Memo

To
Marcel Bottema, Rijkswaterstaat Waterdienst

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Subject
Storm duration at Hoek van Holand

Author		version	Date	Review		Approved by	
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1 Background

In the Netherlands, every five years a safety assessment is performed of the flood defence system along the primary waterways. For this purpose, Hydraulic Boundary Conditions (HBC), consisting of a representative extreme combination of water level and waves, are derived for all dikes, dunes and dams. The current HBC were established in 2006 (HBC2006); the next will be established in 2011 (in the project WTI2011). For the tidal area of the Rhine-Meuse delta the HBC are derived with the probabilistic computation tool "Hydra-B". The one-dimensional hydrodynamic model Sobek is used to set up a database for Hydra-B that consists of water levels along the river for different conditions. These conditions are combinations of the 5 variables sea water level, river discharge, wind speed, wind direction and the state (open/close) of the flood barriers. Hydra-B subsequently combines the Sobek results with statistical features of the 5 variables to compute the probabilities of exceedance of water levels along the river.

In order to simulate a storm event, the Sobek model requires information on the evolution of the *potential* wind speed at 10 m. height over the course of a storm. For HBC2006 the following approach was used[2]

- the evolution of the wind speed in time is schematised as shown in Figure 1.1;
- different values of maximum wind speed, U_{max}, were applied in the simulations: 0, 10, 20, 30 and 42 m/s;
- the storm duration, D_w, is defined as the duration that the wind speed exceeds 10 m/s;
- the storm duration, D_w, is independent of the maximum wind speed, U_{max}.

In this memorandum both the terms storm duration and storm surge duration are used. Storm duration is about (potential) wind speed, while storm surge duration is about surge.

For HBC2006 (and HBC2001) the storm duration, D_w, was assumed to be equal to the duration of the storm surge hydrograph, i.e. 29 hours. Over the years, several experts, for example Van

Weerden et al[4], have questioned the value of the storm surge duration, stating that 29 hours is probably an underestimation. Therefore, the duration of the storm surge hydrograph has recently been recalculated[1]. It was proposed that 40 hours would be a more realistic estimate of the average storm surge duration for Hydra-B

The proposed increase of the storm surge duration in the Sobek simulations for Hydra-B may have consequences for the assumed (wind) storm duration. It does not mean, however, that the storm duration has to be increased with the same number of hours as the increase of the storm surge duration. Even though storm duration and storm surge duration are strongly linked, they are not the same. Therefore, it was decided to analyse storm durations at location Hoek van Holland separately. This memorandum describes the most relevant results and proposes a new value for the storm duration to be used in the Sobek simulations for Hydra-B.

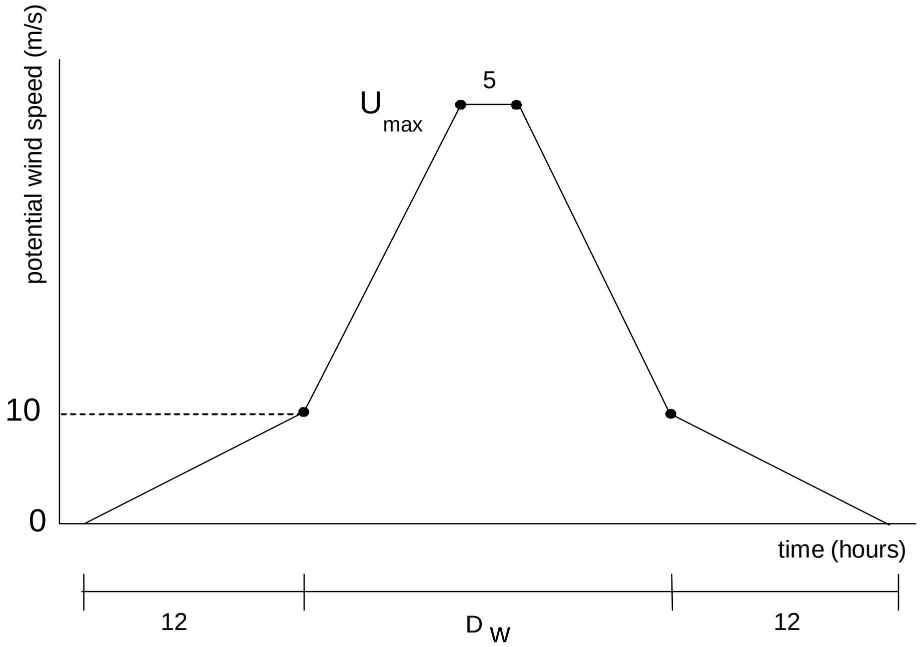

Figure 1.1 Assumed temporal evolution of the wind speed with duration D_w hours and peak value U_{max} (m/s) for HBC2006[2]

2 Objective of this research

It is the aim of this research to determine the average (wind) storm duration for application in Hydra-B. Due to time limitations within the project WTI2011, Hydra-B cannot be rigorously changed in the process of deriving the HBC for the year 2011. This research therefore focuses on deriving the storm duration applicable for the current version of Hydra-B, specifically the requirement of a single peak storm event with a duration independent of the peak wind speed U_{max}. Changes in this concept, such as more complex storm shape or dependence between D and U_{max}, were explored, but only in view of the possible need for future changes.

The temporal evolution of the wind speed as currently used in Hydra-B (Figure 1.1) is not well documented and is inconsistent with the one currently used in Hydra-VIJ (the probabilistic computation tool for the delta of the IJssel and Vecht rivers). In a recent analysis of storm duration for the Vecht and IJssel delta[3], the temporal evolution of the wind speed for Hydra-

VIJ, shown in Figure 2.1, was derived. The Hydra-VIJ schematisation is also considered in the analysis of this research.

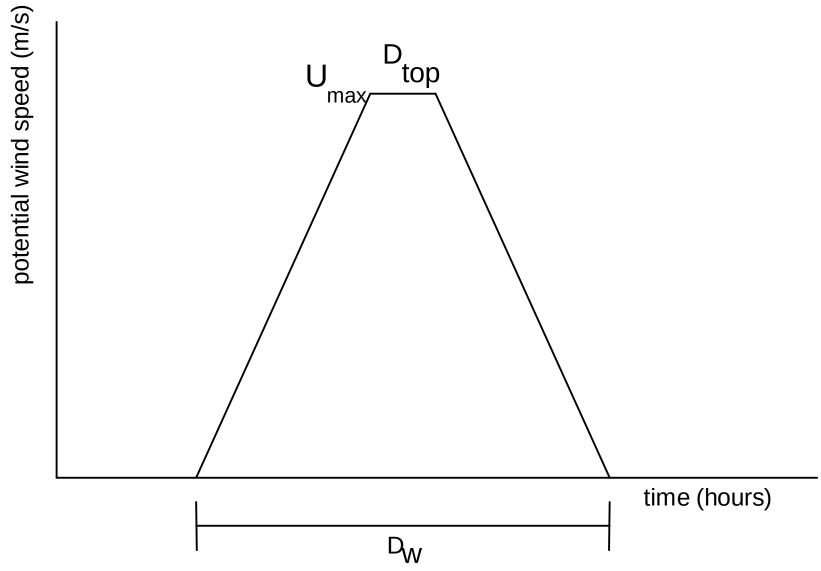

Figure 2.1 Assumed temporal evolution of the wind speed with duration D_w hours and peak value U_{max} (m/s) for Hydra-VIJ, with D_{top} = 2 hours and D_w = 48 hours [3]. Note: the storm duration D_w in this schematisation is at wind speed level 0 m/s.

3 Approach

The time series of *potential*[1] wind speeds at Hoek van Holland over the period 1962 -2005 was analysed[2]. Relevant storm events were selected based on exceedance of a threshold of 20 m/s, which resulted in approximately one storm event per year on average. If two peaks occurred within the time horizon of one day, they were considered to be part of the same storm event. This time horizon of one day is the same as the one used for the analysis of storm surge duration[1] and is consistent with the analysis of storm duration for the Vecht and IJssel delta[3]. The reason to choose a relatively short time horizon of one day is to mainly select single peaked storm events. To come to a storm duration estimate to be applied in the Hydra-B/Sobek model the same methods were used as in the analysis of the storm *surge* duration[1]:

(1) The storm duration at level 0 m/s or 10 m/s, (respectively Figure 2.1 or Figure 1.1), was derived from the peak wind speed and the duration of the wind speed exceeding a chosen threshold, for example 15 m/s. [4]

(2) Every storm event was scaled to a dimensionless peak wind speed of 1, by dividing each observed hourly value in a storm by the peak wind speed. For each event the durations of various threshold levels like 0.95, 0.9, 0.8, 0.7 etc. are derived from the data. The average duration over all storm events is calculated for each threshold to come to an averaged storm

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[1] Potential wind means that the wind speed is corrected to the wind speed at 10 m. height over open land with a roughness length of 0.03 meter.
[2] The time series was downloaded from the KNMI website.

shape. This procedure is only done for higher wind speed levels. The duration at wind speed level 0 m/s is derived by extrapolation of durations at higher levels. [3]

For applications in “flood risk analysis” mainly higher wind speeds are relevant. Therefore, the trapezium used to describe the temporal evolution of the wind speed especially should be a good fit to the highest part of the averaged storm profile, say the highest 30%[3]. Method **(1)** uses the duration of the wind speed exceeding a relatively low threshold to derive the storm duration at wind speed level 0 m/s. Furthermore, method **(1)** turned out to be sensitive to the choice of the threshold used in the extrapolation. This sensitivity is caused by the fact that most storms fan out at lower wind speed levels. Therefore, method **(1)** was rejected in this analysis.

Since method **(2)** scales every selected storm event to a dimensionless peak wind speed of 1, it is not possible to derive an average storm duration at the level of 10 m/s from the data, as is needed for the schematised storm profile currently used in Hydra-B (Figure 1.1). It is only possible to derive storm durations at specified percentages under the peak level. Therefore, the schematisation currently used in Hydra-B was rejected for the analysis of storm duration.

However, it is possible to derive the storm duration at wind speed level of 0 m/s, necessary for the schematisation used in Hydra-VIJ (Figure 2.1), with method **(2)**. Therefore, it was decided to use the schematisation used in Hydra-VIJ, also taking into account the fact that the schematisation currently used in Hydra-VIJ is better documented than the one used in Hydra-B.

4 Results

In our analysis, extrapolation of durations at higher wind speed levels results in an average storm duration at wind speed level 0 m/s of 51 hours. For applications in “flood risk analysis” mainly higher wind speeds are relevant. Therefore, the trapezium used to schematise the temporal evolution of the wind speed especially should at least be a good fit to the highest part of the averaged storm profile, say the highest 30% [3]. A trapezium shape with a top duration of 1 hour and average storm duration at wind speed level of 0 m/s gives a good fit of the highest 30% of the average storm profile, as shown in Figure 4.1.

However, the trapezium used in Hydra-VIJ, i.e. with a top duration of 2 hours and average storm duration at wind speed level 0 m/s of 48 hours also gives a reasonable fit, as shown in Figure 4.2.

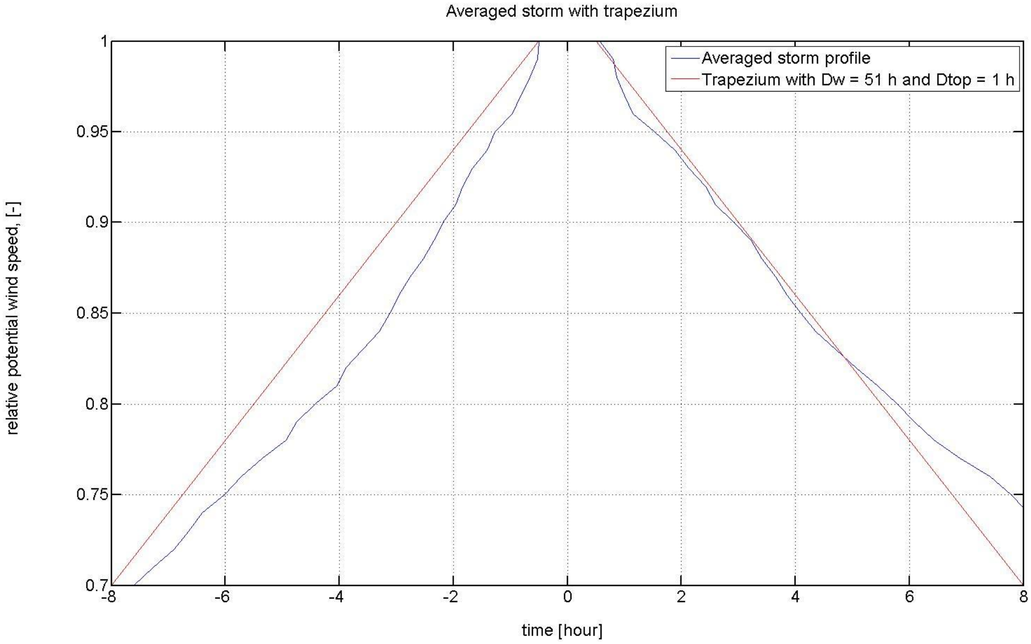

Figure 4.1 Highest 30% of the averaged storm profile and trapezium with top duration of 1 hour and average storm duration of 51 hours. The averaged storm profile is truncated at the top, because the hourly data is actually hourly *averaged*.

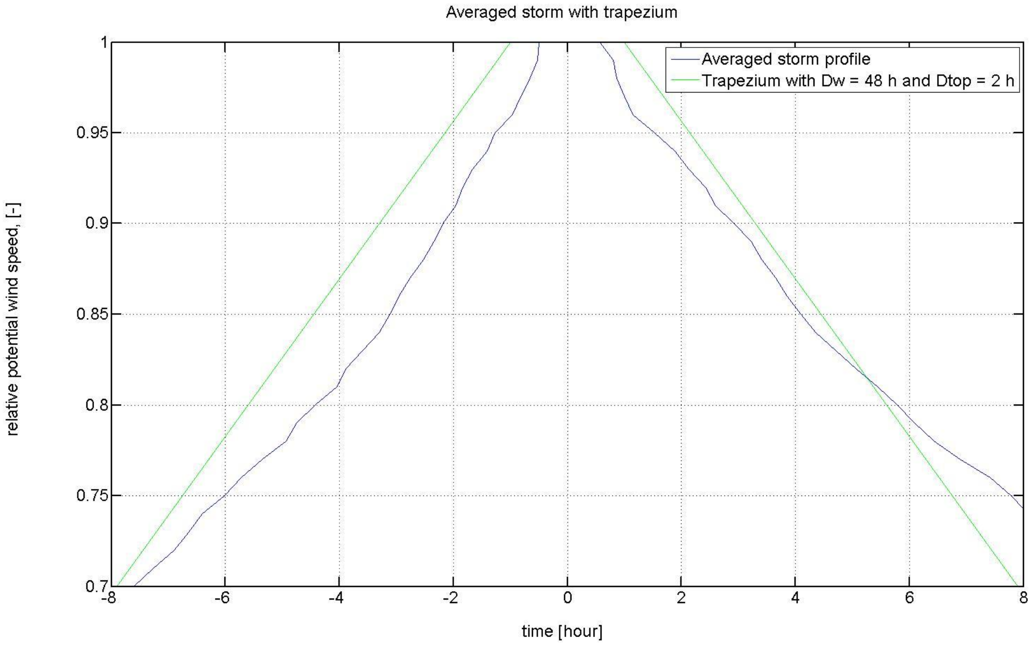

Figure 4.2 Highest 30% of the averaged storm profile and trapezium with top duration of 2 hours and average storm duration of 48 hours. The averaged storm profile is truncated at the top, because the hourly data is actually hourly *averaged*.

Additionally, the assumption of independence between peak wind speed U_{max} and storm duration D_0 was analysed. No strong evidence could be found that the assumption is not valid. Figure 4.3 shows no strong trend. If the data shows any sign of a trend at all, it is a slightly negative trend. In which case extreme storms would have smaller storm durations, meaning that the assumption of independence between peak wind speed and storm duration would be slightly conservative. Hence, the approach of independence of U_{max} and D_0, as applied for the HBC2006, is supported by this investigation.

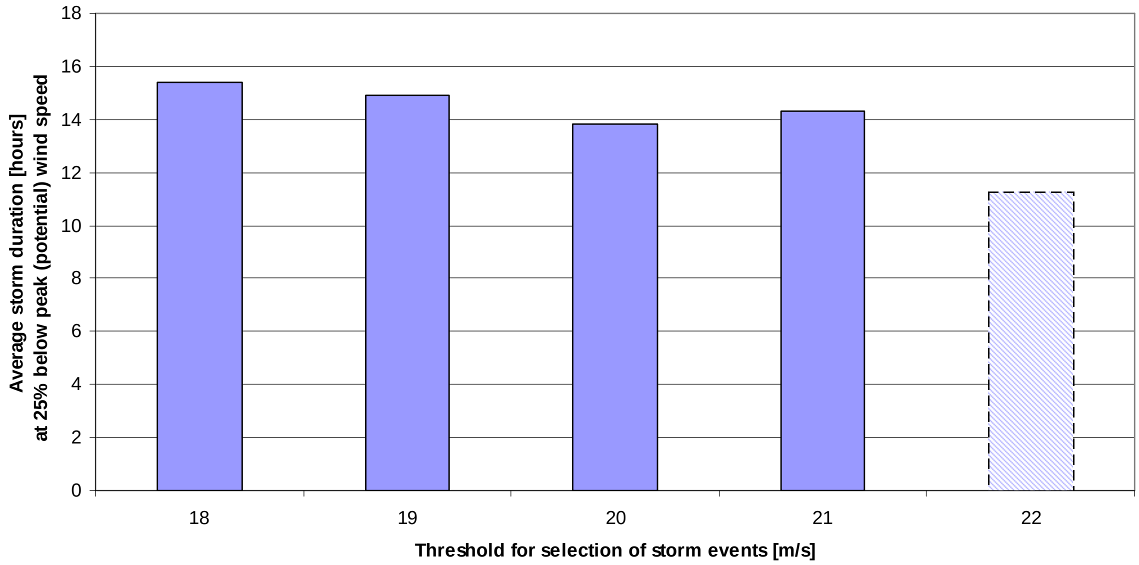

Figure 4.3 Average storm duration at 25% below peak wind speed, derived for storm events selected with different thresholds[3]. Note: the average storm duration at 25% below peak wind speed for a threshold of 22 m/s (column far right) is derived using only 10 storms and is, therefore, very uncertain.

If the storm profile resembles a trapezium shape, e.g. the storm of January 1990 shown in Figure 4.4, the application of the applied method is fairly straightforward. However, if a storm profile does not resemble the trapezium shape, it fails to deliver a good fit. For example, Figure 4.5 shows the storm event of December 1979, which contains multiple peaks, if a time horizon of more than one day is used. When considering the multiple peaks and the non-symmetry, the resulting trapezium shape does not give a satisfying fit of the observed storm profile. This example shows the disadvantage of representing complex storm temporal evolutions by a simplified standard shape and the limited reliability of the derived storm duration.

[3] In case of total independence between peak wind speed and storm duration, the averaged storm duration at a fixed percentage below the peak wind speed would be independent of the chosen threshold for selection of the storm events; i.e. one would expect a constant storm duration.

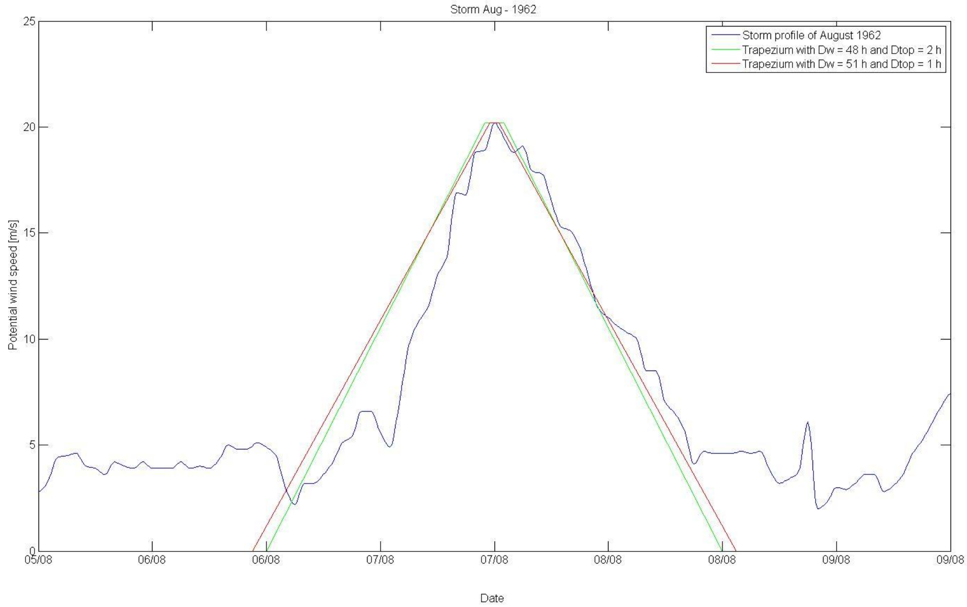

Figure 4.4 Storm event of August 1962

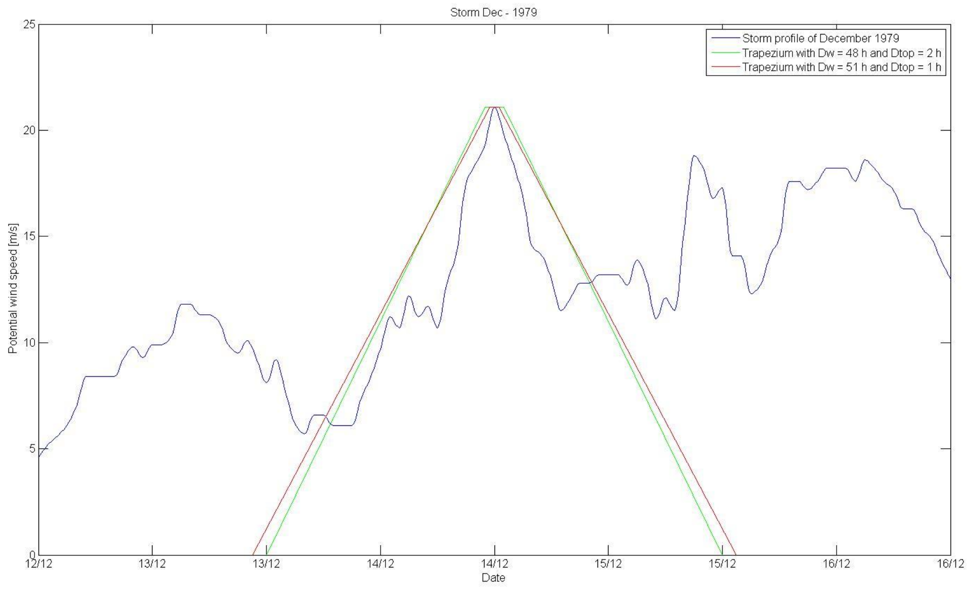

Figure 4.5 Storm event of December 1979

5 Conclusions and recommendations

First of all, we recommend to adopt a temporal evolution of the potential wind speed in Hydra-B which is consistent with the one used in Hydra-VIJ (Figure 2.1), since it is not possible to derive a storm duration for the temporal evolution currently used in Hydra-B with the method used in this analysis. Another method was considered, but dismissed for several reasons.

The results of this study show that the temporal evolutions of the wind speed, described by a trapezium having a top duration of 1 hour and average storm duration of 51 hours gives a good fit of the average storm profile. However, a trapezium with top duration of 2 hours and average storm duration of 48 hours also gives a reasonable fit. The latter is identical to the one used in Hydra-VIJ.

When solely looking at the data, we would have to recommend using a trapezium shape with a top duration of 1 hour and average storm duration at wind speed level 0 m/s of 51 hours in the Sobek simulations for WTI2011. However, the differences between the trapeziums with storm duration of 48 and 51 hours are relatively small, considering statistical uncertainties. Therefore, when preferring consistency between Hydra-VIJ and Hydra-B, a trapezium shape with a top duration of 2 hours and average storm duration at wind speed level 0 m/s of 48 hours can also be used in the Sobek simulations for WTI2011.

Furthermore, we recommend not introducing a dependency between peak wind speed level and storm duration in Hydra-B as the available data showed no strong statistical evidence that a dependency exists.

In order to improve storm profile modelling for future applications (HBC2016) we recommend exploring the application of more complex storm profiles in the Sobek model such as profiles with double peaks. This also involves the evaluation of probabilities of occurrence of these types of profiles.

6 References

[1] Deltares, 2009: Storm surge duration at Hoek van Holand, memorandum of Deltares to the Hydraulic review Team, June, 2009.
[2] RWS RIZA, 2007: Achtergrondrapport HR 2006 voor de Benedenrivieren, Thermometerrandvoorwaarden 2006, RWS RIZA rapport 2007.023.
[3] RWS RIZA, 2006: Hydraulische randvoorwaarden 2006 Vecht- en IJsseldelta, RWS RIZA werkdocument 2006.036X
[4] Weerden van, J.J., J.P.F.M. Janssen en J.K. Vrijling, Effekt van variatie opzetduren op de hoogwaterstanden in het noordelijk deltabekken, DBW/RIZA, nota 87.054, 1987