*River Flow 2010 - Dittrich, Koll, Aberle & Geisenhainer (eds) - © 2010 Bundesanstalt für Wasserbau ISBN 978-3-939230-00-7*

# Analysis of multibeam echo sounding data on bed forms near the Walsoorden sandbar, a first phase in the subtidal habitat classification for the Western Scheldt

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ABSTRACT: Within the scope of the long term vision of the Scheldt estuary, a new disposal strategy was proposed by an international expert team appointed by the Antwerp Port Authority. After the feasibility study, two in situ disposal tests were carried out near the Walsoorden sandbar in the Western Scheldt. Both tests were thoroughly monitored, both morphological as ecological.A project was defined to investigate the impact of bed forms, hydrodynamics and sediment properties on the ecological value in the shallow water area near the Walsoorden sandbar. The goal of this project is to make a habitat classification for the Western Scheldt based on its ecological value, allowing to define which areas are best suited for disposal of dredged material and which areas should be avoided.In the first phase the multibeam echo sounding data were analysed in respect to the occurrence of bed forms. The analysis was executed in four steps, resulting in a limited number of classes.A large spatial variation was found for the analysed parameters. The average length of bed forms ranged from 5 m to 50 m, the average height from 0,10 m to almost 2,00 m, while, considering the asymmetry due to tidal currents, most of the sections were flood dominated.In a second phase the seasonal variation of the bed forms was investigated, analysing the multibeam echo sounding data of the summer condition (September 2007).In the third phase of the project the relation between the occurrence of bed forms and hydrodynamic parameters (using a validated numerical hydrodynamic model) was investigated. With the addition of sediment properties (grain sizes) a classification based on the physical parameters is made. These "physiotopes" were finally validated with the ecological data (i.e. macrobenthos and fish), trying to make a classification in "ecotopes".

*Keywords: Geomorphology, Bed forms, Habitats, Scheldt estuary, Tidal currents*

## 1 INTRODUCTION

Within the scope of the long term vision of the Scheldt estuary, (low dynamic) shallow water areas – between 0 m MLLWS and -5 m MLLWS – are considered to be of high ecological value. At present however, little is known about the location of such areas in the Scheldt estuary, nor about the details of the physical and morphological processes that determine the occurrence of ecologically important shallow water areas.

In order to be able to predict the effects of (expected and unexpected) changes in the physical system of the estuary on the ecology, it is necessary to investigate the relationship between the occurrence of these organisms and their physical environment in a synoptic way.

Therefore, a study project was defined by the Maritime Access Division (Flemish government) to investigate the relation between on one hand the bed forms, hydrodynamics and sediment properties and on the other hand the ecological value of the shallow water areas. This study will result in a habitat classification for the shallow water areas in the Western Scheldt based on their ecological value.

In 2004 and 2006, two in situ disposal tests have been carried out near the Walsoorden sandbar in the Western Scheldt (Plancke et al., 2007). Both tests were thoroughly monitored to evaluate the feasibility, resulting in a vast morphological and ecological dataset for this area. The area near the Walsoorden sandbar was therefore chosen for a case study.

The newly developed insights, resulting from this study, will be used to develop a methodology to extend this classification to the whole of the Western Scheldt. This classification will offer valuable information to define which areas are best suited for disposal of dredged material and which areas should be avoided because of their ecological value.

## 2 BED FORM ANALYSIS

### 2.1 *Study Area and used data*

The study area (Fig. 1) stretches from Bath to Hansweert in the Western Scheldt. Although the project was initially set up for the shallow water areas, it was finally extended to both the shallow and deeper water areas near the Walsoorden sandbar.

The morphological monitoring (Leys et al., 2006) following the disposal tests near the Walsoorden sandbar comprised, among others, of multibeam echo sounding measurements. These surveys were initially conducted every week. Later the frequency was reduced to once every 2 weeks and finally once every 3 months (Flanders Hydraulics Research, 2009).

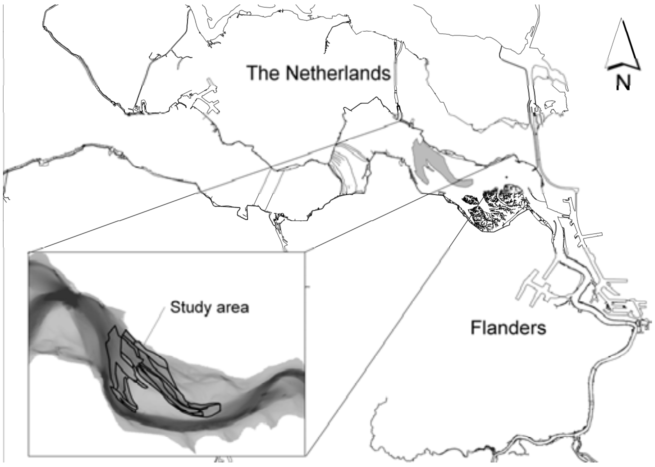

Figure 1. Location of the study area in the Scheldt Estuary

Two multibeam echo sounding surveys were chosen out of this extensive data collection for the realization of a habitat classification. In the first phase the multibeam echo sounding data of the winter condition (March 2007) were analysed in respect to the occurrence of bed forms. In a second phase the seasonal variation of the bed forms was investigated, analysing the multibeam echo sounding data of the summer condition (September 2007).

### 2.2 *Methodology*

The analysis of the bed forms was executed using the following steps:

1 Visual classification of the study area in sub areas based on the dimensions of the bed forms, starting from the shaded view image of the area.
2 Definition of several longitudinal transects (along the direction of the flow, approximately 1000 m long) within each sub area.
3 Analysis of each transect for the following parameters: average length, average height, average asymmetry and average steepness of the bed forms.
4 Classification of the study area in a limited amount of bed form classes.

The first 3 steps in this analysis where executed 2 times: based on the first analysis variations between transects within the same sub area or variations within the transects themselves were discovered. Therefore the classification in sub areas was redone to ensure more homogenous sub areas. Then, new transects were defined and for each transect its characteristic values were determined.

#### 2.2.1 *Visual classification in sub areas*

A so-called “shaded view” map was used as a base for the visual classification in sub areas. This computer-generated map shows a simulated cast shadow of sun upon a raised bathymetry. The angle from which the light shines on the bathymetry was chosen so as to be able to discern the bed forms optimally. The optimal angle was found to be parallel to the direction of the flow, because the direction of bed forms is expected to be perpendicular to the direction of the flow.

Because of the tides in the Western Scheldt 2 preferred angles can be defined, one for flood flow and one for ebb flow, differing approximately 180° from each other. Since flood flow is expected to be dominant in the study area, the direction of this flow is taken as the preferred angle. This direction of flood flow differs within the study area between 315° N and 270° N. Finally an angle of 315° N was chosen because this concurred with the direction of the flood flow for most of the study area.

Based upon this “shaded view” image, different sub areas were delimited. Boundaries were defined visually in those places where differences in bed forms appeared to occur (Fig. 1).

#### 2.2.2 *Definition of several longitudinal transects*

Within every sub area some longitudinal transects were defined, assuming that these sections are representative for the whole sub area. To be sure that enough bed forms were included in each section, a minimum length of 1000 m per section was proposed. However, for some of the smaller sub areas this length couldn’t be obtained. Also, for every sub area 3 sections were defined if possible in order to check the uniformity of the sub area. The depth values of these sections were exported from a 1m*1m raster (multibeam echo sounding) covering the study area using GIS-software.

### 2.2.3 *Analysis of the transects to obtain characteristic parameters*

For every longitudinal transect the following characteristics were deduced:

- Length of the individual bed forms.
- Height of the individual bed forms.
- Asymmetry of the individual bed forms.
- Average steepness of the bed forms per transect.

This analysis was executed using a self developed Matlab routine, based on the methodology used in the Bed form Tracking Tool (van der Mark et al., 2007). This routine consists out of the following steps to define the characteristic parameters of the bed forms in a certain transect (Fig. 2):

1 Choosing a period for a floating average to remove trends (large scale depth variation) from the section without loosing the individual bed forms.
2 Detrending of the section by subtracting the floating average from the original data.
3 Determining the intersections of the detrended signal and the zero-line.
4 Determining the crests and troughs, based upon the assumption that between two intersections with the zero-line, a crest or a trough can be found.
5 Determining the length of every individual bed form, defined as the distance between 2 successive crests.
6 Determining the height of every individual bed form, defined as the difference between the height of a crest and the following trough.
7 Determining the asymmetry of every individual bed form, defined as the ratio between the inclination length ($L_{dstr}$) and the declination length ($L_{ustr}$) of the bed form (from trough to trough).
8 Determining the average steepness per transect, defined as the ratio between the average height and the average length of the bed forms (from trough to trough) in that section.

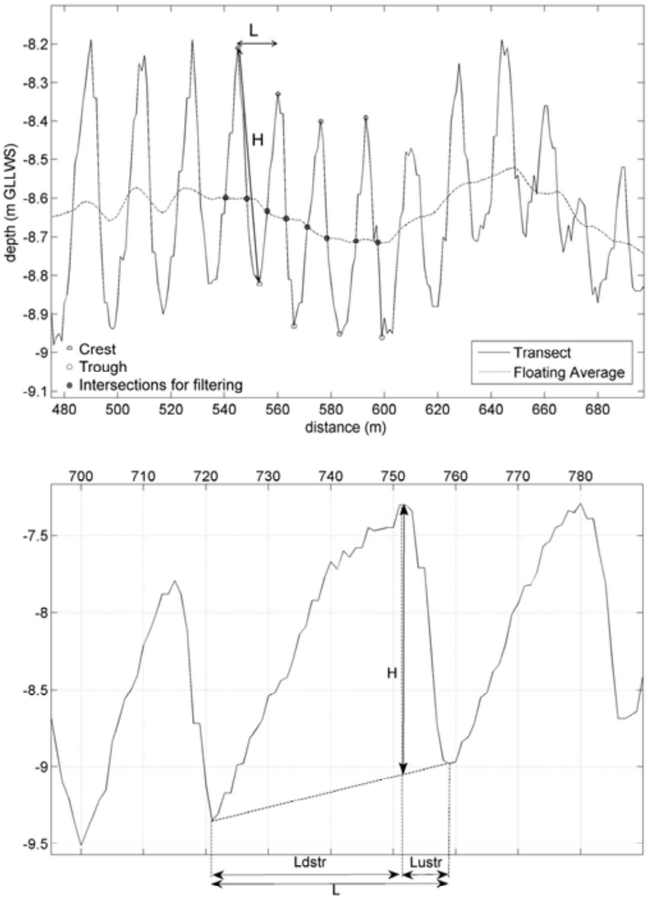

Figure 2. Methodology for determining characteristic parameters, above: step 1 – 4, below: step 5 – 7

Next, the characteristics of the individual bed forms were averaged per transect. The resulting average values for length, height and asymmetry were filtered to minimize outlier-effects: all values outside the interval [0,25*average; 1,75*average] were discarded and a new average was calculated using the remaining values. This interval was determined after a sensitivity analysis, in which the effect of different intervals was investigated with the values of the averaged characteristics.

The transects were always defined from seaward side to landward side. Thus, an asymmetry value greater than 1 implies a bed form where the seaward side is longer than the landward side. This indicates flood dominance. A value smaller than 1 indicates ebb dominance.

### 2.2.4 *Classification of the study area in a limited amount of bed form classes*

In order to group the different sub areas in a feasible amount of classes (maximum 10), the averaged characteristics were compared to each other. This resulted in 2 different classifications: one classification based on the average length and height of the bed forms, another classification based on the asymmetry of the bed forms. The parameter steepness was also considered as a base for classification, but as the steepness differed strongly within the sub areas, it was not considered a good classification parameter.

## 2.3 *Results*

The methodology described above was used on two different datasets. First a classification was made for the winter condition, using the multibeam echo sounding data of March 2007. March is considered to be representative for the winter period, because it is situated at the end of a period with an increased storm occurrence. This might have an influence on the development of bed forms.

Therefore, data of the summer condition (September 2007) was also analysed, in order to be able to detect possible seasonal variations of the bed forms.

### 2.3.1 *Classification of the study area – winter condition*

After the first three steps of the methodology, the original classification was revised to obtain more homogenous sub areas. A total of 24 definitive sub areas were defined, and 44 longitudinal transects were drawn. Next, the characteristic parameters were defined.

The classification based on average length and height of the bed forms resulted in the definition of 7 classes, shown in Figure 3.

Table 1: overview of length/height classes

| Class | Length | Height |
|---|---|---|
| 1 | < 10 m | < 5 cm |
| 2 | ~ 10 m | 15 – 30 cm |
| 3 | 10 – 15 m | 30 – 50 cm |
| 4 | 15 – 25 m | 50 – 100 cm |
| 5 | 15 – 30 m | 100 – 150 cm |
| 6 | > 30 m | > 150 cm |
| 7 | > 30 m | < 100 cm |

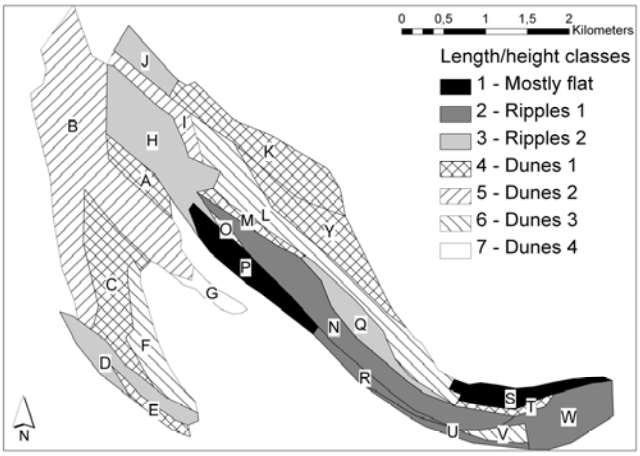

Figure 3. Length/height classes for winter condition

The classification based on average asymmetry resulted in the definition of 4 classes.

Table 2: overview of asymmetry classes

| Class | Asymmetry |
|---|---|
| 1 | < 0,90 (ebb dominance) |
| 2 | 0,90 – 1,10 (no dominance) |
| 3 | 1,10 – 1,50 (flood dominance) |
| 4 | > 1,50 (strong flood dominance) |

### 2.3.2 *Classification of the study area – summer condition*

For the classification of the summer condition, no new visual classification was made, and no new transects were defined, instead the sub areas and transects of the winter condition were used to define the characteristic parameters.

Although this methodology may mean that the boundaries between different sub areas are no longer correct, it will facilitate the comparison between the two seasons.

The sub areas were again assigned to the 7 length/height classes and the 4 asymmetry classes. For some sub areas it was no longer possible to assign all the sections to one class. In some cases the parameter for one of the sections just barely fell outside the limits of a certain class. Then, this sub area was assigned to the predominant class, to which most of the sections could be assigned. In some cases however, the differences between the sections had become so large, that a division of the sub area over different classes was imperative.

The spatial distribution of the length/height classes in summer condition can be seen in Figure 4. Sub areas that were divided over two classes are rendered with a hatch consisting out of the colours of those classes.

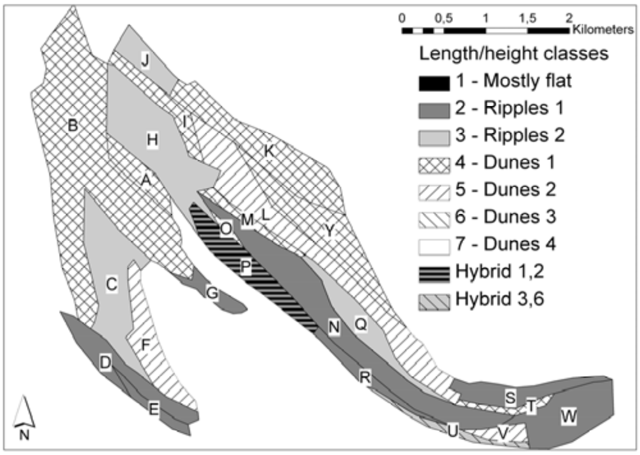

Figure 4. Length/height classes for summer condition

## 2.4 *Conclusions*

A large spatial variation in bed forms was found within the study area. The average length of bed forms ranged from 5 m to 50 m, the average height from 0,10 m to almost 2,00 m. Considering the asymmetry of the bed forms most of the sections were flood dominated. Figure 5 shows the sections of sub areas C and P at the same scale to illustrate the differences in height and length between different sections.

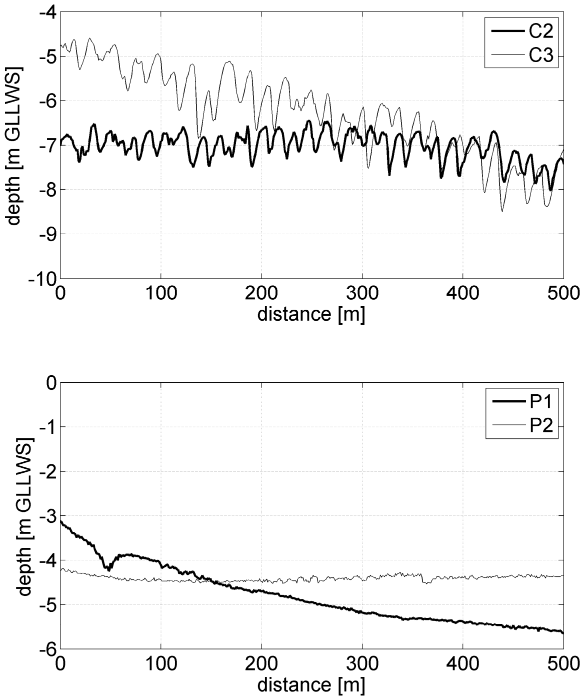

Figure 5. Variation in bed forms between sub areas C and P

The seasonal variation of the bed forms was also investigated, by comparing the classification for the winter condition with that of the summer condition.

It was found that the sub areas located in the "shadow" (i.e. areas with lower velocities) of the intertidal sandbars of Walsoorden and Valkenisse during the ebb phase were characterised by smaller bed forms in summer compared to the winter condition. The average length and height of the bed forms in the sub areas located in the deeper channels did not change much, although in most cases a decrease in length could be found, even if the difference was too small to cause a shift to another class.

With regard to the asymmetry, the comparison between winter and summer condition revealed the following: in the summer the sub areas located in the deeper channels are mostly symmetrical, the areas in the shadow of the intertidal sandbars are flood dominated. This distinction is less explicit in winter. Although for some sub areas a decrease in asymmetry was found in the summer, there was no switch from flood dominance to ebb dominance or vice versa between winter and summer.

## 3 HYDRODYNAMIC ANALYSIS

In a next phase of the study the relation between the occurrence of bed forms and hydrodynamic parameters was investigated. First, a hydrodynamic classification of the study area was made.

### 3.1 *Used data*

A 2D validated numerical model, already used in former studies (Flanders Hydraulics Research 2003, Flanders Hydraulics Research 2004, Flanders Hydraulics Research 2008b), was used as a base for the hydrodynamic analysis. In the current study an additional sensitivity analysis was performed. Effects on water levels and flow velocities of grid refinement and changes in background viscosity were checked in characteristic points, as well as the effects of the use of 3D modelling, fresh water – salt water interaction and the parameterisation of secondary flows using 2D model. Based on the outcome of this sensitivity analysis, the model parameters were set.

The simulation period was set at two weeks (from 18/09/2007 to 01/10/2007), covering a full spring-neap-tide cycle. Additional simulations were performed to generate frequent (every 10 minutes) "map-data" (including flow fields) for the study area for a spring tide, a middle tide and a neap tide.

### 3.2 *Methodology*

Based upon the flow fields, the following characteristic hydrodynamic parameters were deduced:

- Average flood velocity.
- Average ebb velocity.
- Ratio of average flood velocity to average ebb velocity.
- Maximum flood velocity.
- Maximum ebb velocity.

Similar to the bed form analysis, the hydrodynamic analysis was performed using 2 types of classification: on one hand a classification based on the magnitude of average velocities, on the other hand a classification based on the ratio between average velocities.

For the first classification, the used boundary values are related to characteristic velocity boundaries for e.g. initiation of sediment transport (Flanders Hydraulics Research, 2007) and low vs. high dynamic conditions (Bouma et al., 2005). For every point in the flow field, ebb as well as flood velocity was classified using these boundary values, and based upon the combination of ebb and flood velocity the eventual classification was made.

### 3.3 *Results and conclusions*

Within the study area, different sub areas could be defined using hydrodynamic characteristics. The spatial hydrodynamic patterns are comparable for average and maximum velocities. Between spring tide and middle tide the similarities in spatial patterns are also obvious. Neap tide was not further taken into account, due to the lower velocities which are presumed irrelevant for sediment transport processes and bed form development. Figure 6 gives a comparison between average ebb and flood velocities at spring tide.

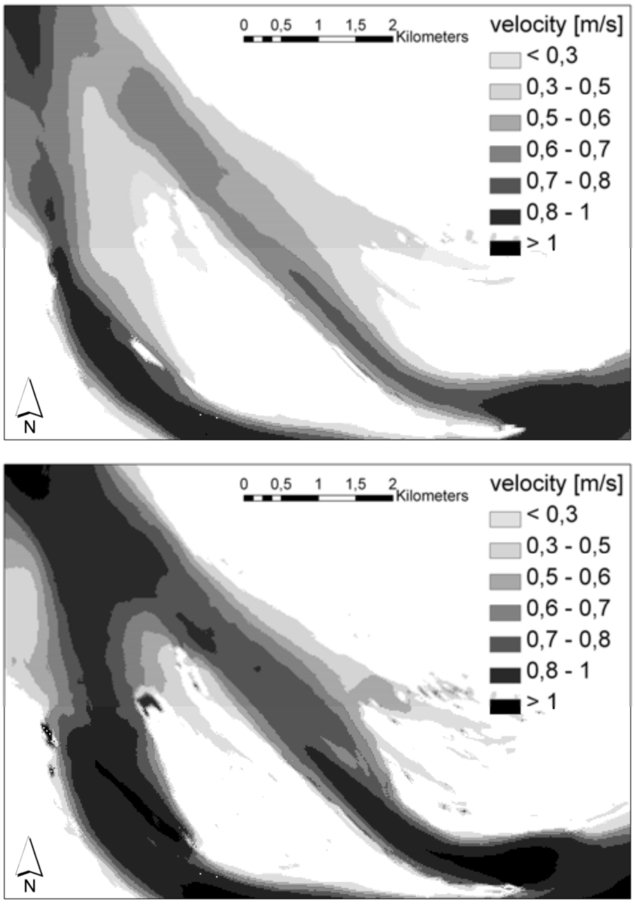

Figure 6. Above: average ebb velocities at spring tide, below: average flood velocities at spring tide

Following typical areas can be distinguished (velocities at spring tide):

- At ebb-tide some sub areas are located in the shadow of the intertidal areas (sandbars of Walsoorden and Valkenisse), and are therefore subject to very low ebb velocities (< 50 cm/s).
- In between the areas located in the shadow of the intertidal areas and those located in the channels, transition zones can be found with ebb velocities between 50 and 60 cm/s
- In the channels ebb velocities between 60 and 80 cm/s can be found
- Close to the landward side of the Valkenisse flood channel, a very dynamic area can be found, with ebb velocities > 80 cm/s

Flood velocities where used to further refine this classification.

The second classification method provided a view on the distribution of ebb and flood dominance in the study area. For middle tide as well as for spring tide, the study area proved to be mostly flood dominated. Only at the northern side of the Walsoorden sandbar and at the southern side of the Valkenisse sandbar, small ebb dominated areas could be found. This flood dominance is slightly less pronounced at spring tide because then average ebb velocities are relatively higher in relation to average flood velocities than at middle tide.

## 4 RELATION BETWEEN BED FORMS AND HYDRODYNAMICS

Based upon the earlier described classifications, a relation between the occurrence of bed forms and hydrodynamic characteristics was being investigated. For this purpose two hypotheses were proposed:

1. Hydrodynamic characteristics are decisive for the creation of bed forms. More dynamic circumstances lead to greater bed forms since the hydrodynamic conditions are always subcritical.
2. The residual flow determines the asymmetry of bed forms; the more ebb or flood dominant, the more asymmetric the bed forms will be.

### 4.1 *Hypothesis 1*

*Hydrodynamic characteristics are decisive for the creation of bed forms. More dynamic circumstances lead to greater bed forms since the hydrodynamic conditions are always subcritical.*

For the purpose of this investigation the (hydro)dynamics are described by average and maximum velocity during ebb and flood conditions. Testing this hypothesis was therefore done by comparing the length/height bed form classification with the hydrodynamic (velocity) classification.

This comparison showed no univocal relation between height and length of bed forms and hydrodynamic (velocity) characteristics.

Because not only the magnitude of velocity was presumed to be important, but also the duration that certain velocities are exceeded, a new classification was made. For spring tide conditions, the duration that a boundary value of 80 cm/s was exceeded during ebb and flood was calculated. The value is according to ZES.1 (Bouma et al., 2005) the transition between low and high dynamic conditions. Next the duration at ebb conditions was subtracted from the duration at flood conditions. In this way the importance (dominance) of flood in regard to ebb could be estimated.

Again this new classification was compared with the length/height classification. No pronounced relation could be found, although it seems that strong ebb or flood dominance is needed to develop the largest of bed forms.

Other hydrodynamic parameters (depth, bed shear stress) were also tested in regard to their influence on the development of bed forms. However, no univocal relations could be found with the occurrence of bed forms.

### 4.2 *Hypothesis 2*

*The residual flow determines the asymmetry of bed forms; the more ebb or flood dominant, the more asymmetric the bed forms will be.*

This second hypothesis was tested using the second hydrodynamic classification, based upon the ratio between average ebb and flood velocity. Taking into account the characteristics used to test the first hypothesis, also the difference between the duration that the flow velocity exceeded 80 cm/s at flood and ebb conditions is taken into consideration.

In both cases a good relation could be found between the asymmetry of the bed forms and the hydrodynamic characteristics. Figure 7 gives as an example a map of the asymmetry classes of the bed forms (for the summer condition) in comparison to a map of time-difference between the duration that the flow velocity exceeding 80 cm/s at flood and ebb conditions.

For this second hypothesis, it can be concluded that a good relation can be found between bed form asymmetry and hydrodynamic characteristics, though in some areas (e.g. near the north of the Walsoorden sandbar) differences can be seen. It has to be kept in mind though that the classification of bed forms, based on asymmetry was made using information from a limited amount of transects, while the hydrodynamic classification was made using spatially covered information.

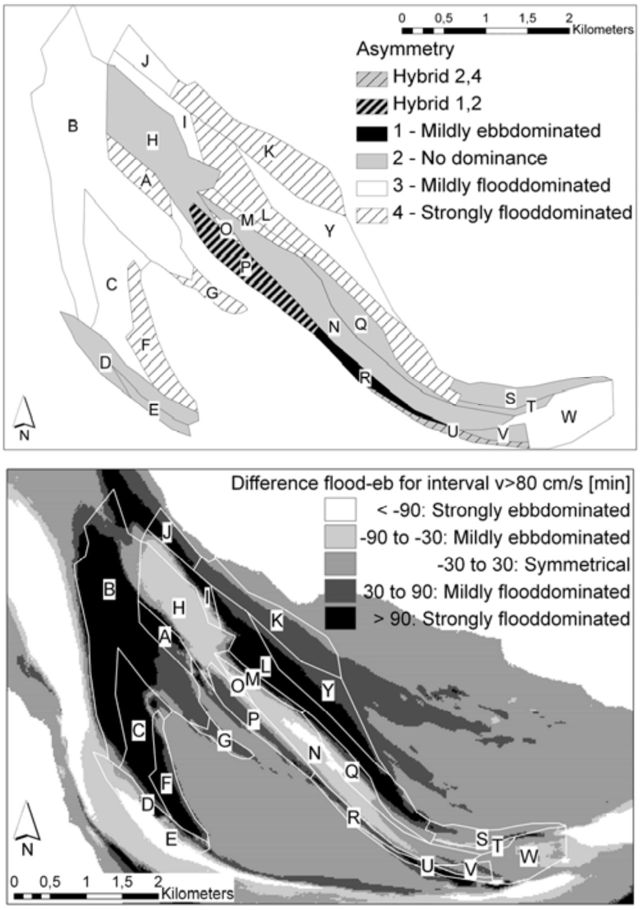

Figure 7. Asymmetry classes of the bedforms for summer condition (above), Time-difference between duration that velocity exceeds 80 cm/s at flood and ebb conditions (below)

## 5 OVERALL CONCLUSIONS

In the first part of this study the bed forms near the Walsoorden sandbar were investigated, making use of multibeam echo sounding data, obtained within the scope of two in situ disposal tests near this sandbar.

First, two classifications for bed form characteristics were made: one based on length and height of the bed forms, resulting in 7 classes, another based on bed form asymmetry, resulting in 4 classes. A great variation in bed forms was found, while, considering the asymmetry most of the transects were flood dominated.

Next, the seasonal variation of the bed forms was investigated. It was found that the sub areas located in the shadow of the intertidal sandbars during the ebb phase, were characterised by smaller bed forms in summer compared to the winter condition. The average length and height of the bed forms in the sub areas located in the deeper channels did not change much. Although for some sub areas a decrease in asymmetry was found in the summer, there was no change from flood domination to ebb domination or vice versa between winter and summer.

In the second part of this study, a hydrodynamic classification was made, based upon a 2D numerical hydrodynamic model.

For the hydrodynamic classification 2 parameters were used: average/maximum velocities during ebb and flood conditions and the duration that a boundary velocity was exceeded during ebb and flood. Using certain characteristic velocities, 4 classes were defined.

In the third part of this study a relation between the bed form and the hydrodynamic classification was investigated, making use of two hypotheses.

The first hypothesis '*Hydrodynamic characteristics are decisive for the creation of bed forms. More dynamic circumstances lead to greater bed forms'* could not be confirmed. Although a large dominance in the duration of flow velocities exceeding the boundary velocity seems to create the largest bed forms, no univocal relation was found between bed form classes (length/height) and hydrodynamic parameters.

The second hypothesis '*The residual flow determines the asymmetry of bed forms; the more ebb or flood dominant, the more asymmetric the bed forms will be'* could be confirmed. An obvious relation between bed form asymmetry and hydrodynamic characteristics could be found.

## 6 FURTHER RESEARCH

Based upon the results of the analysis of bed forms and hydrodynamic characteristics near the Walsoorden sandbar, a sampling strategy was set up in order to extend the existing ecological database (i.e. sediment properties, macrobenthos and fish).

The classifications of bed forms and hydrodynamics, together with information on sediment properties (grain sizes) will be combined to generate a classification based on the physical parameters, resulting in so called "physiotopes".

In a next phase, this knowledge of ecological aspects will be used to validate the physiotopes, and by integrating all information on morphology, hydrodynamics, ecology and the relations between them, a classification in "ecotopes" will be set up.

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