Wave attenuation by vegetation under storm conditions

An analysis of data from the Paulinaschor and the Zuidgors on the interaction between waves and vegetation under storm conditions

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Preface

This report is a result of an analysis of field data from the Paulinaschor and Zuidgors. This has been carried out within the framework of a three months internship, the so called “bachelor eindopdracht”. This internship is part of the study Civil Engineering at the University of Twente. The work has been carried out from February to May of 2006 at the WL|Delft Hydraulics institute in Delft.

I would like to thank the supervisor at WL|Delft Hydraulics, Mindert de Vries and the supervisor at the University Marjolein Dohmen –Janssen for their guidance during my internship. I would also like to thank Annet de Kiewit for her help and patience with completing this report.

Arjen Koopman
June 2009

Contents

1 Introduction

1.1 Background

Salt marshes are transitional areas between land and water, occurring along the intertidal shore of estuaries. Recently the importance of these estuarine mudflat-salt marsh ecosystems is well-recognized (Mol, 2003). These areas have important functions like: coastal protection, nursery function, feeding and breeding areas for birds, area for valuable specific vegetation types. This combined with the continuous demands for human use of the estuary, like industry and transport, has resulted in protective regulation. This means maintenance of the existing mudflat-salt marsh ecosystems. The highly dynamic nature of estuaries complicates such maintenance. Salt marshes for example have a natural cycle of aging and rejuvenation. So to maintain these salt marshes, conditions that allow all stages of this natural cycle, including rejuvenation, are required.

A major complication in understanding the dynamics of mudflat-salt marsh ecosystems is the lack of quantitative information on events such as storms. Therefore field measurements under storm conditions have taken place. This study is an analysis of these wave measurements, where the focus will be on the interaction between salt marsh vegetation and wave attenuation.

1.2 Mistres

This study is carried out within the framework of the MISTRES project. The aim of this project is to understand more about mudflat-salt marsh ecosystems under storm conditions. Information on extreme conditions is lacking, even though they may represent the critical thresholds that are most important for long-term ecosystem development.

The objectives of the MISTRES project are:

1. Quantify to which extend in a tidal system as the Scheldt estuary, hydrodynamic thresholds originate from tidal currents vs. wind driven storm events
2. Validate existing hydrodynamic models for intertidal areas, against hydrodynamic measurements obtained at normal weather conditions and at storm events
3. Identify critical thresholds for rejuvenation of salt marsh vegetation
4. Relate quantitatively, hydrodynamic forces originating from tidal currents vs. wind driven storm events to the short term sediment dynamics at the mudflat-salt marsh continuum

More about the MISTRES project can be found in Appendix A.

1.3 Research objective

The objective of this study reads:

An analysis of field data from the Paulinaschor and the Zuidgors will be made to get some insights on the interaction between waves and salt march vegetation under storm conditions.

To analyze the field data from the Paulinaschor and the Zuidgors a software package called Auke PC will be used. To make future use of this program easier a manual and some excel sheets will be made.

1.4 Research questions

To realize the objective some research questions have been formulated. There is one main question with several sub questions.

Main question:

1. What is the influence of a storm situation on waves in a mudflat-salt marsh ecosystem?

Sub questions:

1.1 Which measurements are available?
1.2 How is the field experiment situated?
1.3 What are the characteristics of the measurement locations?
1.4 What is measured by which measurement devices?
1.5 How does AukePC work?
1.6 What are the significant wave heights en periods that are measured during the field experiment in relation with vegetation and water height?
1.7 What is the effect of the presence or non presence of vegetation on wave attenuation?

1.5 Report structure

In Chapter 2 a description of the field site is done. The Paulinaschor and the Zuidgors will be described and information is given about salt marshes in general.
Chapter 3 will describe the measurements that have been carried out at the Paulinaschor and the Zuidgors. Something will be told about the exact locations of the measurements, about the measurement devices and which data was collected. The following chapter will tell something about the data analysis process with Auke PC and the results of this data analysis.
Finally some conclusions of this study are presented in chapter 5.
There are also some Appendices with all the graphs showing the results. In these Appendices also a manual for using Auke PC, that was made during this study, can be found.

2 Background

2.1 Western Scheldt

The area where the measurements for this study where held is the Western Scheldt (figure 2.1) in the Netherlands. The Western Scheldt is an estuary of the river Scheldt which has his origin in the north of France, north of the town St.-Quentin. The total length of the river before streaming into the Northsea is 355 kilometers. The estuary starts in the Belgian city Antwerp, 160 kilometers from the Northsea.

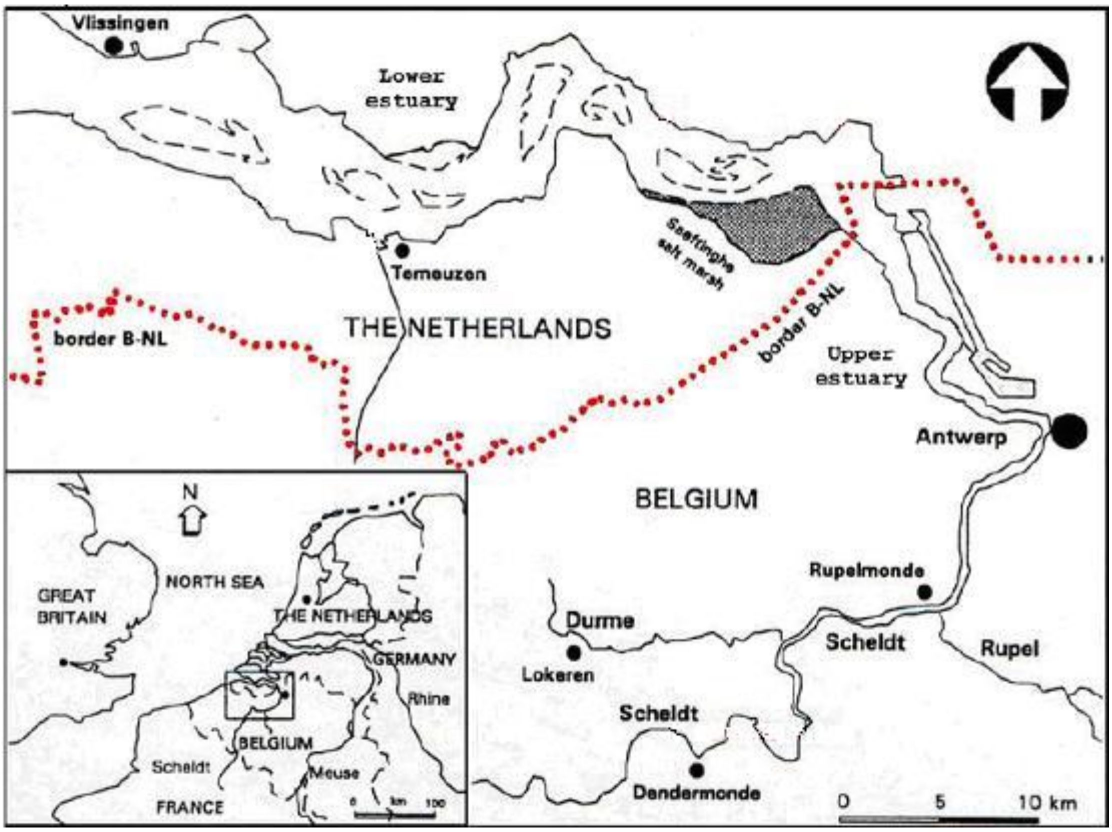

Figure 2.1: The Western Scheldt (Mol, 2003)

It is a unique area within the delta of Sealand, because the Western Scheldt is the only part of the Delta Works that is always in open contact with the sea. There is a tide that fills and empties the estuary twice a day. At Vlissingen about 1 billion m^3 water per day flows in and out of the Western Scheldt. The effects of this tide can be seen far up the river. The tide reproduces itself as a wave through the estuary. As a result, in Antwerp, the high water is 1 hour and 44 minutes later than in Vlissingen.

The Western Scheldt has many different functions like agriculture, tourism, fishing, industry and transport. All these functions have their influence on the estuary and can conflict with one another. Therefore cooperation and communication is very important to keep the ecosystem intact without harming the economy. The transport function is the most important economy factor. The Western Scheldt is an important shipping route to the harbor of Antwerp, which is one of the biggest harbors in Europe.

2.2 Salt marshes

Salt marshes are transitional areas between land and water, occurring along the intertidal shore of estuaries. They are characterized by a branched pattern of channels in a vegetated area. The marshes are bordered by mudflats at the seaside and are backed by dikes or dunes (figure 2.2). In the Netherlands, salt marshes can be found in the Waddenzee and in the province of Zeeland.

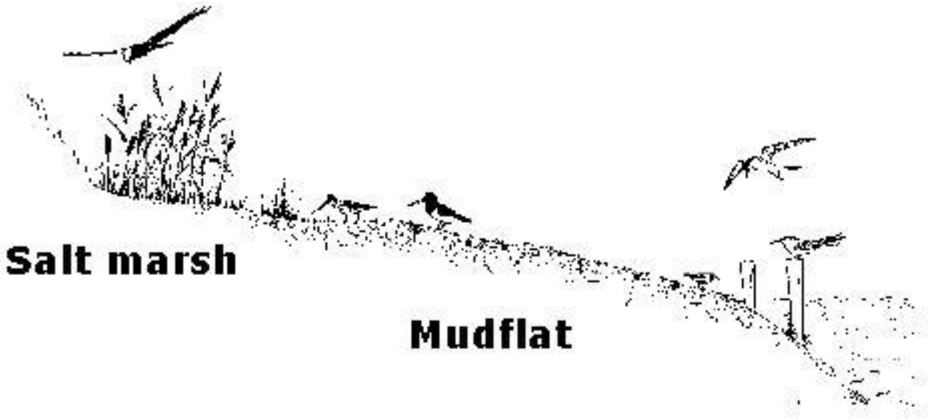

Figure 2.2: Impression of a salt marsh and mudflat. (A. Crosato, e.a., 2002)

Salt marshes have a natural cycle of aging and rejuvenation, due to the interaction between physical environment and organisms. If an area is high and sheltered enough plants can start to grow. This is the beginning of a salt marsh natural cycle. These plants will stimulate sediment trapping, which results in more vegetation. Because of the increased height the salt marsh won't be flooded that much anymore. Other plants will have the change to grow. Also the transition between mudflat and salt marsh will be steeper and a cliff can develop. Waves will cause the breakdown of the cliff, which will push the salt marsh backwards. And if the conditions are right the whole process will start again, with plants growing on the mudflat. This natural cycle is a long process of decades or even centuries.

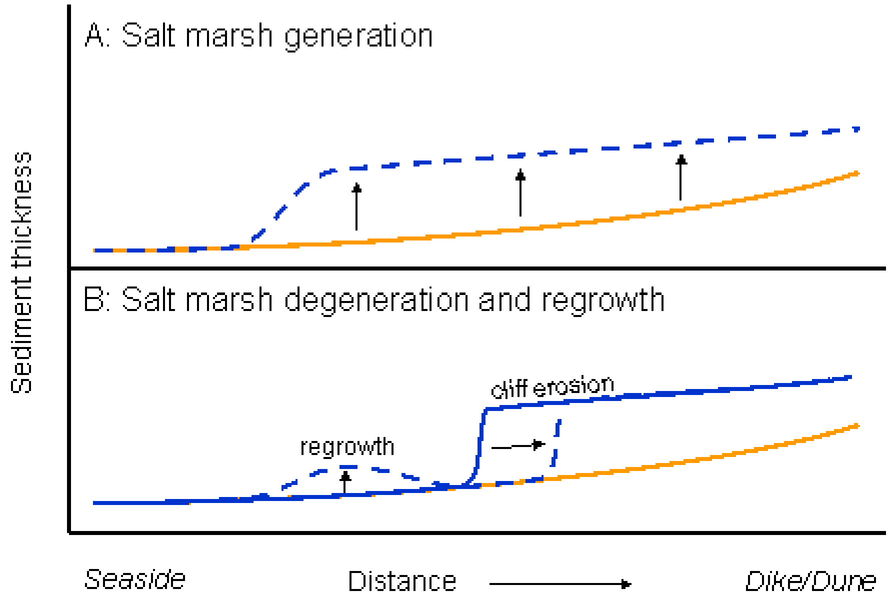

Figure 2.3: During salt marsh development (A), the sediment layer thickens. Cliff erosion will push the salt marsh backwards (B) and re-growth occurs at the same time. (Meijer, 2005)

2.3 The Paulinaschor

The salt marshes in front of the Paulinapolder are a remainder of a much bigger salt marsh area. The Paulina salt marsh is the former mouth of an arm of the sea called Braakman. Until the Second World War this salt marsh was used as a grazing land for sheep. The salt marsh is subject to strong erosion along the sea side. As a result there is a cliff that separates the salt marsh from the mudflat. On the mudflats however there is growth. New plants have grown, which means new salt marshes are about to appear.

2.4 The Zuidgors

The Zuidgors has a surface of about 55 hectares. It is a remainder of a much bigger salt marsh, of which a big part disappeared due to land reclamation. This was done for making the dikes bigger so they would match the guidelines of coastal protection. The Zuidgors is owned by Natuurmonumenten. This is a Dutch organization that protects and maintains nature reserves. At the moment the Zuidgors cliff between the salt marsh and mudflat is going backwards several meters a year due to erosion.

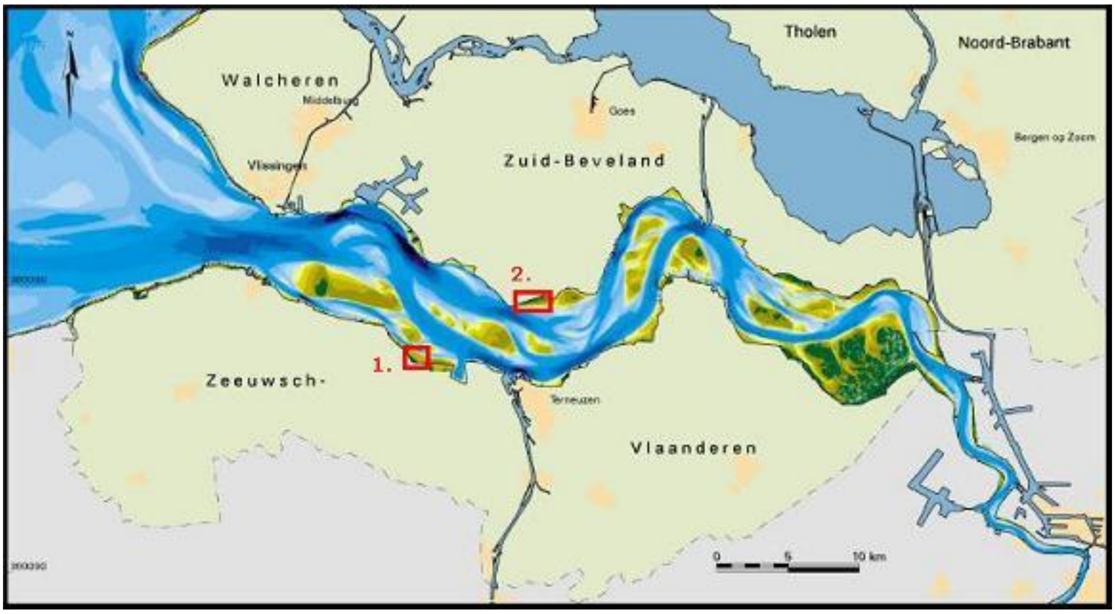

Figure 2.4: The Western Scheldt with the Paulina salt marsh (1.) and the Zuidgors (2.)

3 Data collection

3.1 Measurements

The data in this study is the result of measurements on the Paulina salt marsh and the Zuidgors salt marsh. The measurements for the Zuidgors took place from the 1st of November 2005 till the 7th of November 2005. For the Paulina salt marsh the measurements took place from the 24th of January 2006 till 30 January 2006. These measurements were executed by the NIOO (Netherlands Institute of Ecology). Besides these two datasets other measurements are carried out for the MISTRES project. Not only at the Paulina salt marsh and Zuidgors, but also at the Hellegatpolder and Baarland measurements have taken place or are planned.

At these locations a line of measurement locations is set up from mudflat to salt marsh. For each salt marsh there are five locations on the mudflat before the cliff and three on the salt marsh. At each location (figure 3.1) the water height is measured with pressure sensors. Also four EMF (electromagnetic water flow sensors) sensors and three OBS (optical backscatter sensors) sensors are used. The data that is collected by these devices is directly stored by two data loggers that are present at the site (figure 3.2).

Figure 3.1: A measuring location at the Zuidgors mudflat. With on the left a pressure sensor, in the middle an EMF and on the right an OBS. (NIOO)

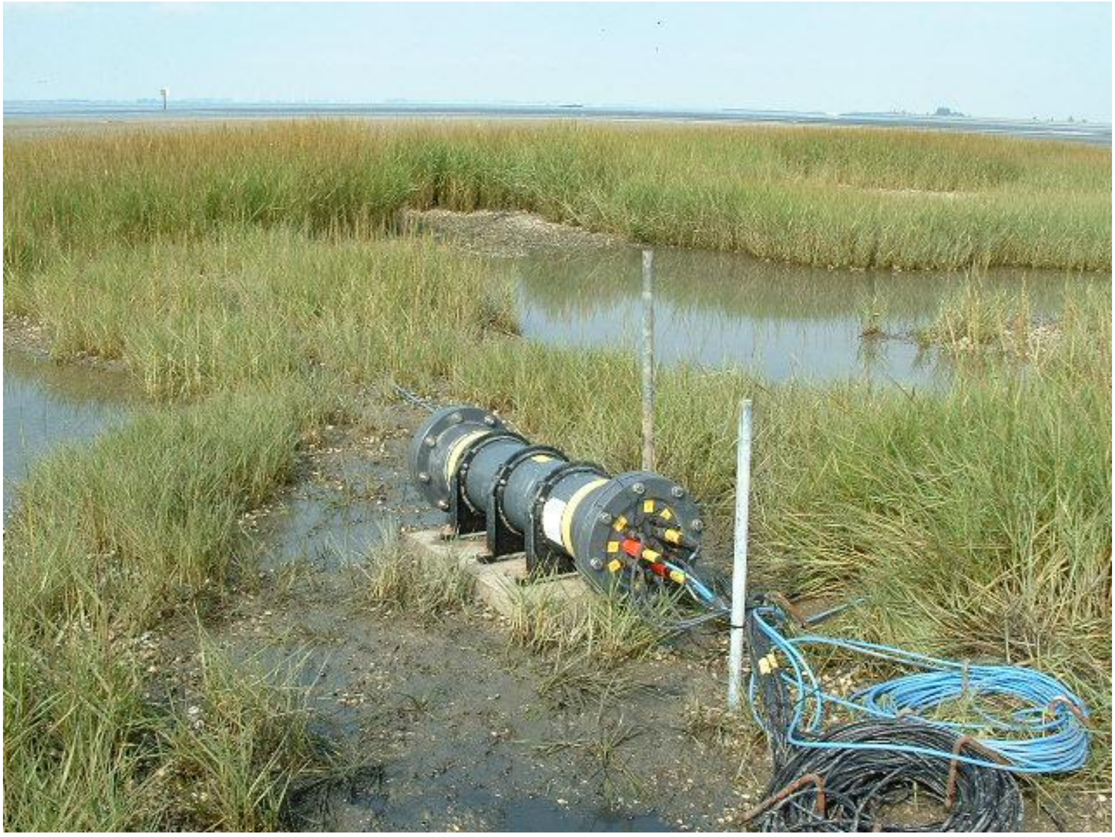
Figure 3.2: A data logger at the Hellegat salt marsh. (NIOO)

At the Paulina salt marsh the eight measurement locations are in a straight line from the dike to far on the mudflat. The first two locations are on the salt marsh and only have a pressure sensor. The third location is also on the salt marsh, five meters outside the cliff edge. Besides a pressure sensor also an EMF and an OBS are present here. On the mudflat there are five locations. The first is five meters from the cliff edge. Then there are three locations around the new vegetation zone. Behind, in the middle and in front of this zone. The last location is 145 meters outside the cliff edge on the mud flat. The four locations that are most close to the dike are stored in the first data logger (red) that is situated on the salt marsh. The data from the other four locations is stored on the data logger (yellow) at the mudflat. Appendix B shows a schematisation of the measurement locations at the Paulina salt marsh.

At the Zuidgors salt marsh the measurement locations are set up the same way as Paulina. Here also eight locations are placed in a straight line with three on the salt marsh and five on the mudflat. Appendix C shows the measurement locations at the Zuidgors.

3.2 Raw data

The measurements were done for only a part of each quarter. Of each quarter measurements were taken for 8.53 minutes (512 sec.). This way the measurement period increases to almost twice as long. This is done, because it is much more interesting to gather information of a bigger period than gather more information in a smaller period. The measurement frequency was 4 Hz, so for each second 4 measurements were stored. This gives 2048 measurements per 15 minutes. These 2048 measurements per measurement device are stored on the two data loggers, which leads to 2 files, one for each logger. So for the red data logger (the three locations on the salt march and the one just in front of it) will produce one file for every 15 minutes. In this file the data is stored in columns with one header row. In this header row data like the year, day, time, recording interval, sample interval and temperature is stored. The first column of each file is filled with a label number. In the next four columns the data from the pressure sensors is stored. In the schematisation of Appendix B and C the numbers of the columns are given. Then the data from the first OBS is given. The next two columns is the EMF, with first the data for the x-direction and then the y-direction. The second OBS is in the ninth column. And in the last two columns the second EMF with x-direction and y-direction is stored. For Paulina the measurement period was the first week of November 2005. Not all the data from this period is useful, because the mudflat will be dry when the tide is low. So only the measurements where the tide was high are useful and will be analysed.

3.3 Data preparation

For analysing the data these raw data files are not enough. Parameters that describe the waves like the significant wave height are needed. Also period information and spectral wave data may be needed.
This kind of information can be obtained using the program Delft-AUKE. This program is developed at WL | Delft Hydraulics and is a set of programs for data acquisition and processing of measured signals from instruments. Three Delft-AUKE programs were used.

1. Conasc
   This program converts a text file to a Delft-AUKE series file. The input of this program are the raw data files. The output is being used for the other two programs.
2. Waves
   With this program the development of series values between two positive zero crossings is determined.
3. Spectrum
   With this program the spectral densities of series are computed. Together with the densities a set of parameters is computed and sent to the chosen output device.

Before Conasc can be used the raw data files have to be changed in such a way that Conasc can use them. If you would have to do that one file at a time, it would take a very long time. Therefore Microsoft Excel is used. With the help of a Visual Basic Macro the files can be changed very quickly. The output of waves and spectrum is stored in files with the extension .par. To get the needed parameters out of these files Excel is also used.
More information about Delft-AUKE, the Excel file and the macro’s can be found in Appendix F. This is a manual for the use of Delft-AUKE made during this study. The manual and Microsoft Excel file is made to help and speed up future data analysis with Delft-AUKE at WL | Delft Hydraulics.

4 Data analysis

4.1 Bathymetry

To better understand the water heights that have been measured the bottom heights of the Paulina salt marsh and the Zuidgors are shown in figure 4.1 and 4.2. The pink dots represent the places where measurements took place. The red line in the bathymetry of the Paulina salt marsh indicates the vegetation in front of the cliff.

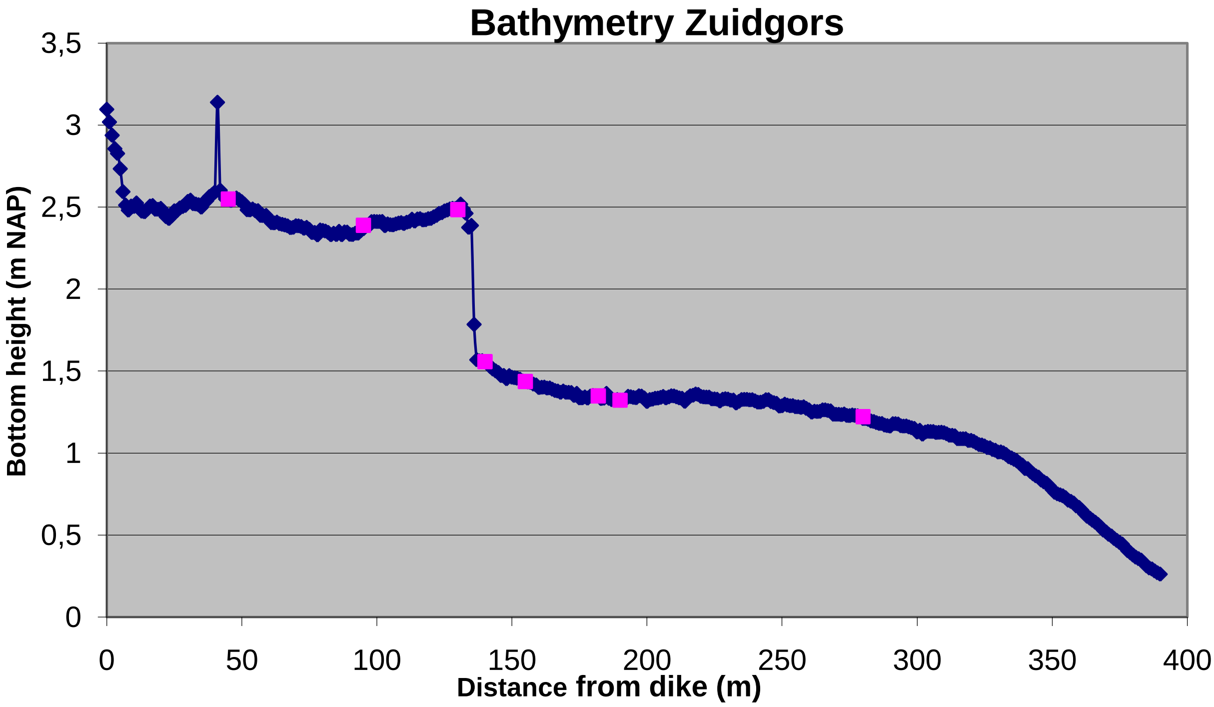

Figure 4.1: Bathymetry Zuidgors

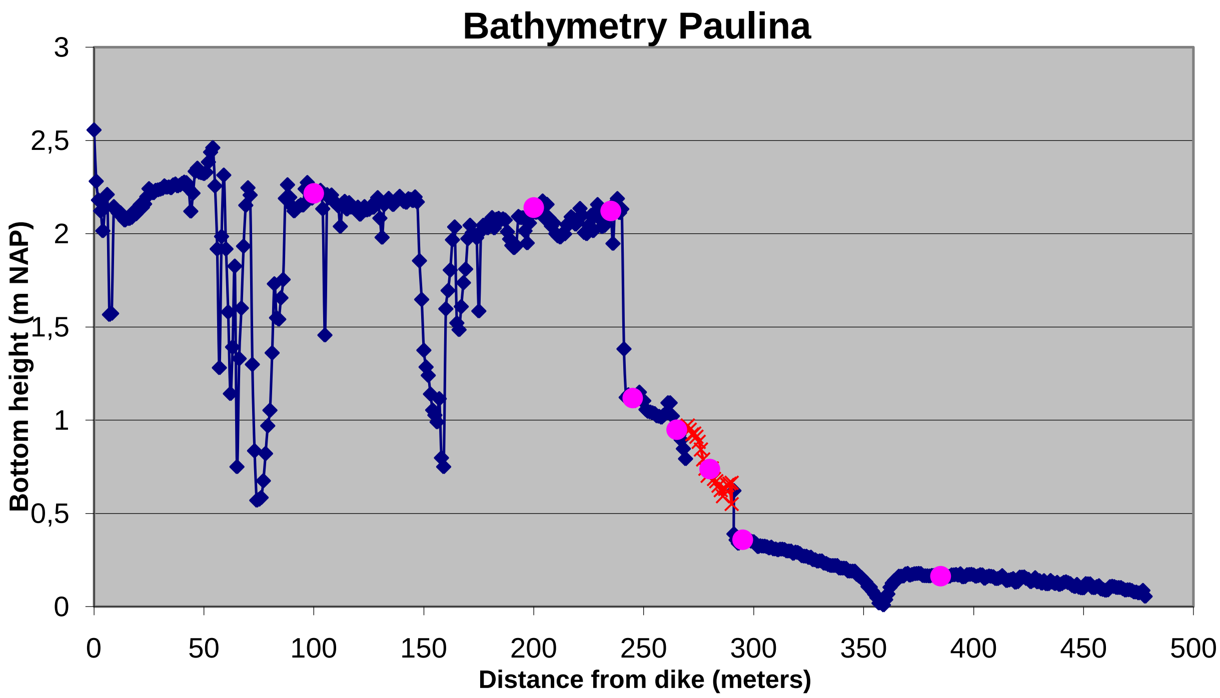

Figure 4.2: Bathymetry Paulina salt marsh

4.2 Water heights

Due to the tides that occur in the Western Scheldt the water level rises two times a day, causing the salt marshes at Paulina and Zuidgors to flood. The water height is measured by the pressure sensors placed on the salt marshes. The results of these measurements are stored in mV, which has to be converted to the metric scale to analyze the water heights. The pressure sensors that are used are giving an output of 1 mV for each mbar. One mbar equals one centimeter of water elevation as shown in the next formula.

$$p = \rho_{water} g h$$

Where:

p Pressure in Pa (1 Pa = 0.01 mbar)

ρ_{water} Density of the water (salt water – 1025 kg/m^3)

g Acceleration due to gravity (9.81 m/s^2)

h The water height (meters)

$$p = 1025 * 9.81 * h$$
$$p = 10055 * h$$

so: 1 mbar = 0.0099 m water

Therefore the results from the pressure sensors can be interpreted as centimeters water elevation. If you take the average water height of each data set of 512 seconds and put it in a graph the tides are visible (figure 4.3).

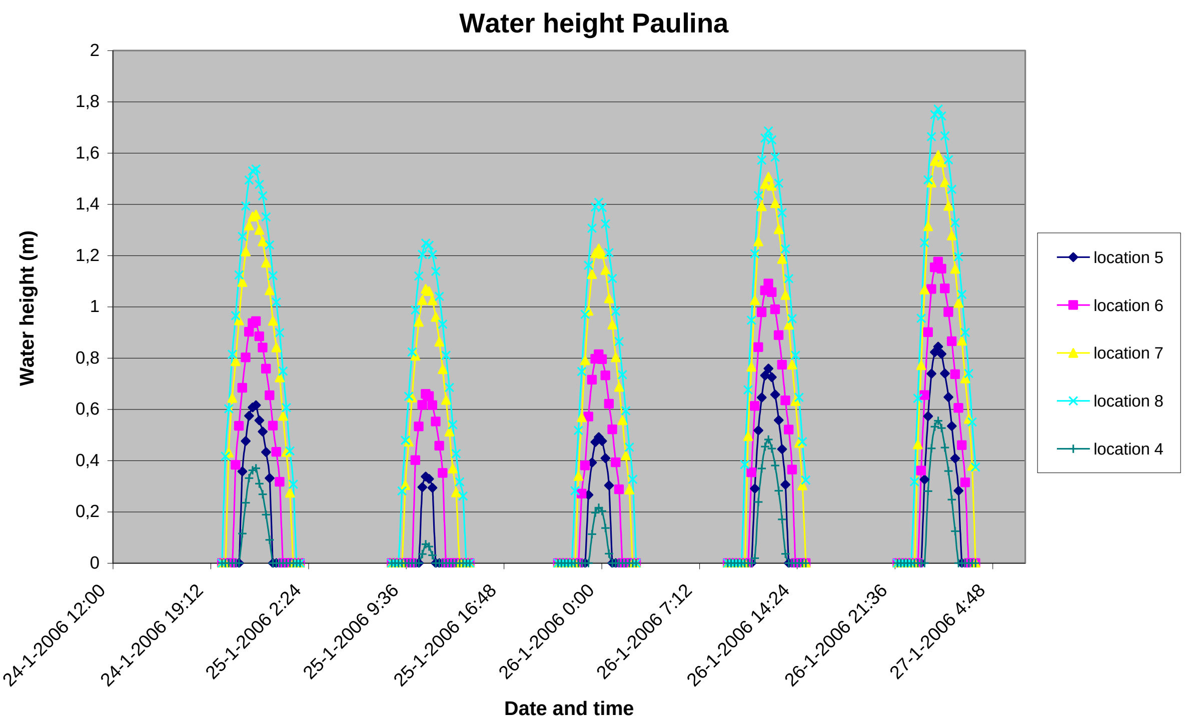

Figure 4.3: Water height Paulina salt marsh during measuring period of 3 days.

This graph shows that a flood occurred five times during the measuring period of 24 January to 27 January. During these floods measuring locations 4 till 8 show a result which indicates that during the flood water was present. From locations 1, 2 and 3 information is missing. This is not because the pressure sensors where not working, but simply because the flood didn't reach these locations. These three locations are located at the salt marsh behind the cliff, which separates the mudflat from the salt marsh. So the water level during this experiment was never high enough for water to flow into the actual salt marsh of Paulina.

The same graph of the water height can be made for the Zuidgors location.

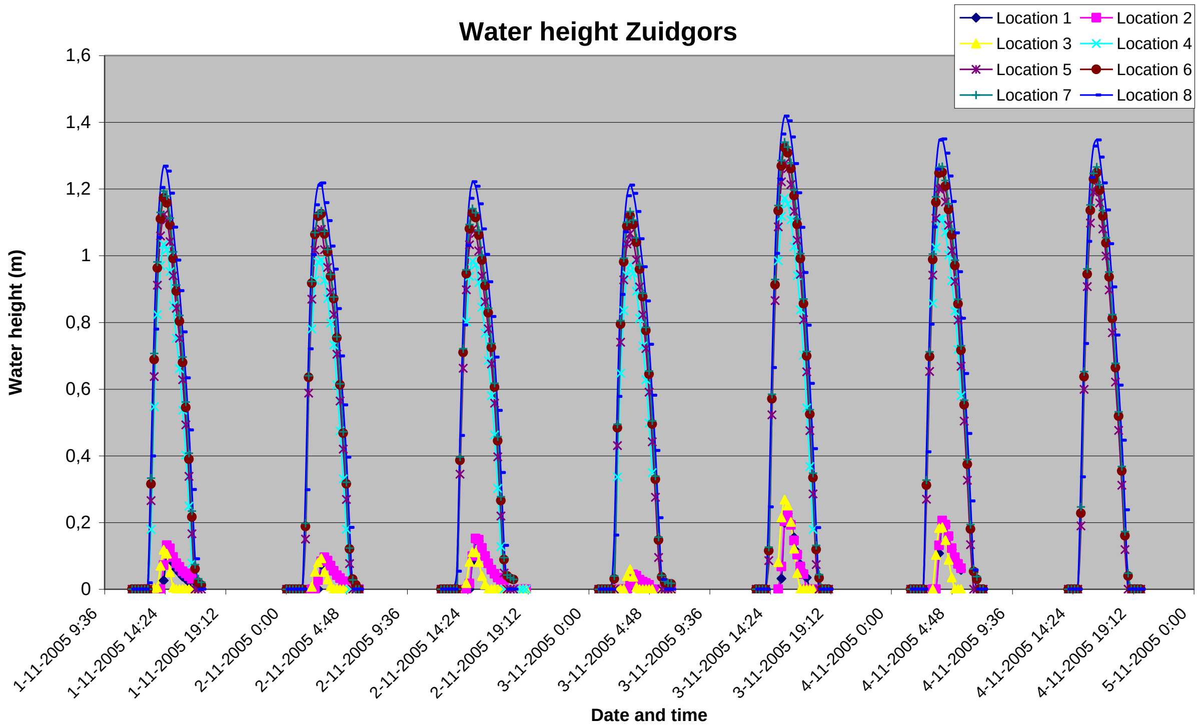

Figure 4.4: Water height Zuidgors salt marsh during measuring period of 4 days.

The experiment at Zuidgors was held during a longer period of time, so there are measurements of more floods available. In the graph you can see that locations 1, 2 and 3 give some results. These locations are located at the salt marsh behind the cliff. So during this experiment the salt marsh behind the cliff did flood a little. The water level was high enough to get water over the cliff into the salt marsh.

4.3 Wave heights

To analyze the influence of the salt marsh vegetation the water height isn't that useful. More important is to know what happens with the wave height. Therefore the wave height has to be determined. The definition of wave height is the overall vertical change in height between the wave crest and the wave trough. Because there are many different waves, with different height, length and frequency, Delft AUKE has been used to get the wave heights out of the measured water heights. Delft AUKE gets the significant wave height of every data set that was measured. The significant wave height is the average height of the highest one-third of all waves occurring in one data set ($H_{1/3}$). This is the most common parameter that is used to describe the wave height.

4.4 Wave attenuation at Paulina

For the Paulina salt marsh the significant wave height of the five floods that were recorded is shown in the figure 4.5.

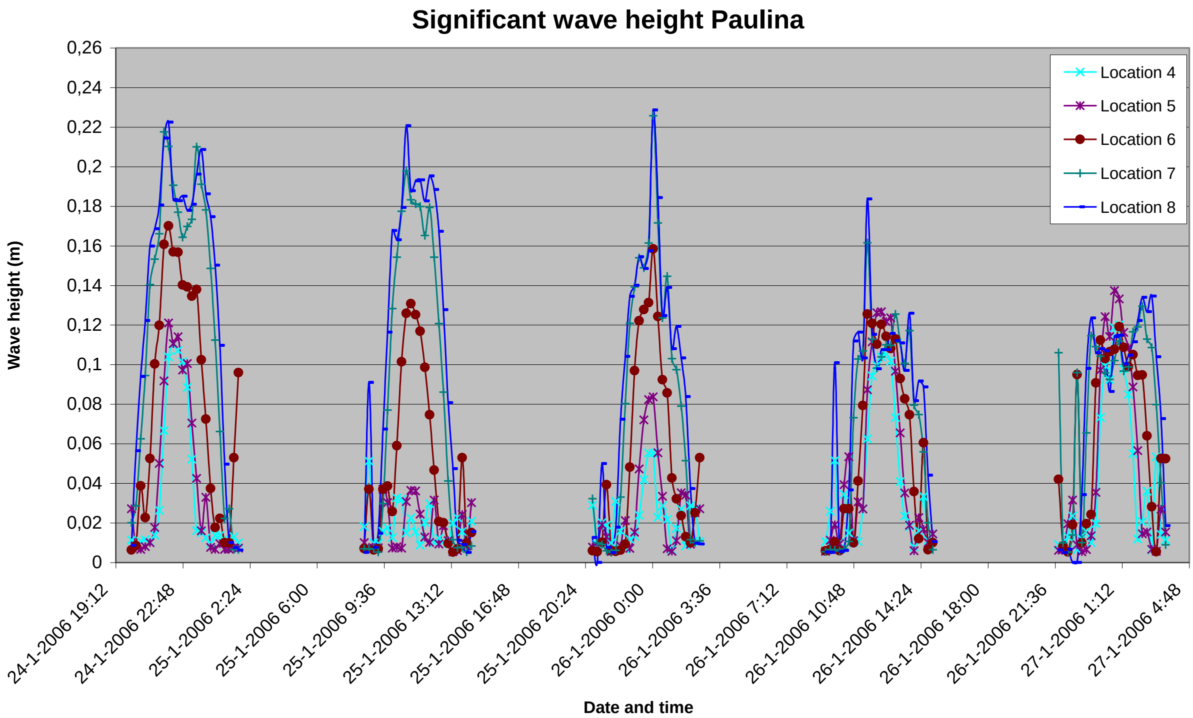

Figure 4.5: Significant wave height ($H_{1/3}$) during the first three tides of the experiment at Paulina.

As seen with the water height there is no water at locations 1, 2 and 3, therefore they don't appear in this graph. In this graph you can see that the wave height isn't the same at each location. Also between the floods are differences in wave height.

First we take a closer look at the first flood period. The waves come on the mudflat and will first reach location 8. The waves have the same height when they reach location 7. When the water reaches location 6 a reduction in the wave height can be seen. Location 6 is standing in the middle of a vegetated area. Also after location 6 the wave height is reduced, but after location 5 the wave height stays the same again. So here the influence of the vegetation around location 6 is visible in the data that was collected at the Paulina site.

The same effect can be seen with the next two flood periods. But because of the lower water height (figure 4.4) the attenuation is much higher. This can be shown with the calculation of the wave damping. The damping is defined as:

$$Damping = \frac{H_5}{H_7} * 100\%$$

Where:

H_5 The significant wave height at location 5 (five meters behind vegetation)

H_7 The significant wave height at location 7 (five meters in front of vegetation)

A wave damping of 100% means that the wave height didn't change between the two locations and a wave damping of 0% means a complete disappearance of the waves at location 5. In table 4.1 the wave damping is given for different water levels in all the five periods.

Time period	Water level (m NAP)	Water height H_6 (m)	Damping (%)
24 January			
21:32	1,44	0,6840015	**30,2**
22:17	1,69	0,9362393	**58,0**
23:02	1,60	0,8404932	**59,2**
23:47	1,29	0,5358276	**8,4**
25 January			
10:32	1,28	0,5328374	**4,1**
11:17	1,40	0,6512031	**19,9**
12:02	1,20	0,4576816	**5,7**
25-26 January			
23:32	1,55	0,7965762	**48,4**
00:17	1,49	0,7320669	**32,3**
01:02	1,15	0,3933936	**5,6**
26 January			
11:02	1,11	0,3540801	**29,8**
11:47	1,74	0,9784307	**98,8**
12:32	1,82	1,0572549	**110,7**
13:17	1,53	0,7740093	**58,8**
26-27 January			
23:47	1,41	0,6557661	**32,5**
00:32	1,91	1,1538911	**123,3**
01:17	1,83	1,0712417	**120,2**
02:02	1,49	0,7367593	**47,4**

Table 4.1: Wave damping at the Paulina salt marsh

The last two flood periods that are available show almost no decrease of wave height or even an increase. This is because of the high water level that occurred during these periods. The vegetation has less influence on the waves because they are approximately 40 cm high. If the water height at location 6 in the middle of the vegetation zone is around or just above this 40 cm the waves are almost completely disappeared. But when the water height is well over 40 cm the vegetation has little or no effect on the significant wave height.

For a better and more detailed look the significant wave heights are plotted against the distance from the dike. The graphs can be found in Appendix D. The various lines represent the different water levels in meters above NAP. Each graph clearly shows that for some water levels, wave height is decreasing along the salt marsh, especially when water levels are low.

4.5 Wave attenuation at Zuidgors

For the Zuidgors salt marsh the significant wave height of the first three floods that were recorded is shown in the following graph.

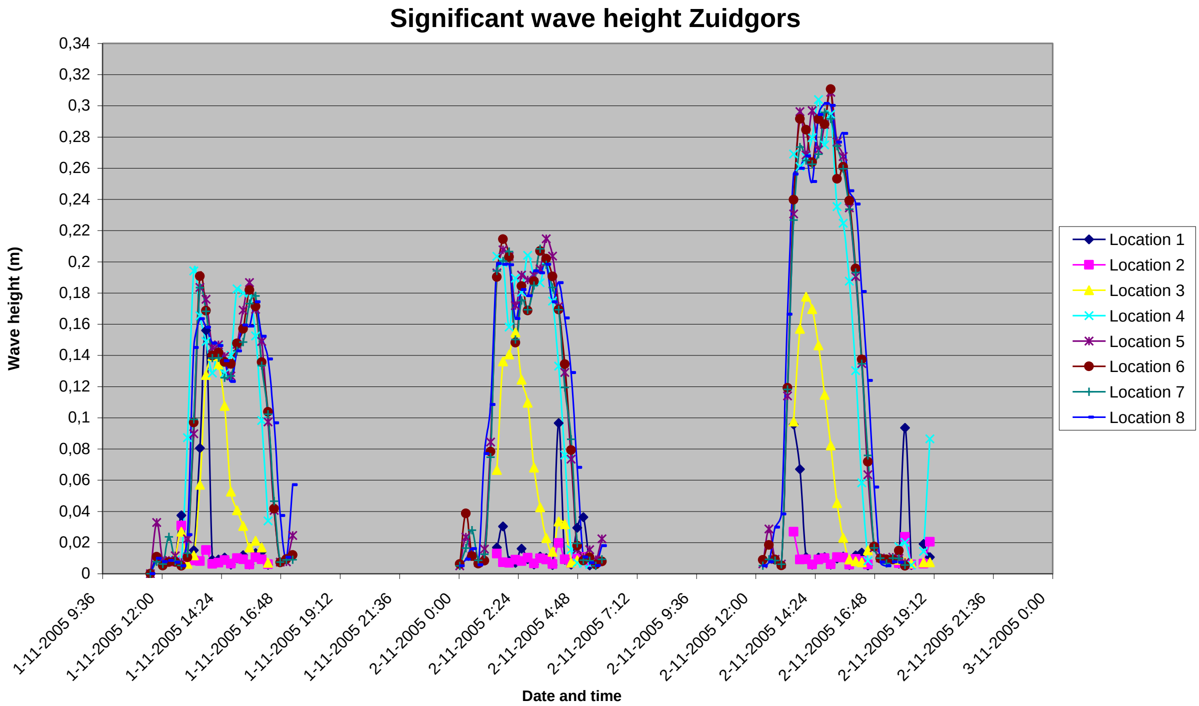

Figure 4.6: Significant wave height ($H_{1/3}$) during the first three tides of the experiment at Zuidgors.

Here you can see that significant wave height is more or less the same for location 4 till 8. At location 3 some attenuation took place and at location 1 and 2 almost no waves are left. There is a simple explanation for this situation. Locations 4 till 8 are located on the mud flat in front of the salt marsh cliff. On this mudflat is no vegetation present. Location 3 is on the salt marsh 5 meters from the cliff edge. So attenuation due to the vegetation and the cliff has occurred. Further on the salt marsh there are barely any waves. This is caused by the vegetation that damped all the waves. This damping can be so effective, because the water level is low. At location 3 the water height stays most of the time under 20 centimeters, while the vegetation is approximately 40 centimeters high. Therefore it’s not that useful to calculate a damping factor, because between location 3 and 2 the damping is complete during all the measurements. A damping factor can be calculated between location 4 and 3, but this won’t be the damping that is caused by vegetation only. The cliff also breaks the waves, because if the water flows over the edge the water height is low.

In Appendix E the significant wave heights are plotted against the distance from the dike for the seven floods that were measured. The various lines represent the different water levels in meters above NAP. The vertical line in the middle of each graph shows where the cliff is located. You can see that in many cases the waves are damped a lot after the water passed the cliff. The cliff edge is 2,388 meter above NAP.

5 Conclusion and discussion

5.1 Damping factor decreases when water height is lower

The damping factor is calculated for the data at the Paulina salt marsh. The results can be seen in table 4.1. These results have been plotted in figure 5.1. Some conclusions can be drawn from this. In this graph a linear relationship between damping and water height can be seen, but there is not enough data to quantify this relationship. Furthermore a complete disappearance of the waves can be seen around a water height of 40 cm. This is also the height of the vegetation that is present at this location. When the water height gets above 1 meter wave attenuation does not occur any more.

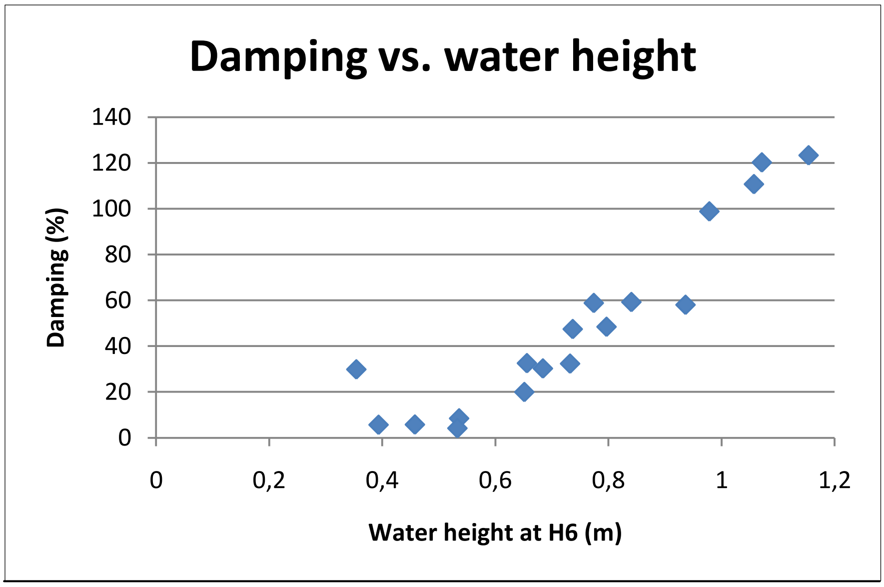

Figure 5.1: Damping vs. water height at Paulina salt marsh

5.2 Comparison with previous study

There have been study's about wave attenuation at WL | Delft Hydraulics in the past. In 2002 there were taken measurements under normal conditions at the Paulinaschor in the Western Scheldt. Arjan Mol analyzed this data in 2003 and calculated the wave heights. He tried to implement vegetation and wave attenuation in the SWAN model. SWAN is a wave model that can be used to simulate waves in different kinds of situations. Mol also calculated a damping factor for different water heights. In figure 5.2 his data is plotted in the same graph as the storm data from this study. Some similarities can be seen between the two data sets. In the data from 2002 there can also be seen a linear relationship between damping and water height. The damping is almost complete at a water height of 40 cm, with vegetation of also approximately 40 cm high. And when the water height is over 1 meter wave attenuation almost does not occur any more.

More conclusions cannot be drawn from this because the data used by Mol where not taken at the same spot at the Paulina salt marsh as the storm data from 2006. The water in 2002 did go over the cliff and over the actual salt marsh while the data from 2006 is about wave attenuation over vegetation on the mudflat in between the sea and the cliff edge.

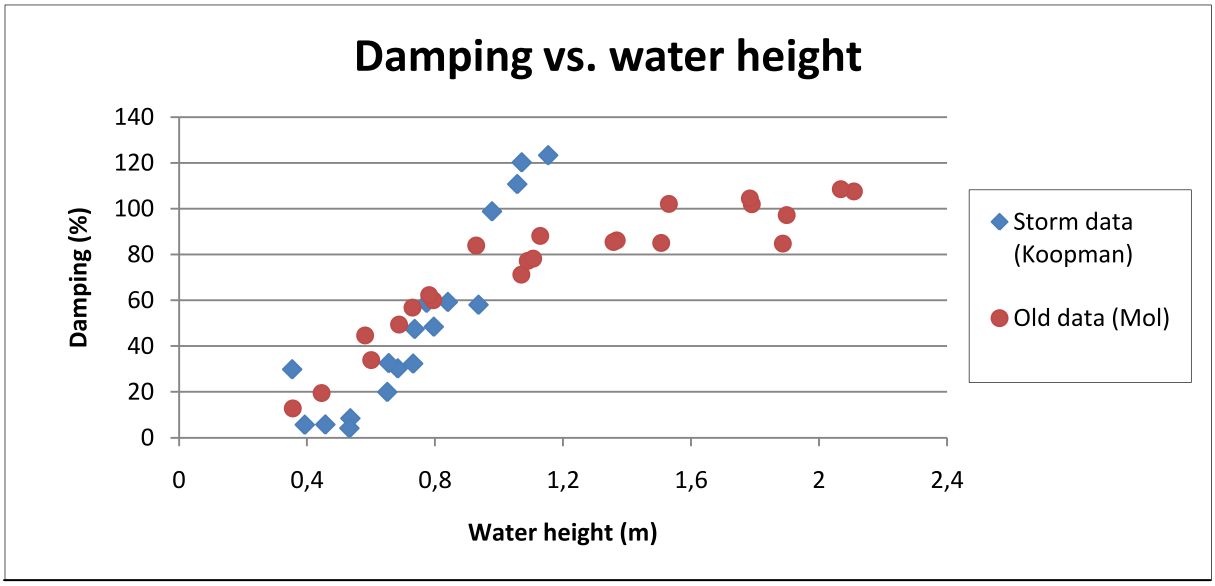

Figure 5.2: Damping vs. water height of old and new data

6.3 No suitable data of salt marsh wave attenuation

The data that was collected in November 2005 at the Zuidgors did not deliver suitable data for studying wave attenuation. The water level was never high enough to go over the cliff edge an onto the salt marsh with the vegetation. The data collected in January 2006 at the Paulina salt marsh also did not have a water level high enough to get water on the salt marsh. Only the data of vegetation in front of the cliff could be used to study wave attenuation. To get a better look at wave attenuation under storm conditions new measurements should be taken when the water level rises at least one meter above the cliff edge.

6.4 Modeling with SWAN

One of the objectives of this study was to see if the SWAN wave model could be programmed to simulate the wave attenuation. With the use of already existing model data of the Paulina salt marsh from previous studies a simulation was run for the first wave of the Paulina salt marsh data which took place on 24 November 2005. Four simulation runs took place with water levels of 1,29 m NAP, 1,44 m NAP, 1,60 m NAP and 1,69 m NAP. The results are plotted in figure 5.3. The simulated wave attenuation is almost similar to the data. With only this run you can conclude that the SWAN model works. But to improve the SWAN model more resurge has to be done into the parameters that have been put into SWAN.

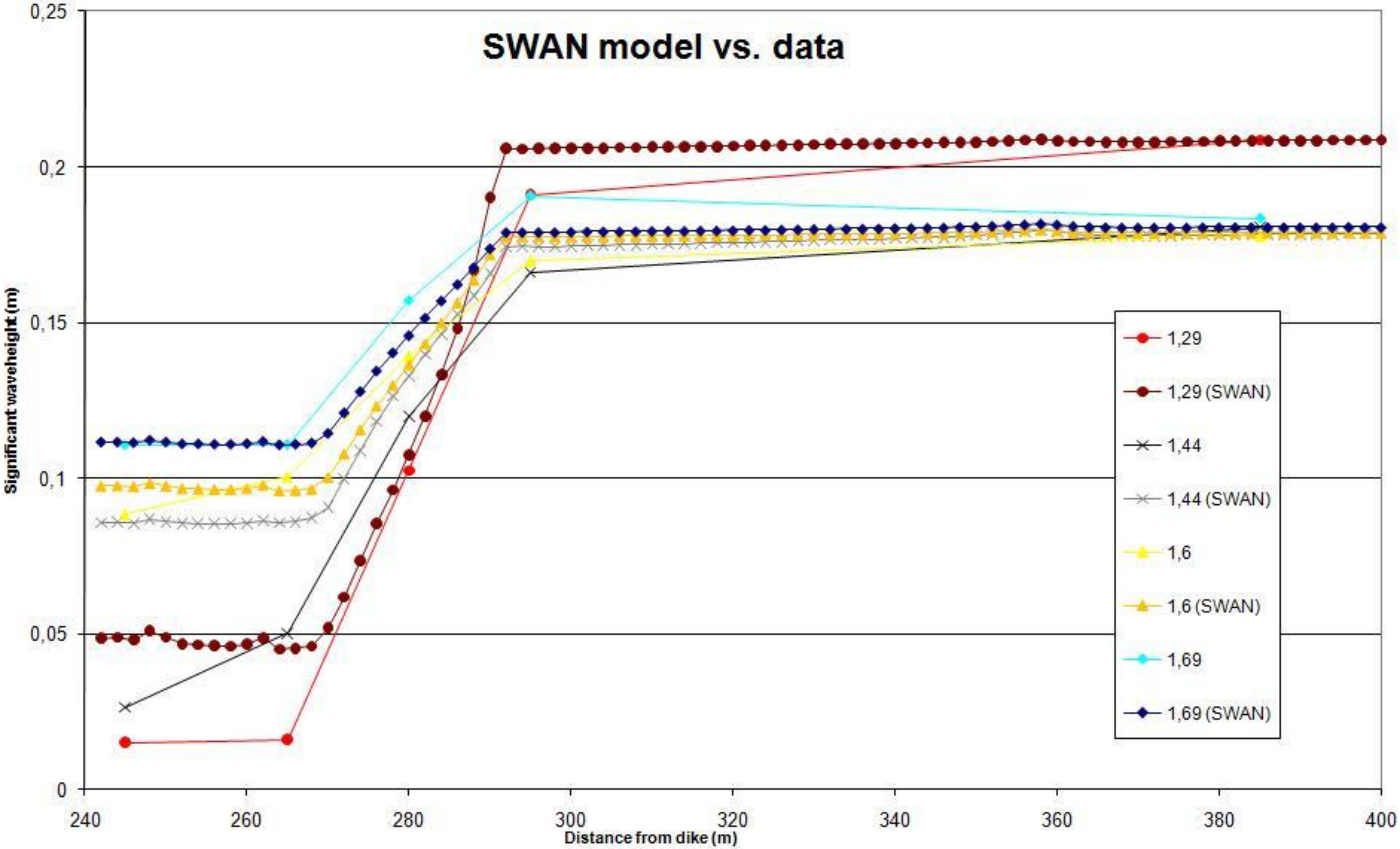

Figure 5.3: Results of a SWAN model run compared with the actual data

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Appendices

A Mistres

Quantifying the relative importance of extreme hydrodynamic conditions as threshold for salt marsh rejuvenation

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Refocused after discussion + comment D.J. de Jong (RIKZ)

Problem definition

The well-recognized importance of estuarine mudflat-salt marsh ecosystems (e.g., coastal protection, nursery function, feeding and breeding areas to birds, valuable specific vegetation types) combined with the continuous demands for human use of the estuary (e.g., navigation, industry, coastal protection) has resulted in protective regulation. Implementation of such protective regulation requires that governments warrant the maintenance of the existing area of habitat types on mudflats and salt marshes. The highly dynamic nature of estuaries complicates such maintenance, as specific habitat types may be cyclic and do not necessarily have a steady state. For example, salt marshes have a natural cycle of aging and rejuvenation, due to the interaction between physical environment and organisms. To maintain these types of habitats thus requires (in time and/or space) conditions that allow all various stages of this natural cycle, including rejuvenation.

A major complication in understanding the dynamics of tidal marsh-mudflat ecosystems is the lack of quantitative information on the importance of events such as e.g. storms in autumn and winter (relevant for e.g. sediment transport and loss of seedlings). Especially during events critical thresholds may be exceeded, leading to functional and/or morphological changes in these ecosystems. For example, events may interfere with essential steps in natural cycles of ecosystem aging and rejuvenation. At present, hydrodynamic models are not yet suitable to simulate intertidal areas at a fine enough scale to capture these types of effects and the models are generally also not validated for this type of analyses due to a lack of suitable datasets. Thus, although we have some knowledge on average conditions, information on the extreme hydrodynamic conditions are lacking, even though they may represent *the* critical thresholds that are most important for long-term ecosystem development.

Objectives

1) quantify to which extend in a tidal system as the Scheldt estuary, hydrodynamic thresholds originate from tidal currents vs. wind driven storm events
2) to validate existing hydrodynamic models for intertidal areas, against hydrodynamic measurements obtained at normal weather conditions and at storm events
3) identify critical thresholds for rejuvenation of salt marsh vegetation (i.e., where can *Spartina* seedlings establish and small tussocks expand)
4) relate quantitatively, hydrodynamic forces originating from tidal currents vs. wind driven storm events to the short term sediment dynamics at the mudflat - salt marsh continuum

Research approach – experimental design

- Based on the weather forecast, perform hydrodynamic measurements at *i)* normal spring-tide conditions (i.e., maximum hydrodynamic force due to normal tidal water movement) and *ii)* **during extreme stormy conditions** (i.e., maximum hydrodynamic force due to wind effects).
- To use 2 highly mobile systems called MISTRES to be able to perform these hydrodynamic measurements on short notice.
- To select a number of contrasting field sites, with areas where salt marsh rejuvenation is just possible vs. just impossible. These sites will be prepared ahead of the stormy season, to be able to easily install the equipment in a storm proof manner. Based on the weather forecast (wind direction and wind force), the mobile MISTRES-systems can be employed at the location where the largest impact is expected for that particular event.
- Around each (storm) measurement, sedimentation or erosion at the field site will be determined by measuring sediment height against a fixed position, In addition, a Malvern analysis will be performed

Measurements may need to be spread out over a few years, to be able to 'catch' a sufficient number of different events into a database, and to be spread out in space, to measure the event at the location where the impact will be the strongest.

Research approach - instrumentation

To create surveying capability on short notice NIOO constructed 2 **M**ulti **I**nstrument **S**ystem for **Tr**ansient **E**vent **S**urveys (MISTRES), each consisting of the following components:

- *to measure wave energy and wave attenuation:* 4 x pressure sensors with cables of 25, 50, 75, and 150 meter
- *to measure sediment concentration in the water column:* 1 (or 2) x Optical Back Scatter with a cable of 100 meter
- *to measure a current velocities:* 2 x 2D-current velocity sensors with cables of 100 meter
- *to control data collection and data storage:* 1 x Campbell scientific datalogger
- Memory capacity to store 3 days of data for the high water periods, using a 4 Hz sampling rate (sufficient to measure waves). The use of a 3-day period allows us to cover a weekend.
- Battery packages that enables 3 days of measurements during high water, using a 4 Hz sampling rate
- Waterproof housing

Research approach – proposed field sites

Field sites are open to discussion. Some 1st ideas of interesting field sites are:

- Paulina polder => well protected area, where *Spartina* can grow at very low NAP
- Hellegat polder => comparable to Paulina, but with larger exposure to Northern storms due to the absence of sand banks in front of the marsh
- Ossenisse plaat => highly exposed area at which *Spartina* seedlings and are establishing and small tussocks are expanding *NOTE: only accessible by boat*
- Zuidgors => strongly eroding marsh with cliff, but with rejuvenation in the most eastward corner of the marsh

Exact locations at these marshes will be based A) on GIS analysis of time series of aerial photographs that show where the marsh is currently growing and eroding (*to be done by NIOO*) and B) results of hydrodynamic model runs that indicate where differences in velocities may be expected (*to be done by RIKZ*)

History of the project

The proposed experimental design results from a major collaborative field campaign at project on Paulina polder that included the NIOO-CEME, RIKZ, RIZA, UIA, KUL and the WL. During this campaign we collected a large number of hydrodynamic parameters on different spatial scales, and came to the conclusion that the proposed 'event-hunting' program would be the minimum effort with the maximum output.

Financial requirements

See attachment

B Measurement locations Paulina salt marsh

Dike	**Dike**	**Dike**	**Dike**	**Dike**	**Dike**	**Dike**		**Dike**	**Dike**	**Dike**	**0**
					pole #						**meters from dike**
	Near creek **140 m from cliffedge**				1	Pressure sensor # 5					**100**
	on salt marsh **40 m from cliffedge**				2	Pressure sensor # 3					**200**
		datalogger 1 on salt marsh 20 m from cliffedge									
	on salt marsh **5 m from cliffedge**				3	Pressure sensor # 2		EMF # 8	OBS # 6		**235**
Cliffedge	**Cliffedge**	**Cliffedge**	**Cliffedge**	**Cliffedge**	**Cliffedge**	**Cliffedge**		**Cliffedge**	**Cliffedge**	**Cliffedge**	**240**
	on mudflat **5 m from cliffedge**				4	Pressure sensor # 4		EMF # 9	OBS # 7		**245**
	between cliffedge and new Spartina zone				5	Pressure sensor # 2		EMF # 8	OBS # 7		**265**
											270
		datalogger 2 on mudflat 40 m from cliffedge									
	Inside new Spartina zone				6	Pressure sensor # 3					**280**
											290
	Outside new Spartina zone (**5 m**)				7	Pressure sensor # 4		EMF # 9			**295**
	on mudflat **145 m form cliffedge**				8	Pressure sensor # 5					**385**
Seaside	**Seaside**	**Seaside**	**Seaside**	**Seaside**	**Seaside**	**Seaside**		**Seaside**	**Seaside**	**Seaside**	**Seaside**

C Measurement locations Zuidgors salt marsh

Dike	Dike	Dike	Dike	Dike	Dike	Dike	Dike	Dike	Dike

Location	paal #	Sensors		
by creek **90 m from cliffedge**	1	pressure sensor # 5		
on salt marsh **40 m from cliffedge**	2	pressure sensor # 4		
datalogger 1 on salt marsh 15 m from cliffedge				
on salt marsh **5 m from cliffedge**	3	pressure sensor # 2	EMF # 8	OBS # 4
Cliffedge				
on mudflat **5 m from cliffedge**	4	pressure sensor # 3	EMF # 9	OBS # 5
on mudflat **20 m from cliffedge**	5	pressure sensor # 2	EMF # 8	OBS # 5
datalogger 2 on mudflat 20 m from cliffedge				
on mudflat **47 m from cliffedge**	6	pressure sensor # 1		
on mudflat **55 m from cliffedge**	7	pressure sensor # 4	EMF # 7	
on mudflat **145 m from cliffedge**	8	pressure sensor # 3		

Cliffedge	Cliffedge	Cliffedge	Cliffedge	Cliffedge	Cliffedge	Cliffedge	Cliffedge	Cliffedge	Cliffedge
Seaside	Seaside	Seaside	Seaside	Seaside	Seaside	Seaside	Seaside	Seaside	Seaside

D Wave attenuation at Paulina

Wave attenuation at the Paulina salt marsh for the 5 floods that occurred during the measurements.

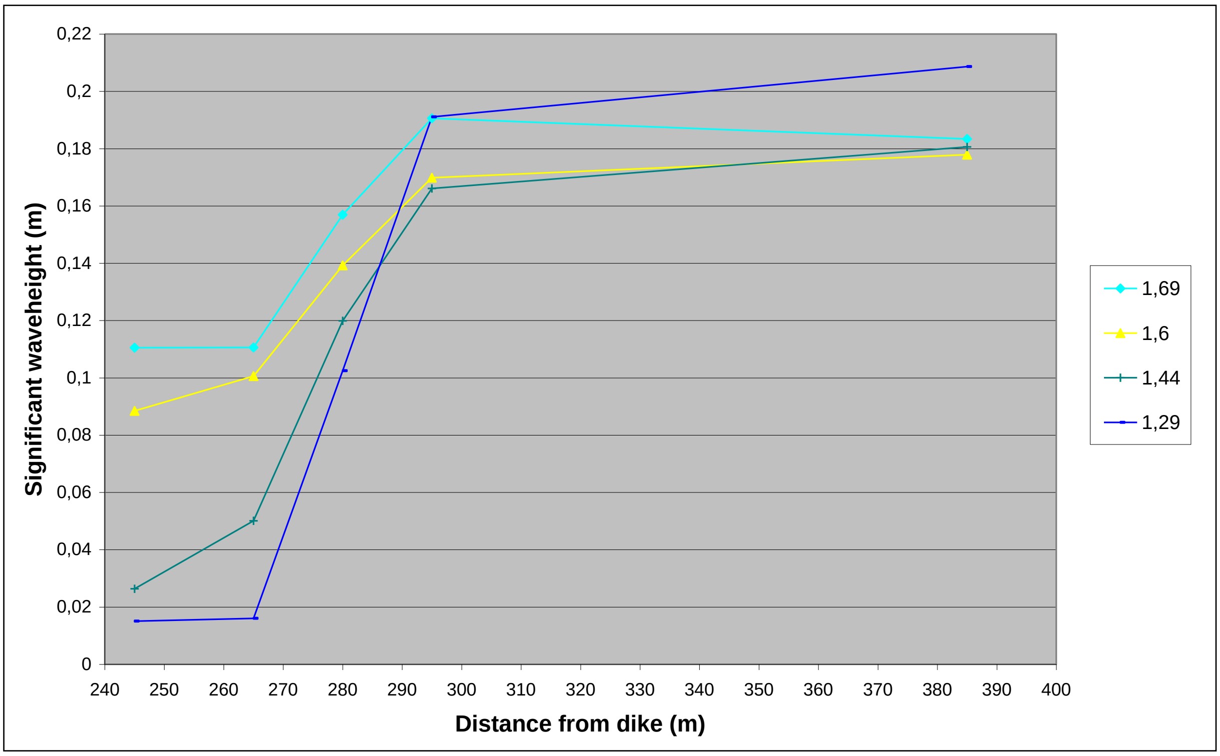

Figure D.1: Wave attenuation of period 1 (24th of January 2006) for different water levels (m NAP)

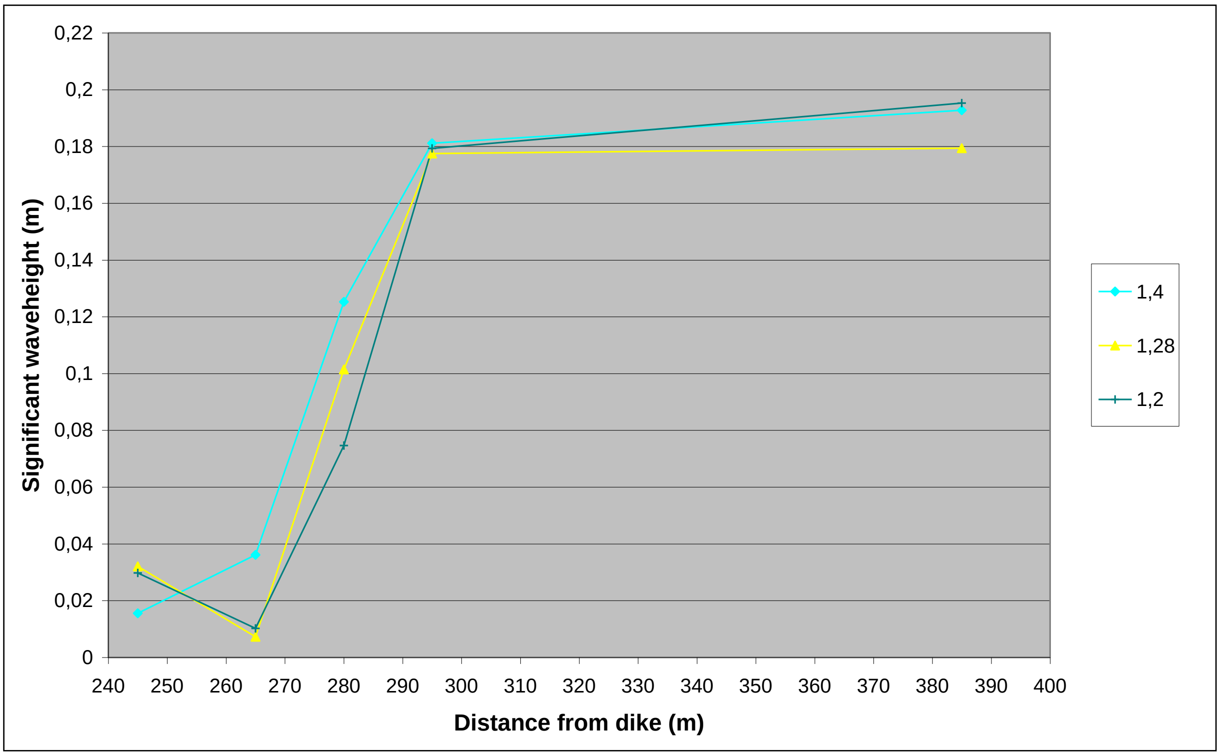

Figure D.2: Wave attenuation of period 2 (25th of January 2006) for different water levels (m NAP)

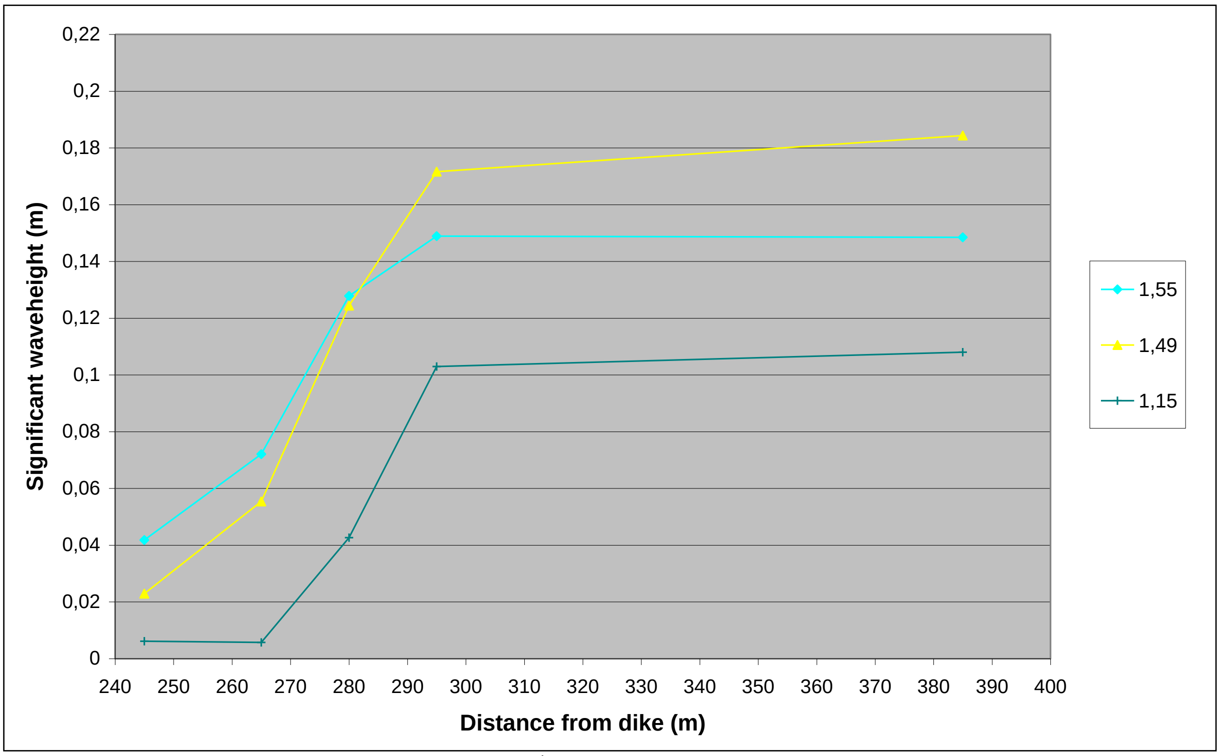

Figure D.3: Wave attenuation of period 3 (26th of January 2006) for different water levels (m NAP)

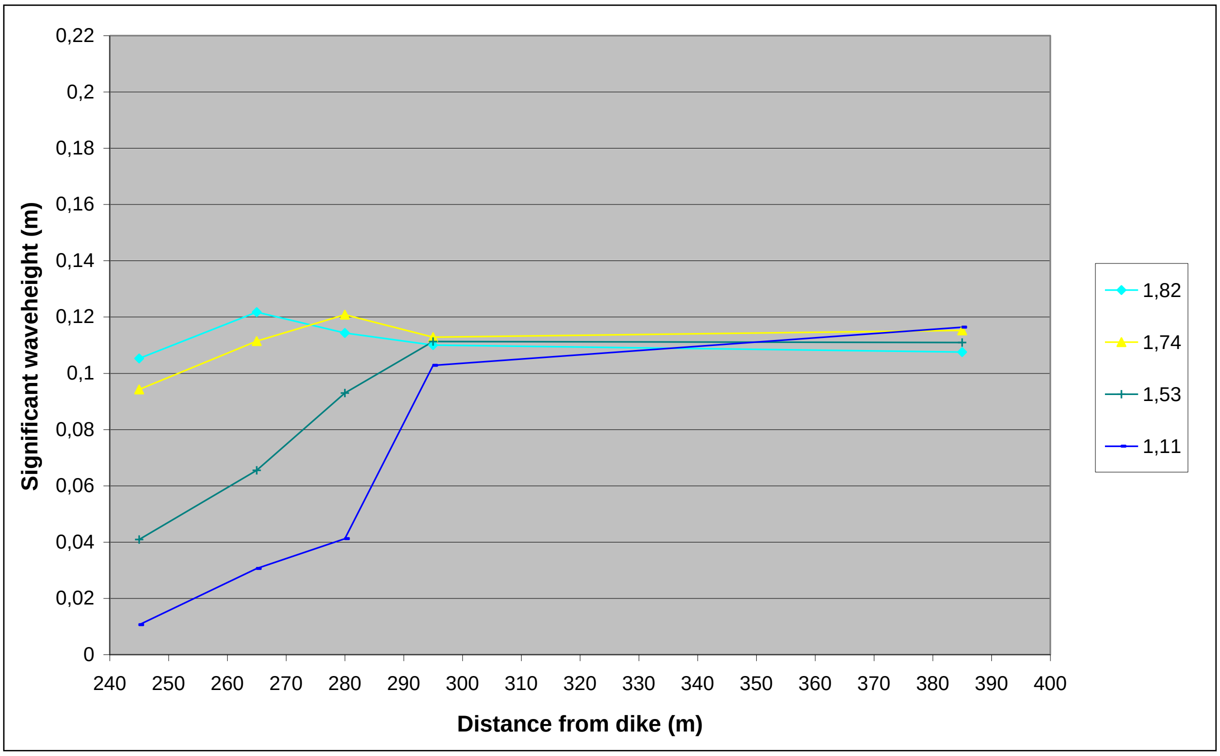

Figure D.4: Wave attenuation of period 4 (26th of January 2006) for different water levels (m NAP)

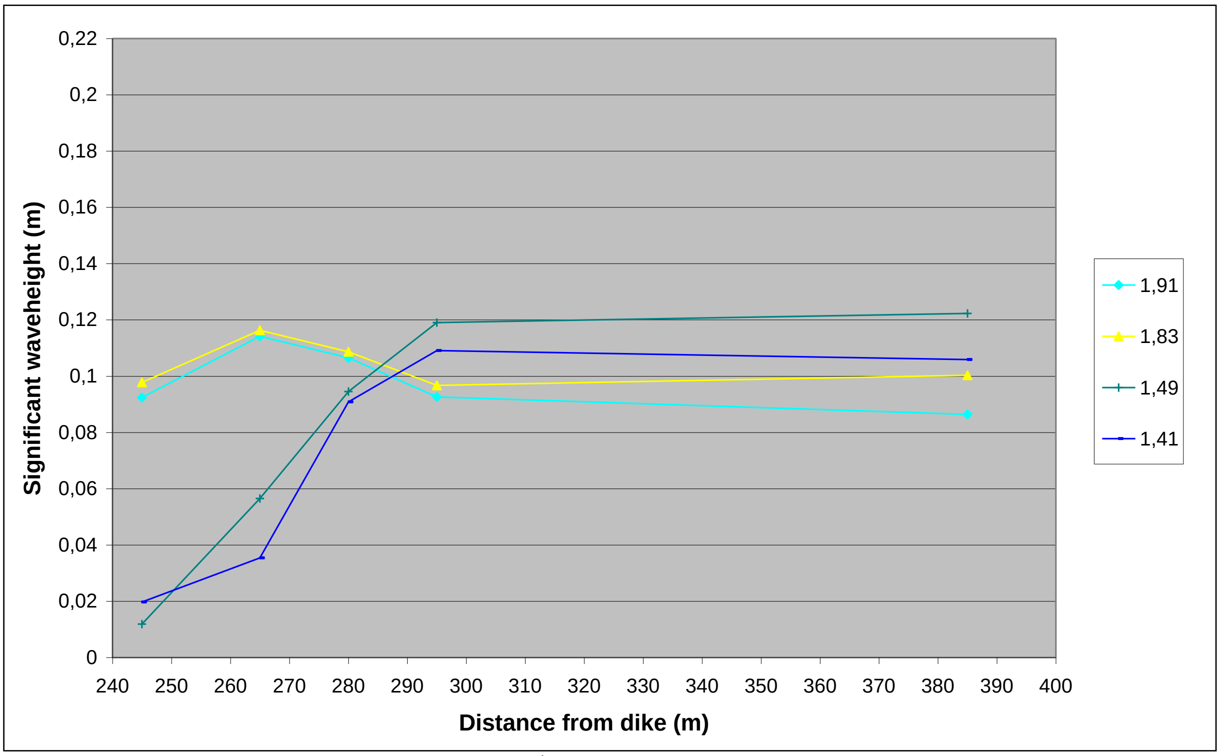

Figure D.5: Wave attenuation of period 5 (27^{th} of January 2006) for different water levels (m NAP)

E Wave attenuation at Zuidgors

Wave attenuation at the Zuidgors for the 7 floods that occurred during the measurements.
The dotted line represents the cliff edge.

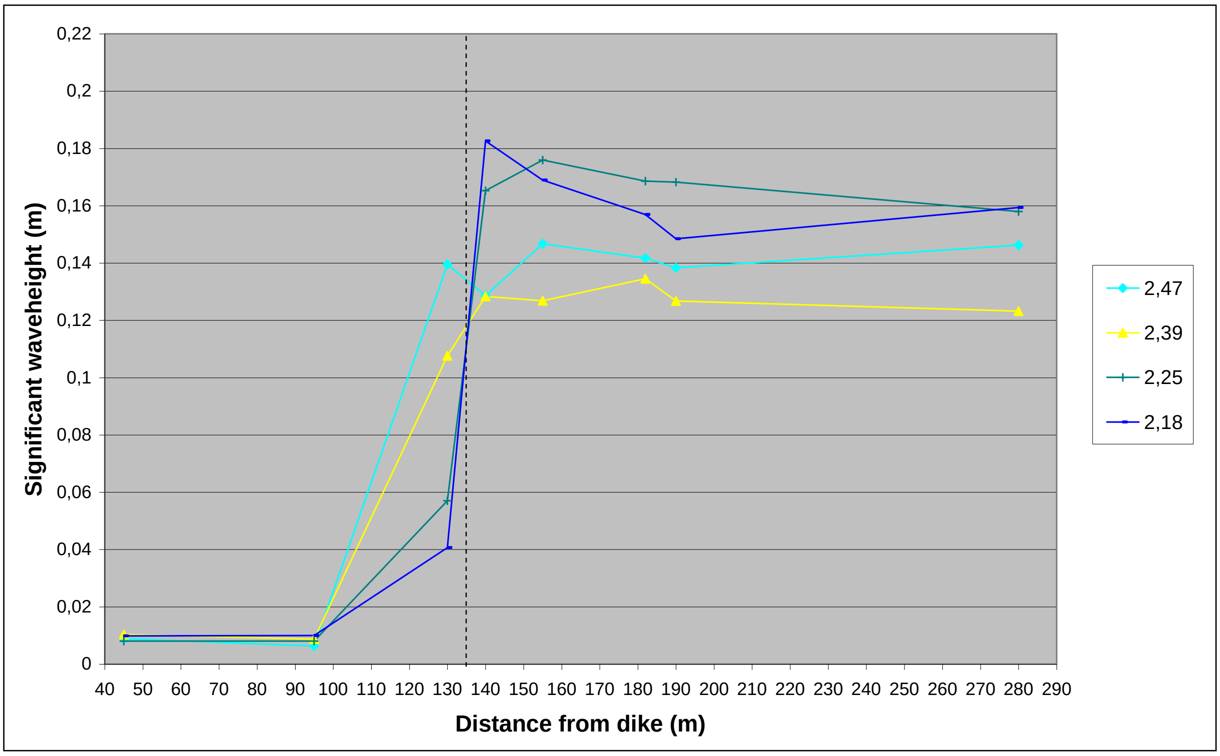

Figure E.1: Wave attenuation of period 1 (1st of November 2005) for different water levels (m NAP)

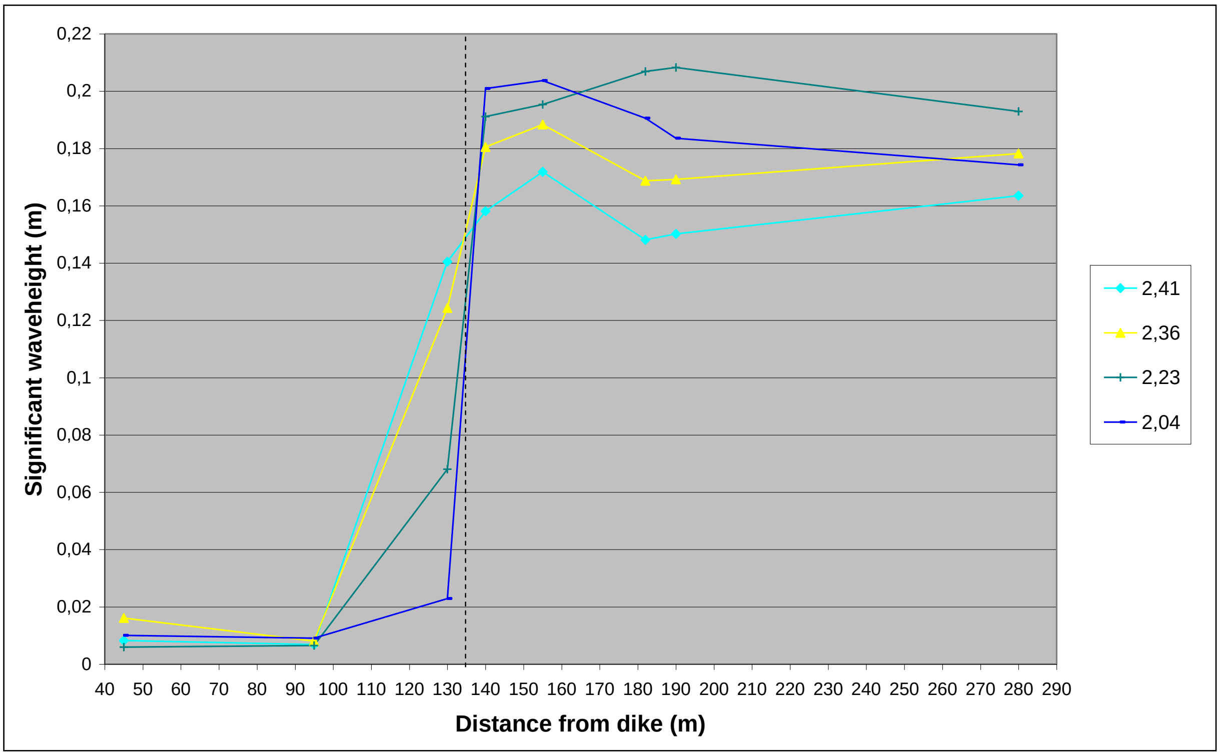

Figure E.2: Wave attenuation of period 2 (2nd of November 2005) for different water levels (m NAP)

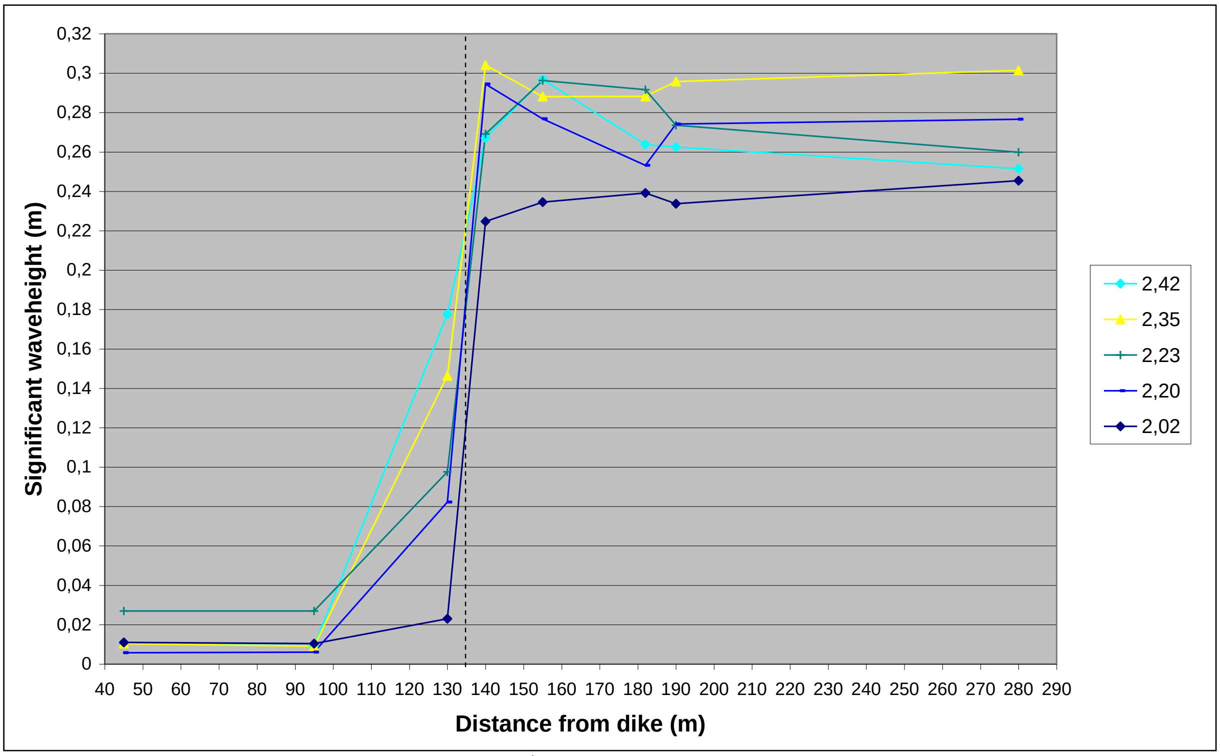

Figure E.3: Wave attenuation of period 3 (2nd of November 2005) for different water levels (m NAP)

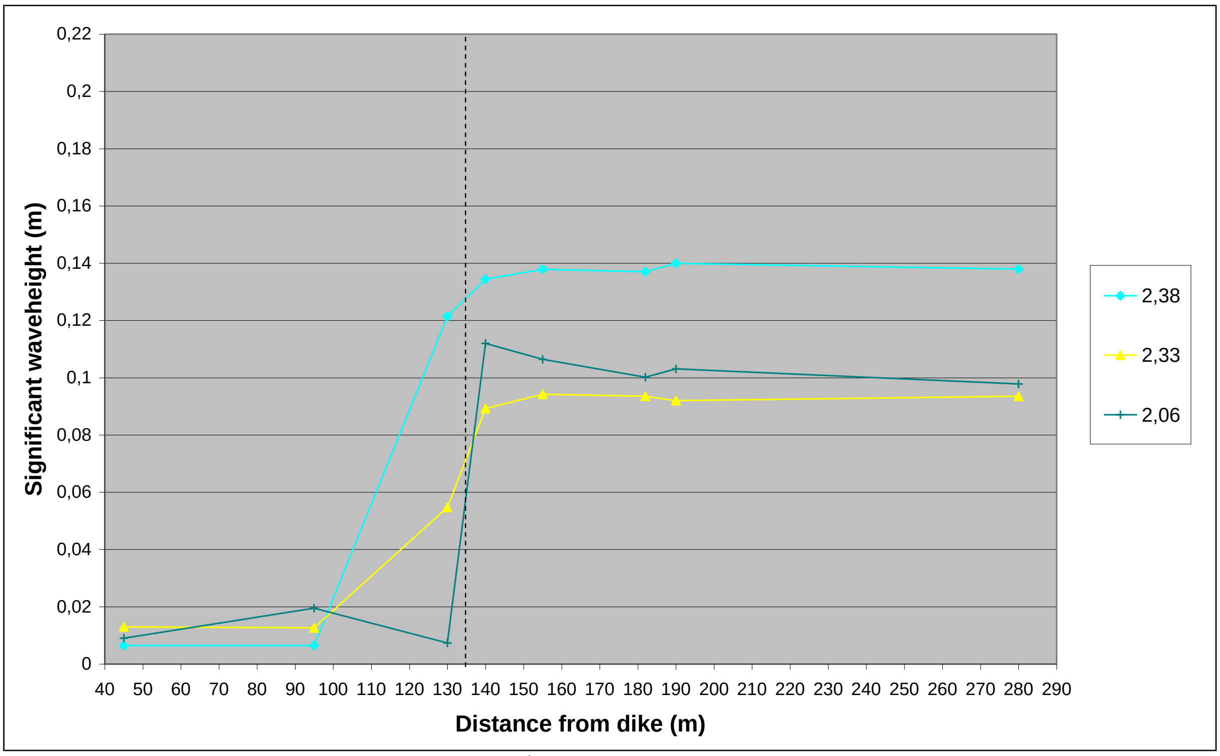

Figure E.4: Wave attenuation of period 4 (3rd of November 2005) for different water levels (m NAP)

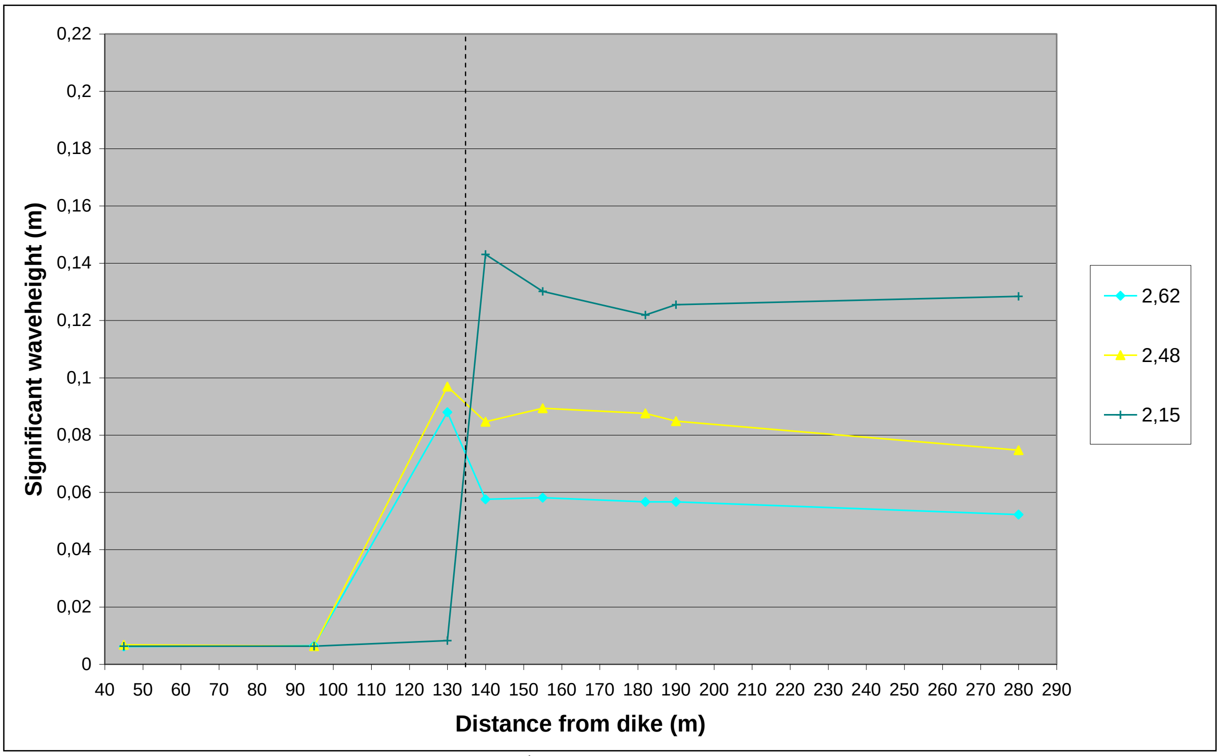

Figure E.5: Wave attenuation of period 5 (3rd of November 2005) for different water levels (m NAP)

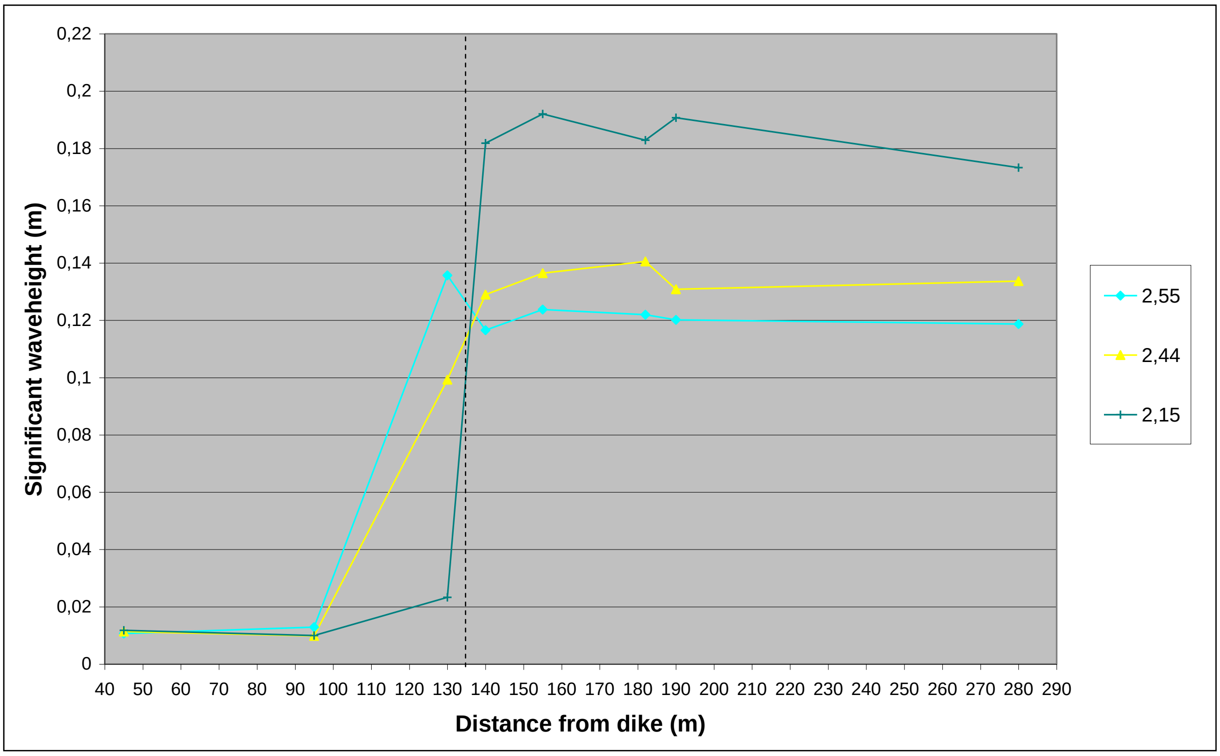

Figure E.6: Wave attenuation of period 6 (4th of November 2005) for different water levels (m NAP)

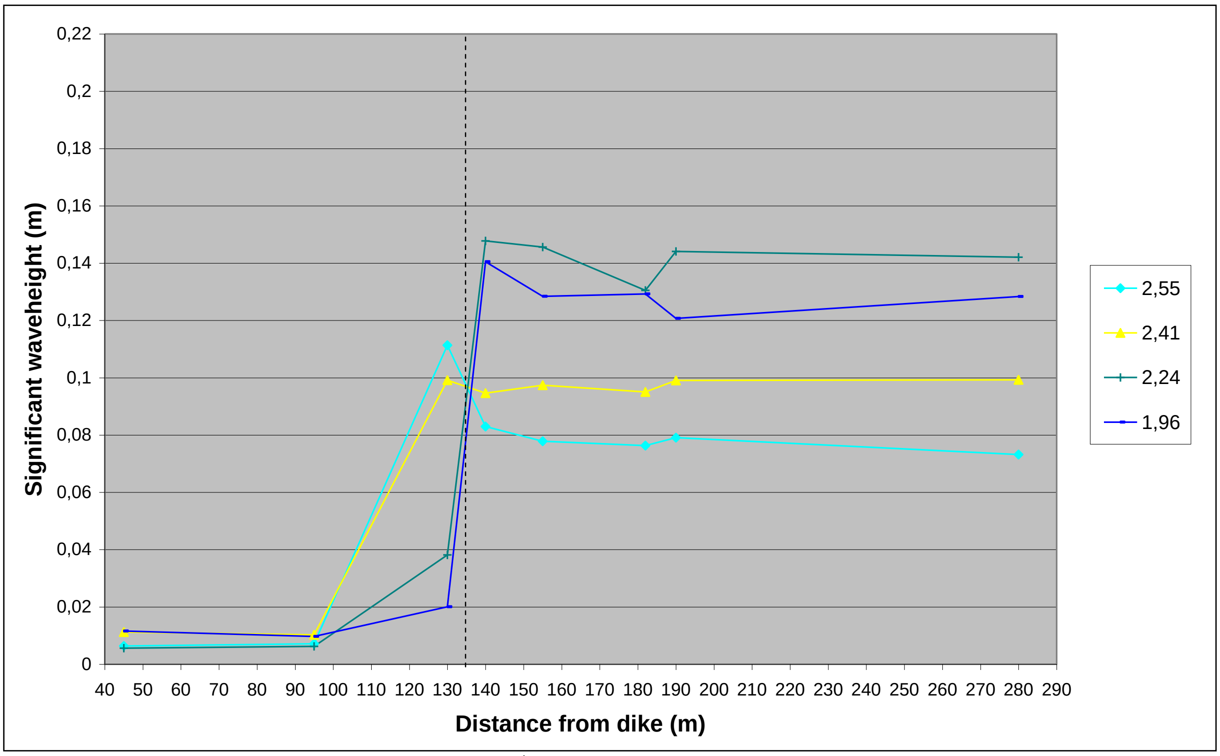

Figure E.7: Wave attenuation of period 7 (4th of November 2005) for different water levels (m NAP)

F Manual for the use of Delft-AUKE