THE SBW FIELD MEASUREMENT PROGRAM

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1. INTRODUCTION

The safety of the Dutch primary water defences must be assessed every six years for the required level of flood protection. In this assessment, Hydraulic Boundary Conditions (HBC) in the form of extreme water levels and wave conditions are required. They are based on wind, waves and water levels measured in open water, extrapolated to extreme conditions, followed by the transformation of the estimated extreme wave conditions from open water towards the shallow areas near the water defence structures using the SWAN spectral wave model.

Validation material for SWAN is obtained in a dedicated SBW (Strength and Loading of Water Defences) field measurement program in the Netherlands, which carries out field measurements during each storm season in the following three areas:

- Dutch Wadden Sea: a complex area enclosed by a series of barrier islands and the Dutch mainland coast, featuring ebb tidal deltas, tidal channels and shallow tidal flats.
- Petten coastal area: a bathymetric profile typical for the open Dutch coast, starting offshore (> 20 m deep) and gently sloping, including some sand banks, towards the dike.
- Lake IJssel: a large (20 x 60 km^2) and relatively shallow (~ 4 m deep) lake.

The information requests from research studies determine the strategy of the campaign, which gives researchers an explicit chance of gaining complete data sets for model evaluation and development. Waves are measured using buoys and wave measuring instruments installed on measuring poles. In addition, the essential SWAN input quantities (seabed topography, water level, wind and currents) are measured as well. The use of X-band radars to obtain spatial wave, current and depth data is under investigation in the Wadden Sea. The three SBW measurement sites combined have been evolving over the past 10 years or so into one of the largest campaigns in Europe for high-quality on-line measurements of physical parameters such as waves, winds and water levels.

This paper aims to give a short overview of the SBW field measurement programme. The background and goals of the measurements are explained. Furthermore, the paper gives insight in the layout of the three measurement sites (which instruments are employed where and why), the experience acquired with the instrumentation and the site logistics, and how the data is processed and disseminated.

2. BACKGROUND AND GOAL OF THE MEASUREMENTS

Water defence structures protect the Netherlands from flooding from the North Sea, the major rivers and the large inland lakes. The Dutch Water Act ('Waterwet, 2009') stipulates that these primary water defence structures must be assessed once every six years with regard to their statutory prescribed level of safety for representative extreme water levels and waves. For the coastal regions the representative wave conditions in deep water (with an occurrence probability of once in a few thousand years) required for this assessment are estimated on the basis of wave statistics derived from measurements over the last 30 years at five permanent wave measuring stations in deep water. These estimated extreme wave conditions offshore are then transformed from deep to shallow water near the water defence structure

using the SWAN spectral wave model. On the inland lakes the wave growth is fetch-limited in storm situations. Therefore main emphasis there is on calibrating the wave model for short fetch conditions. It is essential that SWAN accurately reproduces the essential physical processes so that reliable extreme wave conditions (that we will probably never encounter in our short measuring programs of only a few decades) can be calculated near the water defences. Reference is made to Groeneweg & Van Dongeren (2002) and Hoekstra & Hoitink (2002), who already dealt extensively with the relevant parameters for the wave processes under investigation.

Consequently the main purpose of the field measurement campaign is to produce data that can be used to check the validity and robustness of the SWAN wave model under relatively mild to stormy conditions in order to gain trust in its usefulness under very extreme, not yet encountered situations. Current focus is on wave measurements during storm conditions, because in such conditions waves are the parameter with the highest uncertainty. In addition, until recently hardly any wave data were available in certain areas like e.g. the Wadden Sea. Consequently, in the field measurements main emphasis has been on the processes of wave growth, propagation and dissipation. It is also necessary to monitor near the water defence structures several other hydraulic and meteorological parameters required for issuing reliable HBC. For, in the unlikely event that SWAN should produce substandard wave predictions, such measurements could provide valuable short term statistics of storm conditions occurring near the defence structures. In addition to the above mentioned measurements devoted to the HBC, specific instruments have been installed at the Petten dike to measure wave run-up and wave overtopping on the dike. The data acquired with these instruments are helpful for better assessing the strength of such a dike under extreme conditions.

All the above mentioned measurements are carried out within the framework of the SBW program set up by Rijkswaterstaat (a division of the Dutch Ministry of Infrastructure and Environment) specifically to fill any remaining knowledge gaps in the areas of HBC and of failure mechanisms of water defence structures.

3. INFORMATION REQUIREMENTS

In general, water levels are monitored on a routine basis at a large number of stations and, when combined with the hydraulic WAQUA or Delft3D model, they are believed to be adequate for estimating the extreme water levels. Wind information is a very important parameter for reliable wave hindcast studies. Thus more wind measuring locations were needed in addition to the already existing stations, because an inventory has shown that the existing (predominantly land-based) wind measuring stations gave in the areas of interest insufficient spatial coverage and were also not representative enough for the wind field over open water. Therefore, it has been decided to install several new semi-permanent wind measuring stations (conform KNMI quality standards) in open water. Furthermore, it is investigated whether additional current information can contribute to an improvement of the HBC. This applies not only to the current-wave interaction process as modelled in SWAN, but also to the calibration and validation of the WAQUA model. In most cases, current vector profiles over the water column are needed. In addition to local point current measurements, there is also a need for measured current maps with the perspective of supplying complete spatial coverage of the area. For the moment, however, it is decided to limit the current measurements to a few point measurements. For reliable wave calculations accurate and up-to-date information about the bottom topography is necessary. Since ship borne depth sounding and airborne laser altimetry campaigns are very accurate, yet also time consuming and costly, a lot of effort has been devoted to optimizing these campaigns.

4. MEASURING STRATEGY AND TECHNIQUES

A large number of wave buoys is deployed in the Wadden Sea and at Petten and, because these buoys are very flexible in their deployment position and can also become operational quite readily and quickly. Given the very small water depth no wave buoys are deployed in the large inland lakes, but measuring

poles are used. They are (considering their structural strength, continuous power supply and on-line telemetry to a land-based receiving station) universal measuring platforms and thus well suited to serve as (semi-)permanent measuring platforms, especially because we are mainly concerned with measuring (wave) events in extreme weather conditions. Such poles can be equipped with a suite of sensors, like e.g. radar level sensors, step gauges, current meters, wind sensors etc. and are thus very well suited to measure (simultaneously and at the same location) a large number of important hydraulic and meteorological parameters, like e.g. water level, current, wind, air pressure etc. This enables us to put the measured wave processes in a broader physical perspective. Contrary to anchored buoys the wave sensors on a pole can measure the water level and the very low frequency wave energy (e.g. surf beat and seiches), which are also very interesting under storm conditions. However, the measuring instruments are often bothered by water droplets in the air (e.g. the capacitive and resistive gauges, the radar level sensors etc.) and sometimes by air bubbles in the water (e.g. all under water acoustic sensors like ADCP's). This holds especially for the near shore measuring poles at Petten, where wave breaking occurs. Moreover, the accuracy and the ability to measure short waves is deteriorated for underwater wave sensors (e.g. current and pressure sensors) by the attenuation of the wave orbital kinematics signal with depth.

5. REGIONAL MEASUREMENT PROGRAMS

5.1 Wadden Sea

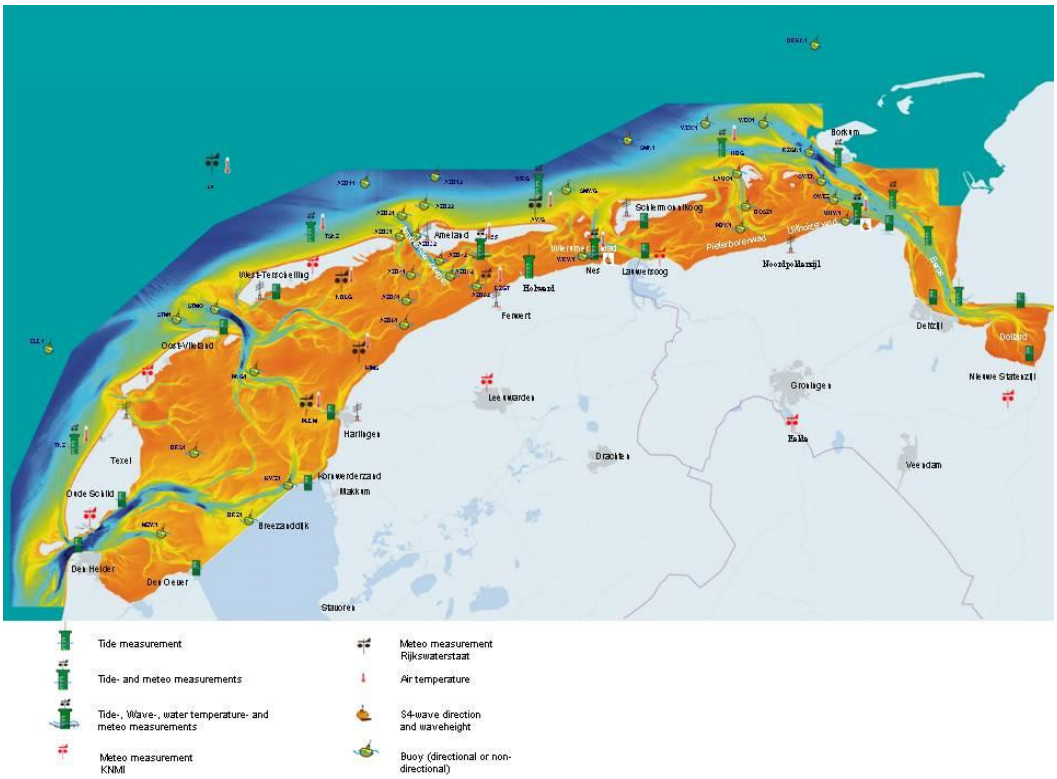

Figure 1: Measurement configuration in the Dutch Wadden Sea.

In the Wadden Sea area the emphasis is on following the waves from the deep North Sea via the tidal inlets between the islands to the shallow water near the sea defence structures, primarily to validate and (if necessary) to improve the wave model SWAN in such a complex area.

The SBW measurement program in the Wadden Sea started in 2003. The measurement strategy was developed based on a priori SWAN model hindcasts, field knowledge and expert judgement. The general information requirements for the model had to be matched with possible wave measurement methods and available measurement locations. Reference is made to Zijderveld and Peters (2008). At the moment the wave-measuring configuration in the Wadden Sea is mainly confined to a rather large number (about 25) of wave measuring (non-)directional Wave riders buoys. These buoys were spread out inside as well as outside the Wadden Sea area in such a way that a rather good spatial coverage over the entire Wadden Sea area is accomplished. A number of buoy locations were chosen to provide information of the wave conditions as close as possible to the dikes (e.g. at the Afsluitdijk at the border of Lake IJssel). The buoys in the two transects at the Ameland tidal inlet yield information about the wave penetration through the inlet, both in the channels and over the tidal shoals. Nine buoys perform wave measurements in the eastern part of the Wadden Sea near the Groningen coast, while five additional buoys were deployed in the Western Wadden Sea to measure wave conditions there.

In addition, in the summer of 2008, three long-term measuring poles became operational; one south of Ameland (Nes), the second in front of the Frisian coast (Wierumerwad) and the third (Uithuizerwad) in front of the Groningen coast. The poles are measuring a suite of parameters such as waves, wind, water level and current. They were planned near the dike in order to measure the short-term (10 years or so) wave statistics and thus to estimate the credibility of the (with SWAN) calculated wave conditions near the sea defence using a couple of mild to severe storms. Furthermore, four additional poles were installed at Pollendam, Kimstergat, Dantziggat and Noorderbalgen specifically for wind measurements. Also, wind sensors were placed on several already existing poles belonging to the National Water Monitoring Network ('Landelijk Meetnet Water' or LMW).

5.2. Measurement programme at the Petten sea dike.

The measurement campaign (since 1995) at Petten is devoted to measuring the HBC at a specific site along the Holland coastline. This is accomplished by a number of measuring stations (poles and buoys) in a transect (see Figure 2a) more or less perpendicular to the dike. Note that the two buoys are too far (resp. 3 and 8 km offshore) from the coast to be seen in Figure 2a. In addition, since 2007, the Petten measuring site is also equiped to measure the process of wave run-up and wave overtopping on the sea dike by using several dedicated sensors installed in or on the Petten sea dike itself. This can be seen in the right panel (b) of Figure 2. For the purpose of relating the measured run-up and overtopping to the incoming wave height instead of the total wave height, special measures have been taken for measuring the wave reflection coefficient in the transect using electromagnetic current sensors.

Figure 2: Measurement configuration in the Petten transect (left, a) and on the dike (right, b).

5.3. Measurement programme in Lake IJssel and Lake Marken.

Since 2005, in the large inland lakes IJssel and Marken measurement poles are measuring waves, but also a lot of other parameters like wind and water level. As discussed, this is done in order to establish a reasonable estimate of the HBC in such confined and shallow lakes. Note that the fetch in lakes is much smaller than at the sea sites of Petten and the Wadden Sea. On these lakes an efficient measurement configuration has been created by combining the poles for the HBC with other poles installed for the ANT (Autonome Neerwaartse Trends) and NMIJ (Natuurlijk Markermeer/IJmeer) projects. Moreover, some of the poles have an operational purpose (like FL2 for ship guidance) as well. Due to their small size and weight the poles can be placed and removed easily, which is advantageous when the measuring locations have to be altered or when the poles have to be removed in the winter before an emerging period of frost in order to prevent possible damage by moving ice packages.

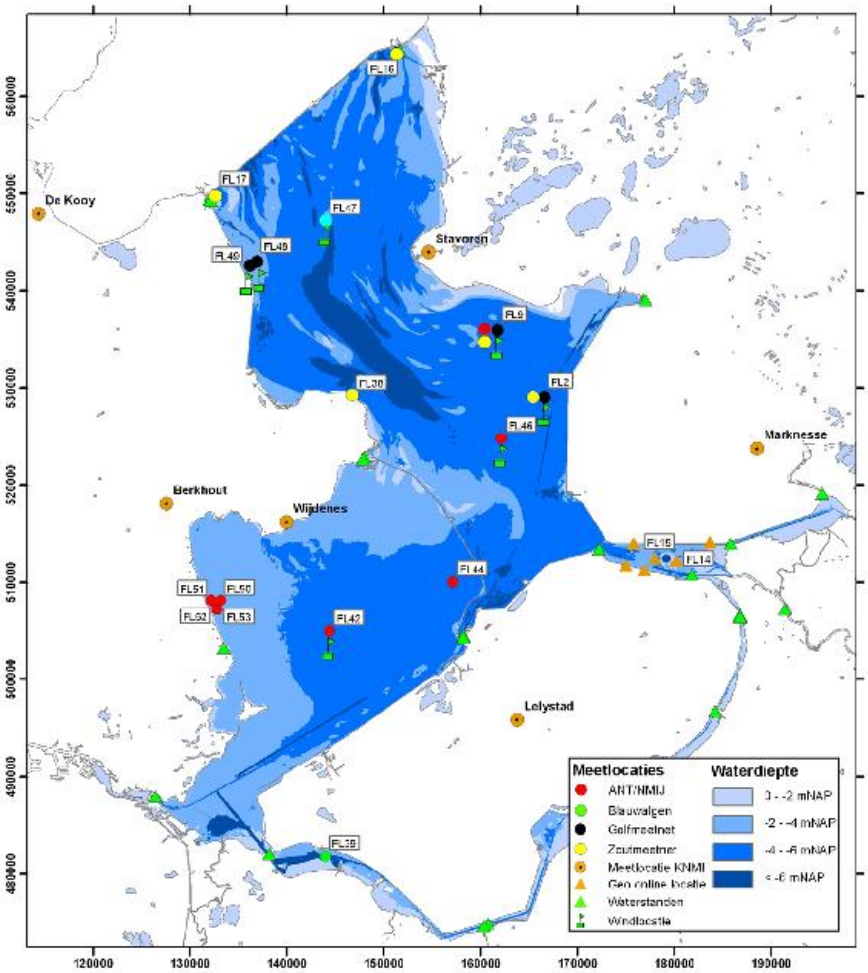

Figure 3: Measurement configuration in Lake IJssel and Lake Marken.

6. DATA MANAGEMENT

All the data (from poles and buoys) is transmitted by radio links in real time to a few land-based receiving stations and from there to a few central computer stations. There the wave data is processed in time and frequency domain with the so-called SWAP (Standard Wave Analysis Package) software module belonging to the central processing systems of the National Water Monitoring Network or (in a kind of stand-alone

configuration) with the so-called WAVES package, that was originally only intended to process the Petten wave data. All the other hydrological and meteorological data are processed there as well. With automatic validation algorithms the data are checked for possible outliers and staggers. Moreover, a visual check is performed on a regular basis with respect to the time series and the calculated parameters e.g. wind speed and wave spectra. Thus a quality control system exists in the form of a procedure for sensor status surveillance and data validation. For validating the important wave parameters use is made of the so-called WAVIX neural network, which (after a preliminary learning stage using a reliable initial data set) has managed to establish robust relations between the wave parameters at neighbouring measurement stations and the local wind conditions. In case of data loss the operational measuring and information divisions of Rijkswaterstaat are contacted with the request to repair the malfunctioning equipment (measuring sensors and/or data communication links) as soon as possible. Thus downtime of the measurement site is minimized. Immediately after an interesting storm an extraction is made from the database of relevant storm data. These data are combined in a so-called storm report. Furthermore, monthly reports (describing the overall data availability) are generated on a regular basis and finally encompassed in a storm season report. After the monitoring and validation steps the validated wave and other data is stored in the Rijkswaterstaat national data base DONAR. This thoroughly backed-up data base guarantees the integrity of all the measurement data.

7. FUTURE DEVELOPMENTS

Unfortunately the measuring site at Petten will vanish within a few years, because a major sand supply is envisaged for this part of the Dutch coast. However, if the information requirement for such data persists, we should look for an alternative site, which could in due course deliver comparable data. It is now foreseen that the wave measurement programme in the Wadden Sea will include more measurement locations in the Eems-Dollard estuary. This area can encounter very high water levels in severe storms, such as November 1st, 2006. Another interesting aspect is that in 2009 a software package has been connected to the microwave marine traffic surveillance radar on the Ameland lighthouse. This SeaDarQ software package has shown promising results in displaying wave patterns, current fields and bottom features, see Gautier et al. (2012). Such remote sensing techniques are envisaged to image the spatial wave and current fields in specific areas of the Wadden Sea. Furthermore, the possibility exists that a new measuring site will be created in the Western Scheldt in the South-western part of the Netherlands.

On the long term the whole SBW measurement campaign will be transformed into a monitoring campaign, to fulfil the information need of several stakeholders. One of the stakeholders is the Dutch Storm Surge Warning Department (SVSD) that is responsible for accurate storm surge warnings for the coastal areas. It is planned to include wave information in these warnings in the future.

8. REFERENCES

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