic Boundary Conditions. Temporary workgroup within ENW: advisory committee for hydraulic conditions for safety assessment.
EVA	Extreme Value Analysis. Method for determination of extreme values from time-series
GEV	Generalized Extreme Value distribution. Family of continuous probability distributions developed within extreme value theory, applied to describe maxima of a sequence.
GPD	Generalized Pareto Distribution. Family of continuous probability distributions developed within extreme value theory, applied to describe peaks over a threshold.
GRADE	Generator of Rainfall And Discharge Extremes. Model for generating (synthetic) precipitation and discharge records covering thousands of years.
HR (HR20xx)	Hydraulic Boundary Conditions, if used in combination with a year than it concerns the Hydraulic Boundary Conditions as established in that year.
HBC	Hydraulic Boundary Conditions. Hydraulic Boundary Conditions, part of

	the WTI.
HBC&VTV	Combination of HBC and VTV (HBC&VTV = WTI).
HIRLAM	High Resolution Local Area Model. HIRLAM is a European cooperative scientific programme developing a high resolution numerical weather prediction system for the synoptic scale and the mesoscale.
HISWA	HIIndcast Shallow water WAVes. 2D Wave model, second generation (dated).
Hydra	Hydraulic Boundary Conditions. Family of PC applications for the assessment of the HBC at specified locations in the Netherlands.
KNMI-HYDRA	Project of KNMI, RIKZ and RIZA, aimed at updating the extreme wind statistics in the Netherlands.
Hydra-B	Hydra Tidal Rivers. Hydra for the tidal river area of Rhine and Meuse.
Hydra-K	Hydra Coastal. Hydra for coastal areas.
Hydra-VIJ	Hydra Vecht and IJssel delta. Hydra for the delta of IJssel and Vecht.
IMPLIC	1D hydrodynamic model (dated).
KNMI	National institute for weather, climate research and seismology. Agency of the Ministry of Transport, Public Works and Water Management (Ministerie van Verkeer en Waterstaat).
NEXTRA	NEXT ReAnalysis. Dataset consisting of long-term wind, wave, surge and current hindcast datasets, covering an area which includes the North Sea.
PC-Overslag	PC-Overtopping. PC application for the assessment of wave overtopping of a dike.
PCRing	PC application for the probabilistic assessment of the safety of dike rings, applied in VNK.
RIKZ	National Institute for Coastal and Marine Management. (Formerly) part of Rijkswaterstaat for Coastal and Marine Management.
RIZA	Institute for Inland Water Management and Waste Water Treatment. (Formerly) part of Rijkswaterstaat for Inland Water Management and Waste Water Treatment.
RWS	Directorate-General for Public Works and Water Management (Rijkswaterstaat). Agency of the Ministry of Transport, Public Works and Water Management (in Dutch 'Ministerie van Verkeer en Waterstaat').
SBW	Strength and loads on water defences. Research and development

	project, aimed at filling knowledge gaps pertaining to the WTI assessment.
SIMONA	Modelling suite of Rijkswaterstaat for the simulation of water aspects.
SOBEK	SOBEK is a 1D and 2D instrument for flood forecasting, drainage systems, irrigation systems, sewer overflow , ground-water level control, river morphology, salt intrusion and water quality.
STOWA	Foundation for Applied Water Research. The foundation coordinates and commissions research on behalf of a large number of local water administrations: 26 water boards, the provinces and the Ministry of Transport, Public Works and Water Management.
SWAN	Simulating WAVes Nearshore. 2D Wave model, third generation
UBW	Uniforming Loads on Water defences. Research and development project, aimed at enhancing the uniformity of the modelling of loads on water defences within the probabilistic context.
VNK (VNK2)	Flood Risks and Safety in the Netherlands (Floris). Explorative study into flood risks and safety, following a new approach that focusses on dike rings instead of separate dike sections.
VTV	Statutory assessment rules. Rules for the statutory safety assessment of water defences in the Netherlands, part of the WTI.
WAQUA	WATER QUALity. 2D Hydrodynamic model (also a part of SIMONA).
WTI	Statutory Safety Assessment Suite (Wettelijk Toets Instrumentarium) Data and rules for the statutory safety assessment of water defences in the Netherlands (WTI=HBC&VTV).
WTI-2011	Project aimed at delivering the WTI edition of 2011.
WV21	Water Safety in the 21st century. Explorative study into the broader chain of safety against flooding (instead of just flood prevention).