

Influence of Relative Sea-level Rise on Tidal Inlets

Global Vulnerability Assessment

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Master of Science Thesis

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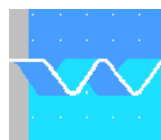
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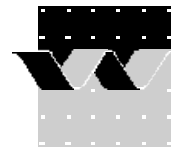
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ABSTRACT:

This study is a part of the EU-funded project DINAS-COAST intended to predict the global impact of climate change on the coastal zone for the next 100 years. The objective of this project is the development of a tool which can assess the effects of different climate scenarios. As a part of this tool an algorithm is developed which predicts the influences of relative sea-level rise on coasts interrupted by tidal basins, in terms of loss of land and loss of sand which would be required to restore the present situation.

As base of the algorithm the ASMITA-model is used (Stive et al. 1998). The model predicts the adaptation-capability of a tidal inlet to increasing sea-level rise, based on the ratio between transport rate into the system and the rate of sea-level rise. Previous studies studying the Wadden Sea inlets (Van Goor et al, 2001) showed that there exists a critical rate of sea-level rise, above which the system is no longer capable to follow sea-level rise and the tidal basin will drown.

A major problem in predicting the adaptation-capability in the present study is the applicability on world wide scale. As the model is applied to all tidal lagoons in the world for several climate scenarios, the even relatively simple ASMITA model needs to be simplified furthermore. Second, the availability of data on global scale is restricted. Based on the ETOPO2 data-set the general characteristics (size, tidal range etc.) of about 200 tidal lagoons have been collected. Empirical relations are used to estimate the missing geometric parameters and the coefficients in the algorithm are determined by the Wadden Sea derived values (the default setting). But the user of the DIVA-tool will be allowed to replace the default setting by more detailed information for more accurate predictions.

The analysis of the tidal inlets in the world showed that the so-called 'micro-tidal' areas (like Baltic Sea and Mediterranean Sea) will drown before 2100 with a sea-level rise of 6 mm/y, this is due a small tidal prism resulting in a low sediment-import rate. As sea-level rise is still increasing till 2100, the remainder of the tidal areas will not have reached their dynamic equilibrium state. In 2500 the tidal inlets are closer to their dynamic equilibrium state and more tidal areas will have been drowned. These areas have a critical sea-level rise that is lower than the 6 mm/y and this is mainly influenced by the size of the area. Large areas need more sediment to compensate the lose of volume due to sea-level rise, and therefore they have a lower critical sea-level rise.

REFERENCES:

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Preface

This report forms my Master of Science thesis and is the completion of my study Civil Engineering at the faculty of Civil Engineering and Geosciences at the Delft University of Technology.

The base of this report is a EU-funded project, which concerns the world-wide influences of climate change on coastal areas. This study is a part of that project and deals with the translation of relative sea-level rise into the changes of tidal inlets in the world. The project has been carried out at WL | Delft Hydraulics.

First of all I would like to thank my supervisors prof. dr. ir. M.J.F. Stive (Delft University of Technology), dr. ir. Z.B. Wang (Delft University of Technology and WL | Delft Hydraulics), dr. L. van der Valk (WL | Delft Hydraulics), dr. ir. C.J. Sloff (Delft University of Technology and WL | Delft Hydraulics) and ir. P. Huisman (Delft University of Technology) for sharing their knowledge and support during the past year. Besides that I would like to thank the DINAS-COAST project-partners from the Potsdam Institute for Climate Impact Research, the Flood Hazard Research Centre of the Middlesex University and the Cambridge Coastal Research Unit of the University of Cambridge for their contribution during our meetings. Furthermore, I would like to thank my colleagues and fellow graduate students at WL | Delft Hydraulics for a pleasant stay and helping me out from time to time, with a special attention to Gerben Boot who helped me a lot with the data-collecting. Last but not least I would like to take the opportunity to thank my girlfriend, family and friends for their support and making the years, I spent in Delft, a pleasant time.

Luc Bijsterbosch,
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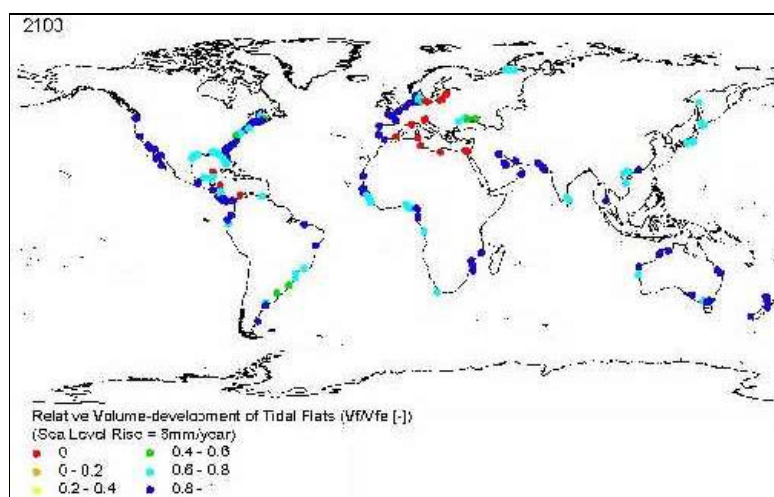
Summary

This study is a part of the EU-funded project DINAS-COAST intended to predict the global impact of climate change on the coastal zone for the next 100 years. The objective of this project is the development of a tool which can assess the effects of different climate scenarios. As a part of this tool an algorithm is developed which predicts the influences of relative sea-level rise on coasts interrupted by tidal basins, in terms of loss of land and loss of sand which would be required to restore the present situation.

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A major problem in predicting the adaptation-capability in the present study is the applicability on world wide scale. As the model is applied to all tidal lagoons in the world for several climate scenarios, the even relatively simple ASMITA model needs to be simplified furthermore. Second, the availability of data on global scale is restricted. Based on the ETOPO2 data-set the general characteristics (size, tidal range etc.) of about 200 tidal lagoons have been collected. Empirical relations are used to estimate the missing geometric parameters and the coefficients in the algorithm are determined by the Wadden Sea derived values (the default setting). But the user of the DIVA-tool will be allowed to replace the default setting by more detailed information for more accurate predictions.

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Development of tidal areas in 2100 with a relative sea-level rise of 6 mm/y

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1 Introduction

1.1 Background

A large part of the world population lives in the coastal zone. It is estimated that 21% of the world's population nowadays live within 30 km from the sea, and 37% live less than 100 km from the coast (Gommes et al., 1998 and Cohen et al., 1997). The coastal population is even growing and urbanising more rapidly than the global trend.

At the same time, the sea-level rise is expected to accelerate significantly during the 21st century due to climate change. By 2100, global mean sea level is expected to have risen by 23 to 96 cm, with a best estimate of 55 cm, assuming 'business as usual' (Warrick et al., 1996), while the present sea-level rise in the Netherlands is 20 cm/century. Besides that the vertical rise causes an even bigger horizontal expansion (order of 10-20 times).

The high population density in coastal area gives little room for coastal adaptation to the increasing sea-level and thus increases the vulnerability to climate change. The combination of high population-density and vulnerability to sea-level rise creates a great public awareness of the threat imposed by the expected climate changes for the next century.

Therefore research to understand and predict the morphological response of the coastal zone to climate change and relative sea-level rise is ongoing. DINAS-COAST is a EU-funded project intended to give the policymakers a tool, which provides a dynamic and interactive assessment of national, regional and global vulnerability of coastal zones to climate change and sea-level rise, the so-called DIVA-tool (Dynamic, Interactive Vulnerability Assessment). The project investigates the whole chain from greenhouse-gas emission to coastal change and socio-economic impacts.

This study is a part of the DINAS-COAST-project and deals with the influence of increasing sea-level rise on tidal inlets, the so-called open coast, and is the link between sea-level rise due to climate change and the socio-economic impacts of the coastal erosion. The erosion of the so-called closed coast (such as sandy coastal stretches) falls outside the scope of this report and will be done by others in the DINAS-COAST-project.

1.2 Problem Analysis

It is to be expected that sea-level rise will cause erosion of the coastal areas resulting in land loss. In case of tidal areas sea-level rise will result in drowning of the tidal flats and deepening of the channels. In order to counterbalance the influence of sea-level rise the tidal inlet is expected to import sediment from outside. The transport rate and distribution over the different parts of the area determines the capability of the inlet to compensate for sea-level rise while keeping the tidal flats from drowning.

The transport rate and re-distribution of sediment is determined by the interaction between the spatial elements of the tidal area and between tidal area and the outside world. To give a proper prediction of the transport rate and distribution it is therefore needed to have detailed information about the area and volume of the elements. As it is too expensive to do field-measurements all over the world, there should be searched for detailed data already available in the world (from remote sensing like satellite-images, etc.). As probably the data will not have the good properties, the data has to be translated to the appropriate input-parameters, needed for modelling.

The quality of the modelling results (besides availability of data) is determined by the degree of detail. More detailed modelling will give better results but will also mean more computational effort. As the assessment-tool DIVA is meant for EU-policymakers on the use of climate change and coastal zone management, the tool must be user-friendly and widely available. This implies that the DIVA-tool must fit on a CD-ROM and that the total computation-time should be short. To lower the computational effort a existing model must be chosen with short computation-time and with the possibilities to decrease that computation-time even further.

1.3 Objective

The main objective of the present study is to predict long-term morphological behaviour of any tidal area in the world to accelerated rise in relative sea-level. To achieve this main objective the research can be divided into four parts:

- Collect data-sets with information of all tidal areas in the world
- Simplify an existing model in order to decrease the computation time of the DIVA-tool
- Fit the available data-sets into a simplified algorithm
- Predict the morphological behaviour of all tidal areas for next 100 to 500 years.

To check the results of the algorithm simulation-runs will be done with data-sets of the Wadden Sea. The data-sets have been used in previous studies and the model-runs have given good results (Van Goor, 2001).

1.4 Reader

In order to achieve the objectives first an overview of the general theory of modelling of tidal inlets will be given in chapter 2. In chapter 3 the concept of the ASMITA-model will be explained and based on the ASMITA-principles the model set-up will be described, followed by a linearization of the model. Based on the results of the model set-up and the linearization the concept of the algorithm will be chosen. After that the data-collection and the translation of data into input-values of the model are discussed in chapter 4. Chapter 5 contains the test-runs of the ASMITA-model with the subject of the Wadden Sea, a comparison of the algorithm with the basic ASMITA-model and the results of the algorithm for all tidal inlets. Finally in chapter 6 the conclusions and the recommendations of the study are presented.

2 General Theory

2.1 Introduction

In this chapter the theory relevant for tidal inlets will be discussed (van Goor, 2001 and Kragtwijk 2001). First, section 2.2 gives an overview of all parameters involved, followed by the description of the elements in a tidal inlet in section 2.3. Finally, section 2.4 deals with equilibrium relations of the elements in a tidal inlet.

2.2 Parameter-analysis

2.2.1 Relative sea-level rise

During the Holocene, the period in the history of the Earth just after the last Ice Age the mean sea level has been rising, but the rate of rising has dropped from above 1.2 m per century before 6000 BC to approximately 17 cm per century nowadays (Louters and Gerritsen, 1994 (see Figure 2.1)).

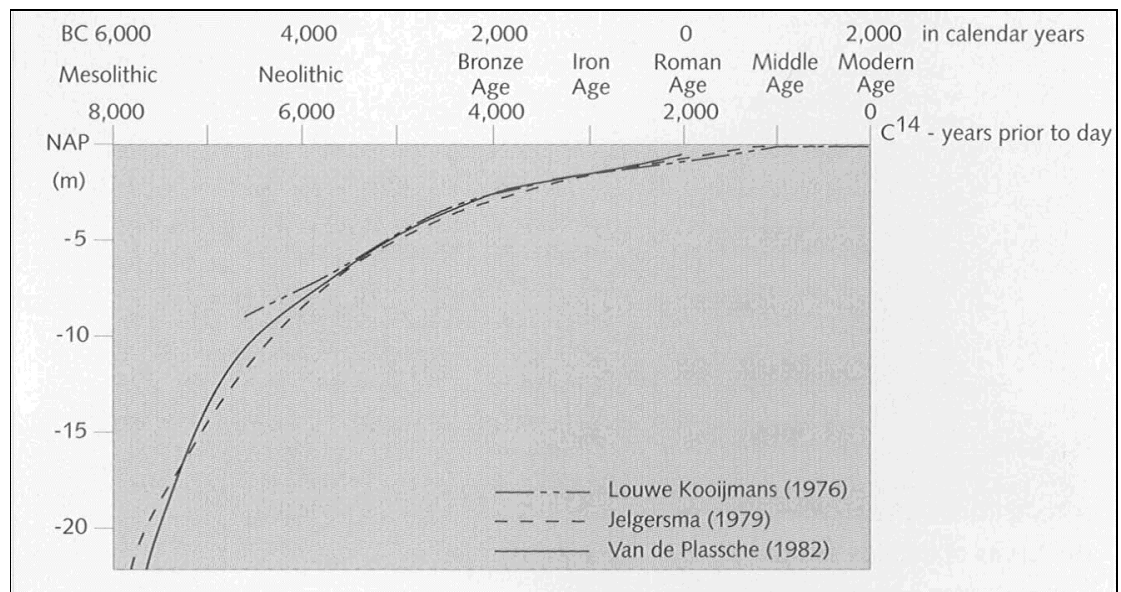


Figure 2.1: Development of Relative sea-level rise after the last Ice Age (from 6,000 BC to 2,000 AD)

Speaking of sea-level rise not only the absolute change of the water-level is meant but also the vertical movement of the land (both subsidence and emergence). Therefore it is better to define the changes as relative sea-level changes (see Figure 2.2).

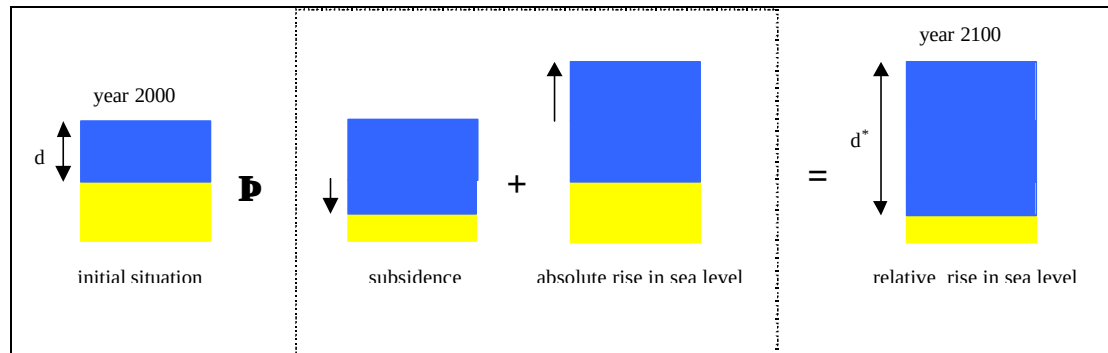


Figure 2.2: Relative Sea Level Rise; also influenced by subsidence or emergence of the earth (van Goor, 2001)

The relative sea-level change is mainly caused by 3 types of eustasy, crustal movement and local changes (see Figure 2.3). Crustal movement and local compaction are responsible for vertical land-movement. The sea level change is due to earth movement under oceans, redistribution of ocean water by gravity rotation, melting of icecaps, caused by climate change, and some local changes.

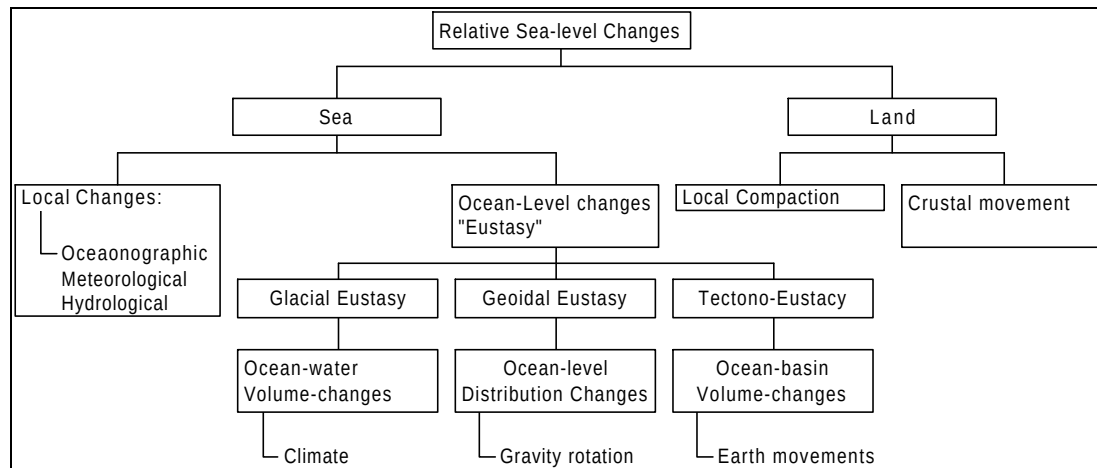


Figure 2.3: Processes controlling the relative sea-level changes (De Vriend et al, 1999)

The crustal movement is a result of the last Ice Age. The enormous amount of ice caused a high load on the northern countries and as a result the bottom was pushed down. The drop in the level of the land in the north was accompanied by a rise of the level of the land in the more southern countries (a turning over of the tectonic plate). Nowadays the load on the bottom has decreased as the ice has melted away and the tectonic plate wants to return to a equilibrium state equal to the situation before the last Ice Age, giving a emergence in the north (like Scandinavia) and a subsidence more southward (The Netherlands for instance).

Besides the more global effects, the human interference in the nature causes local changes in land-level. The expansion of infrastructure and buildings leads to a higher load on the bottom resulting in settlement of the sub-soils. The stringent water-management in lowlands (for agriculture purposes, etc.) leads to irreversible compaction of fine-grained and peaty soils. And the extraction of gas and oil from the bottom also results in vertical land lowering.

Due to industrial expansion in the last century the rate of relative sea-level rise grows again. The increased concentration of carbon dioxide in the atmosphere results in a global warming of the earth (so-called Greenhouse-effect). This heating up causes melting of the polar ice and a volume-increase of the ocean-water due to warming.

As climate change has a great public and scientific interest many studies have been done the last years and they all vary in their scenarios of relative sea-level rise. A study done by the Intergovernmental Panel on Climate Changes (IPCC) showed that the best estimate for the policy scenario "Business As Usual" is a relative sea-level rise of 23-96 cm per century in 2100 (Warrick et al., 1996), with a best estimate of 55 cm per century as the average rise by 2100, while the present sea-level rise in the Netherlands is 20 cm per century.

2.2.2 Tide

The combination of gravitational attraction between earth, moon and sun and rotation of the earth generates tidal waves in the oceans. The tide has a semi-diurnal behaviour mainly, but due to non-linear interaction of the forcings the ebb-tide is not always a mirror-image of the flood-tide. This is called tidal asymmetry and causes residual sediment-transport.

All of the inlets are exposed to the tidal waves, but the tidal influences differ from place to place in time and magnitude. The water volume, passing the narrow gorge of the inlet, during each tidal cycle, is determined by the tidal range in the inlet. For relatively small basins, compared to the tidal wave, this volume can be computed by multiplying the average basin area and the tidal range minus the volume of the tidal flats.

$$V_{ctv} = A_{basin} \cdot H_{tidal} - V_{flat} \quad (2.1)$$

with:

V_{ctv}	=	Characteristic tidal volume / mean tidal prism [m ³]
A_{basin}	=	Area of tidal basin (channels + flats) [m ²]
H_{tidal}	=	Mean tidal range [m]
V_{flat}	=	Volume of tidal flats above MLW [m ³]

The water volume passing the gorge determines the volume of the gorge as the area of the cross-section of the gorge, the flow velocity and the flow rate are related (see sub-section 2.3.3). And the amount of sediment transported into the tidal inlet is also influenced by the volume of the tidal prism. Therefore the tidal prism determines most of the large-scale morphological behaviour of the inlets.

2.2.3 Wind and waves

Wind induces a shear stress at the water surface, which generates waves and currents. The flow-component of the current directed perpendicular to the coastline is compensated by a 'return flow' caused by a slope in the water surface. This results in an circulation pattern, with flow in the wind-direction on the surface and an opposite flow along the bottom. The slope in the water surface also causes a wind set-up or set-down at the coast, depending on onshore or offshore directed wind.

Normally the tidal flow will be dominating the inlet, but in the occasion of strong winds (storm-conditions) the wind-driven flow can play an important role. For this research the assumption is made that the influences of a storm are relatively small compared to the yearly trends.

Waves induce a shear stress on the seabed and thus stir up sediment. Because most waves break on the ebb-tidal delta, as they break at a depth of roughly twice their height, they hardly enter the basin area. Therefore waves influence the basin only during high storm floods. On the other hand waves have a strong influence on the volume and form of the ebb-tidal delta.

2.2.4 Sediment

Sediment-transport is needed to adapt the tidal inlet to a new stable situation under changing conditions, like relative sea-level rise. The rate of transport is determined by sediment-type and availability. These characteristics determine the sediment-concentration of the tidal flow into and out of the inlet. Together with the tidal-asymmetry this can give a net sediment-transport into or out of the tidal inlet.

Sediment is mostly characterised by diameter. A subdivision in diameters gives the categories silt (10^{-6} - 10^{-4} m), sand (10^{-4} - $5 \cdot 10^{-3}$ m) and gravel ($5 \cdot 10^{-3}$ - $8 \cdot 10^{-2}$ m). The density of the sediment particles is about 2.5-3 times the density of water, thus in case of still water this means settlement of the sediment. But water-motion, due to waves or currents, causes turbulence and shear stress on the bottom. The shear stress results in stirring up of the sediment-particles and the turbulence keeps the sediment in the water. The rate of settlement and the amount of stirred up sediment determine the amount of sediment in and the turbidity of the water.

The conditions of large-scale sedimentation and erosion are also depending on the sediment-transports from or to an adjacent coasts and from or to offshore. For instance, a river can supply a large amount of sediment on yearly base to the adjacent coasts. Nevertheless, the presence of an oceanic canyon will result in a constant loss of sediment at the coastline.

2.3 Elements of a tidal inlet

2.3.1 Introduction

A tidal inlet is a complex system with many different elements. Because it is impossible to reflect all elements in the model, the tidal area is schematised into 3 parts (see Figure 2.4). The ebb-tidal-delta covers the sea-ward part of the inlet, the ‘throat’ between the barrier-islands is the channel, and the tidal flats are located in the intertidal zone (emerging during low-tide).

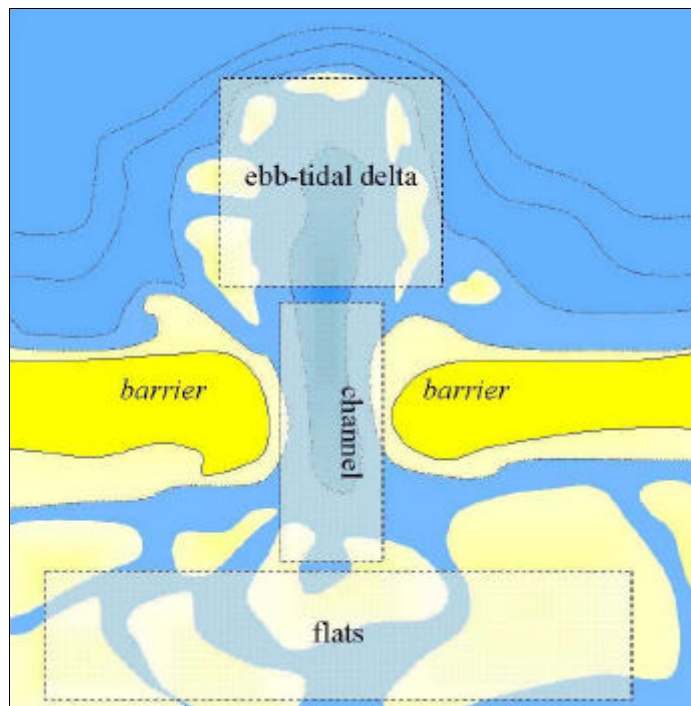


Figure 2.4: Elements of the tidal inlet (van Goor, 2001)

2.3.2 Ebb-tidal delta

The ebb-tidal delta lies at the seaward side of the inlet and it is mainly influenced by the tidal current and the waves. The velocity of the ebb-tidal flow decreases considerably when it leaves the channel between the islands, resulting in settlement of sediment in the ebb-tidal delta area. On the other hand high waves will result in erosion of the ebb-tidal delta. Therefore the classification of the ebb-tidal delta is divided into 3 forms; tide-dominated, mixed-energy and wave-dominated (Hayes, 1979). The tide-dominated delta tends to protrude into the sea and has well-developed sandbars. In a mixed-energy climate the delta has a smooth and curved outer sandbar, and the wave-dominated delta has very little accumulated sediment in the ebb-tidal delta. The properties of the ebb-tidal delta can be determined by the difference between the delta bathymetry and the ‘no-inlet’ bathymetry (Dean and Walton, 1975) (see Figure 2.5).

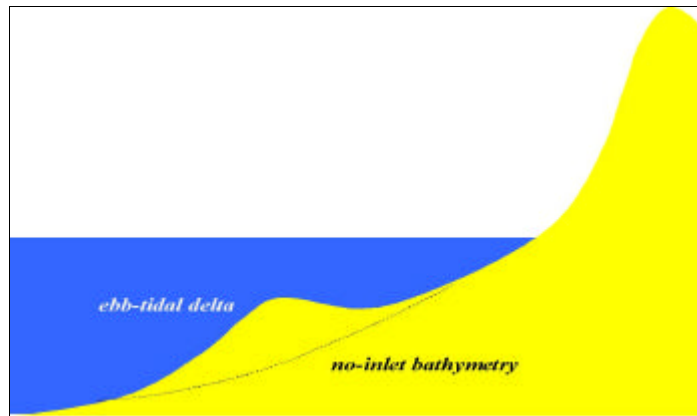


Figure 2.5: Cross-section of ebb-tidal delta and the no inlet bathymetry

2.3.3 Channels

The channel area is the distribution-system of the inlet. It transports the water and sediment into and out of the tidal basin. Escoffier (1940) found an relation between the maximum flow-velocity through a channel and a parameter X , related to the area of the wet cross-section of the channel (such that a larger area gives a larger value of X) (see Figure 2.6).

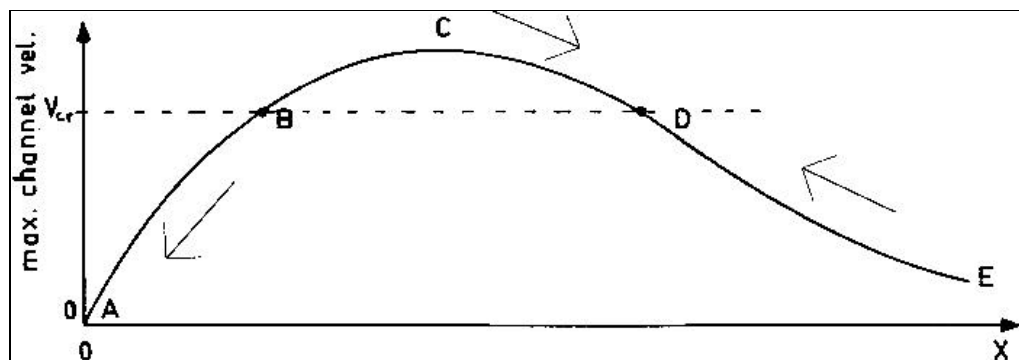


Figure 2.6: Relation between maximum channel velocity (V_m) and cross-section related parameter (X)

Escoffier defined a velocity (V_{cr}) such that below this velocity no erosion will take place, this critical velocity is represented by the horizontal line in the figure, assuming it is independent of the channel geometry.

The figure can be divided in 3 parts, the first part (A-B) is characterised by a low velocity and a small area, the low velocity will give sedimentation resulting in a decrease of flow-area and eventually the cross-section will be silted up. In the second part (B-D) the velocity is higher than the critical value and erosion will take place, this means that the value of X will increase and the inlet will 'move' along the curve to point D. The last part (E-D) has a large cross-sectional area and a low velocity, the low velocity results in a decrease in area, but a decrease in area causes a increase in velocity and sedimentation will take place until point D is reached.

Both point B and D represent an equilibrium situation only point D is a stable point as a deviation of point D will result in erosion or sedimentation such that the inlet will return to point D, and point B is an unstable situation as a small deviation will result in a bigger deviation and the inlet will tend to move to point A (in case of a decrease of area) or to point D (see arrows in Figure 2.6).

When the system is in a situation of (dynamic) morphological equilibrium (point D in Figure 2.6) a well-established relation between the cross-sectional area of the tidal channels and the tidal prism exists (Eysink and Biegel, 1992). Integrating the cross-sections over the length of the channels gives the volume of the channels (see Section 2.4.2).

2.3.4 Tidal flats

The tidal flats are the areas in the intertidal zone, this means they are flooded during high tide and falling dry during ebb-tide. During these dry periods the flats are a good spot for birds (feeding ground) and seals (resting-place).

The presence and shape of the tidal flats depend on the tidal range, basin area, shape and orientation of the basin relative to the dominating wind-direction (Eysink 1993). Large basins allow significant wave action due to larger fetch length, especially with long and deep basins orientated in the wind direction. This wind-induced wave action is likely to prevent the extensive growth of the tidal flat areas. Besides that, the average height of the tidal flats is determined by the tidal range, as increasing tidal range the average tidal flat height increases. The equilibrium relations derived by Eysink are discussed in Section 2.4.3.

2.4 Empirical equilibrium relations

2.4.1 Introduction

When the environmental factors do not change, the tidal inlet tends to a morphological equilibrium. In this state of balance, relationships exist between the equilibrium state and the hydrodynamic parameters. When changes in these values occur these relationships enable us to predict the new equilibrium state. Therefore substantial research has been done to find a relation between the morphological balance and the tidal prism. The basics for these relations were found in the United States of America (O'Brien, 1969; Jarret, 1976; and Walton and Adams, 1976) and more presently in other parts of the world (Eysink and Biegel, 1990-1995).

2.4.2 Channels

A great number of empirical studies have shown that there is an almost linear relation between the area of the cross-section and the tidal prism (Van Kleef, 1991). The description of the 'throat area - tidal prism' relationship is (Eysink, 1990):

$$A_{MSL} = \alpha_A \cdot V_{ctv} \quad (2.2)$$

where:

$$\begin{aligned} A_{msl} &= \text{Flow area below MSL (Mean Sea Level) [m}^2\text{]} \\ \alpha_A &= \text{Empirical coefficient for the equilibrium flow area [m}^{-1}\text{]} \\ V_{ctv} &= \text{Characteristic tidal volume / mean tidal prism [m}^3\text{]} \end{aligned}$$

When a relationship exists between the area of the cross-section and the tidal prism, it is likely that the volume of the channel system and the tidal prism are related too (Eysink, 1990). Plotting data of the channel volumes versus the tidal prisms of the different tidal basins of the Wadden Sea provides an illustration of this principle (see Figure 2.7).

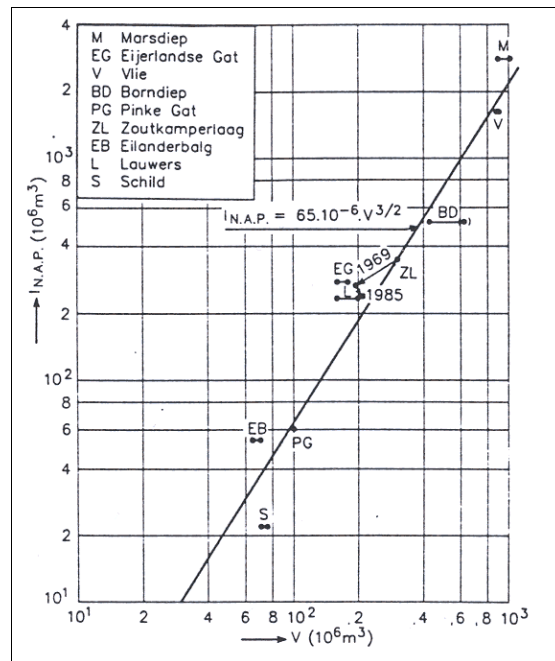


Figure 2.7: Channel Volume versus Tidal Prism (Eysink, 1990)

The relation valid for the channel volume of a tidal inlet with minor upland discharge is:

$$V_{channel} = a_c \cdot V_{ctv}^{1.5} \quad (2.3)$$

where:

$$\begin{aligned} V_{channel} &= \text{Channel (water) volume below MSL [m}^3\text{]} \\ \alpha_c &= \text{Empirical coefficient for the equilibrium volume [m}^{-1.5}\text{]} \\ V_{ctv} &= \text{Characteristic tidal volume / mean tidal prism [m}^3\text{]} \end{aligned}$$

2.4.3 Tidal flats

The area of the tidal flats is largely dependent on the area of the tidal basin and the tidal range, Eysink (1991) found for the Wadden Sea a relationship between relative flat area ($A_{\text{flat}} / A_{\text{basin}}$) and the size of the basin (see Figure 2.8).

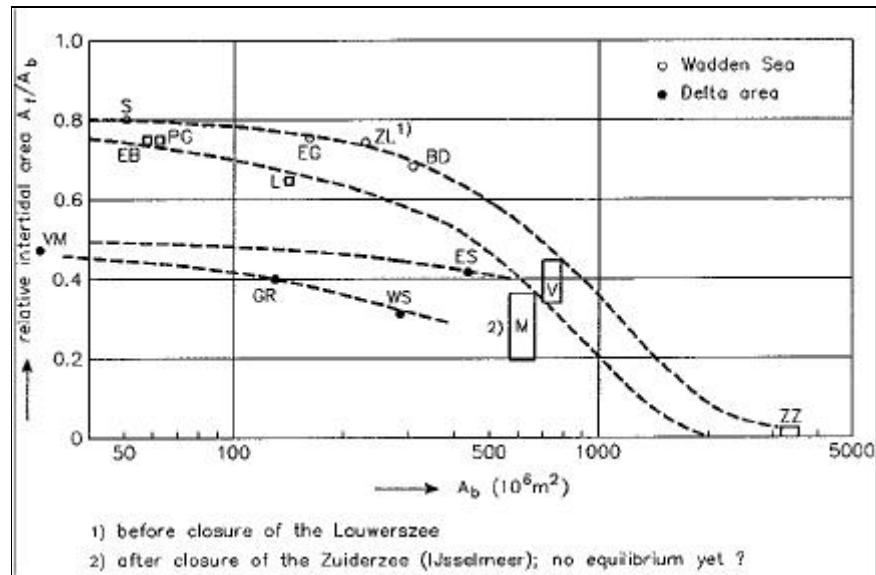


Figure 2.8: Relative area of the intertidal zones in the Dutch Wadden Sea against the tidal basin area.

The relation between flat area (above Mean Low Water) and basin area found for German Bight is (Renger and Partensky, 1974):

$$\frac{A_{\text{flat}}}{A_{\text{basin}}} = 1 - 2.5 \cdot 10^{-5} \cdot \sqrt{A_{\text{basin}}} \quad (2.4)$$

where:

$$\begin{aligned} A_{\text{flat}} &= \text{Area of tidal flats (area above MLW)} [\text{m}^2] \\ A_{\text{basin}} &= \text{Area of tidal basin (channels + flats)} [\text{m}^2] \end{aligned}$$

This means that a larger basin has a relatively smaller tidal flat area. This is due to wind, which has more effect on a long basin than on a smaller one (longer fetch-length), and thus causes more wave-action along the edges of the basin (see Section 2.3.4).

The height of the flats (above Mean Low Water) is influenced by the tidal range. Eysink (1991) stated that this relationship can be described as:

$$H_{flat} = \alpha_{fe} \cdot H_{tidal} \quad (2.5)$$

where:

$$\begin{aligned} H_{flat} &= \text{average tidal flat level above MLW} \\ \alpha_{fe} &= \text{empirical coefficient for average tidal flat level [-]} \\ H_{tidal} &= \text{Mean tidal range [m]} \end{aligned}$$

The coefficient α_{fe} is related to the area of the tidal basins, and Eysink found for the Wadden Sea tidal inlets the following empirical relationship:

$$\alpha_{fe} = 0.41 - 0.24 \cdot 10^{-9} \cdot A_{basin} \quad (2.6)$$

And by defining the volume of the tidal flats as the product of average flat-height (equation (2.5)) and area of the tidal flats (equation (2.6)), one can formulate the value of the volume of the tidal flats:

$$V_{flat} = H_{flat} \cdot A_{flat} = \alpha_{fe} \cdot H_{tidal} \cdot \frac{A_{flat}}{A_{basin}} \cdot A_{basin} \quad (2.7)$$

where:

$$\begin{aligned} V_{flat} &= \text{Volume of tidal flats above MLW [m}^3\text{]} \\ \alpha_{fe} &= \text{empirical coefficient for average tidal flat level [-]} \\ H_{tidal} &= \text{Mean tidal range [m]} \\ A_{flat} &= \text{Area of tidal flats [m}^2\text{]} \\ A_{basin} &= \text{Area of tidal basin (channels + flats) [m}^2\text{]} \end{aligned}$$

2.4.4 Ebb-tidal delta

The ebb-tidal delta is like a 'storehouse' for sediment. The volume of the ebb-tidal delta (see Section 2.3.2) is related to the tidal prism and wave climate (Walton and Adams, 1976). Deltas in a high wave-energy climate are relatively smaller than deltas in a low wave-energy climate (see Figure 2.9).

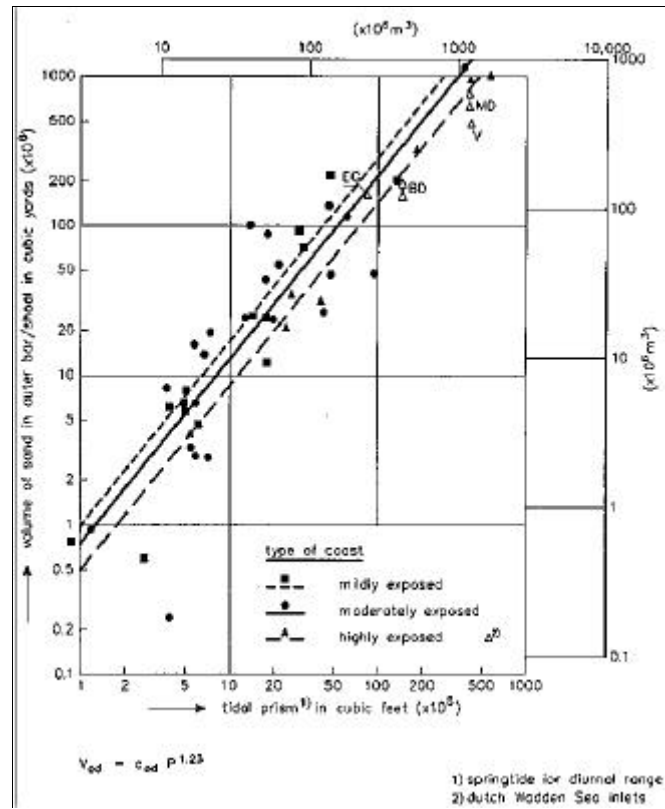


Figure 2.9: Sand volume ebb-tidal deltas in USA and Dutch Wadden Sea in relation to the mean tidal prism and wave climate of the inlet (Walton and Adams, 1976).

The relation found for the ebb-tidal delta is:

$$V_{\text{delta}} = \alpha_{\text{WA}} \cdot V_{\text{ctv}}^{1.23} \quad (2.8)$$

where:

$$\begin{aligned} V_{\text{delta}} &= \text{Ebb-tidal delta (sand) volume (see Figure 2.5) [m}^3\text{]} \\ \alpha_{\text{WA}} &= \text{Empirical coefficient based on wave-conditions [m}^{-1.23}\text{]} \\ V_{\text{ctv}} &= \text{Characteristic tidal volume / mean tidal prism [m}^3\text{]} \end{aligned}$$

As stated above the value of α_{WA} varies with the wave conditions:

- low wave energy coast: $\alpha_{\text{WA}} = 8.64 \cdot 10^{-3}$
- moderate wave energy coast: $\alpha_{\text{WA}} = 6.44 \cdot 10^{-3}$
- high wave energy coast: $\alpha_{\text{WA}} = 5.33 \cdot 10^{-3}$

It was also found that the relationship was valid for the Wadden Sea (Eysink, 1990):

$$V_{\text{delta}} = 6.57 \cdot 10^{-3} \cdot V_{\text{ctv}}^{1.23} \quad (2.9)$$

Which is consistent with a moderate wave energy coast.

3 Model formulation

3.1 Introduction

In order to give an good estimate of the morphological response of a tidal inlet to increasing rate of relative sea-level rise, two kinds of models can be used. The first one uses a ‘process-based’-approach, in which the knowledge of small-scale process is integrated for long-term developments. In the quantitative prediction for long-term developments the integration of small errors in the process-based-approach can cause an significant error to the predictions.

The second approach is based on the assumption that the morphological developments tend to a (dynamic) equilibrium state, so-called ‘behaviour-oriented’ approach. This approach is less sensitive to accumulation of errors, but requires a quantitative notion of underlying large-scale morphology processes. The quantitative notion can be derived from measurements in field but due to the relatively small time span of the data the reliability is limited.

As the second approach requires less computational effort and the demanded long-term prediction is less sensitive to integration of errors, the algorithm will be based on a ‘behaviour-oriented’ model. ASMITA (Aggregated Scale Morphological Interaction between Tidal inlet and the Adjacent coast, Stive and Wang 1996) is a so-called behaviour-oriented model. This semi-empirical model is based on the physics of sediment-exchange between elements and empirical knowledge of the equilibrium state. This model has proved to be valuable for prediction of long-term effects, but the exactness is dependent on the availability of several parameters, not included in most global data-sets.

First the ASMITA-concept will be explained in section 3.2. In section 3.3 a 1-element model will be set up based on the ASMITA-concept, followed by the 2-element model in section 3.4 and the 3 element model in section 3.5. Finally in section 3.6 the possibilities of linearization of the model will be discussed.

3.2 ASMITA-concept

3.2.1 Equilibrium concentration

One of the most important steering factors in the Asmita-concept is the local equilibrium sediment-concentration in the elements (c_e) relative to the overall equilibrium concentration (c_E). When an element is in a morphological equilibrium ($V=V_e$) the local equilibrium concentration is equal to the overall equilibrium concentration. On the other hand when c_e is smaller then c_E there is a tendency to erosion ($V>V_e$, in case of 'dry' volume (flat and delta), for 'wet' volume (channel) $V<V_e$) and when c_e is larger then c_E the system tends to accrete ($V<V_e$). This behaviour can be modelled with an power relation:

$$c_e = c_E \cdot \left(\frac{V}{V_e} \right)^n \quad (3.1)$$

where:

c_e	=	Local equilibrium sediment-concentration in element [-]
c_E	=	Overall equilibrium concentration [-]
V	=	Actual volume of element [m ³]
V_e	=	Equilibrium volume of element [m ³]
n	=	2, negative for wet volumes (channels) [-]

The value of n is determined by the power in the non-linear relationship between sediment transport and mean flow velocity. The sign of n depends on the definition of the volume of the element, in case of 'wet' volumes accretion ($c_e > c_E$) means a decrease of volume and erosion ($c_e < c_E$) means an increase of volume, a reversed situation applies for the 'dry' volumes. For easy handling with one overall equation the power ' n ' only need a negative value in case of 'wet' volume (see equation (3.1)).

An important concentration value is the sediment-concentration in the outside world (c_E), in the model-concept this is the overall sediment-supply for the system. A higher concentration in the outside world gives a higher concentration in the elements, resulting in higher potential of the transport rates. The adaptation rate of the tidal inlet is thus also determined by the 'outside world'-concentration.

As the outside world is much larger than the tidal basin area it is assumed the concentration will not be affected by changes in the basin. Therefore the concentration in the outside world has a constant value, except for changes in the boundary conditions.

3.2.2 Morphological change

The morphological changes are determined by the deviation of the actual sediment concentration in the element from the local equilibrium concentration. Erosion occurs when the actual concentration (c) is smaller then the equilibrium concentration (c_e) and with a larger c accretion occurs. In equation-form this reads:

$$\pm \frac{dV}{dt} = w_s \cdot A \cdot [c - c_e] \quad (3.2)$$

where:

$\pm$	=	Positive for dry volumes, negative for wet volumes [-]
dV/dt	=	Rate of volume change due to erosion or accretion [m^3/s]
w_s	=	Vertical exchange coefficient (m/s)
A	=	Area of element [m^2]
c	=	Actual sediment concentration, volumetric concentration including porosity of the bottom [-]
c_e	=	Local equilibrium concentration [-]

Besides that, the sediment has to be distributed between the elements and between the elements and the outside world. The sediment transport is assumed to be dominated by the diffusive transport. The diffusive transport can be written as:

$$T_{1 \rightarrow 2} = \delta_{1,2} \cdot [c_1 - c_2] \quad (3.3)$$

where:

$T_{1 \rightarrow 2}$	=	Sediment transport from element 2 to element 1 [m^3/s]
$\delta_{1,2}$	=	Horizontal exchange rate between elements 1 and 2 [m^3/s]

In order to fulfil the sediment mass-balance the accumulation of transport to an element must equal the rate of volume change of the element:

$$\sum d_{1,n} \cdot [c_n - c_1] = w_s \cdot A_1 \cdot [c_1 - c_e] \quad (3.4)$$

where n stands for all adjacent elements (and outside world) of element 1.

Another morphological change is due to the external forcing of the relative sea-level rise. The rise causes a increase in wet volume and a decrease in dry volume:

$$\pm \frac{dV}{dt} = -A \cdot \frac{dz}{dt} \quad (3.5)$$

where:

$\pm$	=	Positive for dry volumes, negative for wet volumes [-]
$d\zeta/dt$	=	Relative sea-level rise [m/s]

Combining of equation (3.2) and (3.5) gives:

$$\pm \frac{dV}{dt} = w_s \cdot A \cdot h_c - c_e q - A \cdot \frac{dz}{dt} \quad (3.6)$$

With 3 base-equations ((3.1), (3.4) and (3.6)) and three unknown variables (c , c_e and V , the rest of the variables should be known or estimated), this problem can be written as a partial differential equation of volume versus time ($dV/dt = f(V)$). In the next subsections this formulation will be used for the 1, 2 and 3 element models.

3.3 1-element model

3.3.1 Introduction

Considering the physics in the tidal inlet the channel is the central element, as it supplies the distribution of sediment, and will be taken as the basis for the 1-element model. The model consists then of two parts, the channel and ‘the outside world’ (see Figure 3.1). The outside world represents the tidal flats, the ebb-tidal delta, adjacent coasts and all other elements of the sea, which influence the tidal inlet, and it is assumed always to be in equilibrium state.

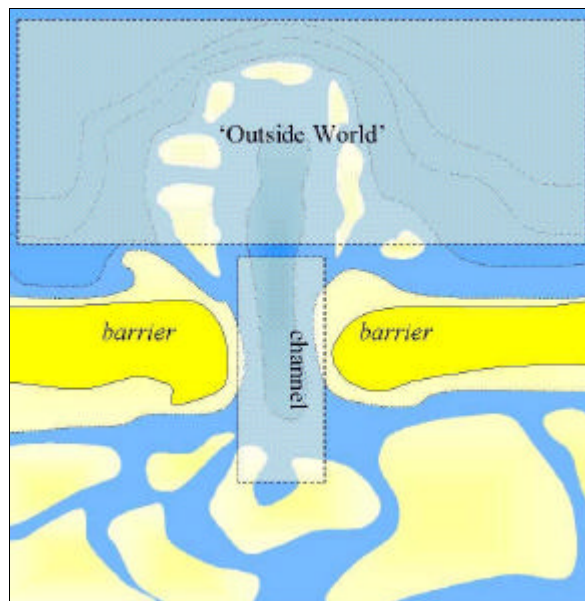


Figure 3.1: Single element model, Channel

3.3.2 Model set-up

In this 1-element model the equilibrium state will be derived from the equilibrium relation between the volume of the channel and the tidal prism (see sub-section 2.4.2):

$$V_{ce} = f \cdot V_{ctv} \quad (3.7)$$

As stated in sub-section 3.2.1 the difference from the actual volume to the equilibrium state is related to the ratio of local equilibrium concentration (c_{ce}) and global equilibrium concentration (c_E):

$$\frac{c_{ce}}{c_E} = \left(\frac{V_c}{V_{ce}} \right)^{-n} \quad (3.8)$$

The overall equilibrium concentration c_E is determined by the ‘equilibrium state’ of the outside world and acts as the boundary condition of the system. As the outside world does not fall inside the actual model c_E is time-invariant. With a relative big outside world in comparison with the tidal basin this assumption is reasonable as the change in sediment-volume in the tidal basin will not much influence the sediment balance of the outside world.

The rate of volume change is determined by the difference of c_{ce} and the actual concentration and by the volume change due to relative sea-level rise concentration (see equation (3.2)):

$$\frac{dV_c}{dt} = A_c \cdot \frac{dz}{dt} - w_{sc} \cdot A_c \cdot (c_c - c_{ce}) \quad (3.9)$$

with:

dV_c/dt	=	Rate of (wet) volume change [m ³ /s]
w_{sc}	=	Vertical exchange coefficient in channel (m/s)
A_c	=	Area of channel [m ²]
$d\zeta/dt$	=	Relative sea-level rise [m/s]

As the sediment must have a source, the diffusive sediment-transport between the outside world and the channel must equal the change in sediment-volume in the channel (assuming the volume change by relative sea-level rise does not influence the sediment volume):

$$d_{co} \cdot (c_E - c_c) = w_{sc} \cdot A_c \cdot (c_c - c_{ce}) \quad (3.10)$$

Extracting c_c from equation (3.10) gets:

$$c_c = \frac{d_{co} \cdot c_E + w_{sc} \cdot A_c \cdot c_{ce}}{d_{co} + w_{sc} \cdot A_c} \quad (3.11)$$

Combining equation (3.11) with (3.9) gives:

$$\frac{dV_c}{dt} = A_c \cdot \frac{dz}{dt} - w_{sc} \cdot A_c \cdot \left[\frac{d_{co} \cdot c_E + w_{sc} \cdot A_c \cdot c_{ce}}{d_{co} + w_{sc} \cdot A_c} - c_{ce} \right] \quad (3.12)$$

$$\frac{dV_c}{dt} = A_c \cdot \frac{dz}{dt} - \frac{w_{sc} \cdot A_c \cdot d_{co}}{d_{co} + w_{sc} \cdot A_c} (c_E - c_{ce})$$

Using equation (3.8) eliminates c_{ce} :

$$\frac{dV_c}{dt} = A_c \cdot \frac{d\zeta}{dt} - \frac{w_{sc} \cdot A_c \cdot \delta_{co} \cdot c_E}{\delta_{co} + w_{sc} \cdot A_c} \left[1 - \left(\frac{V_c}{V_{ce}} \right)^{-n} \right] \quad (3.13)$$

With no relative sea-level rise the volume change goes to zero as the actual volume goes to the equilibrium volume, this is called the static equilibrium state. If the volume is bigger than the equilibrium volume the volume change is negative and the system tends to the equilibrium state. Thus the equation described the evolution of the channel-element towards its equilibrium state.

If the relative sea-level rise is not equal to zero the volume change will be zero if the volume change due to difference between actual volume and equilibrium volume equals the volume change by relative sea-level rise:

$$A_c \cdot \frac{d\zeta}{dt} = \frac{w_{sc} \cdot A_c \cdot \delta_{co} \cdot c_E}{\delta_{co} + w_{sc} \cdot A_c} \left[1 - \left(\frac{V_c}{V_{ce}} \right)^{-n} \right] \quad (3.14)$$

$$V_{ce}^* = \left[1 - \frac{d\zeta}{dt} \cdot \frac{\delta_{co} + w_{sc} \cdot A_c}{w_{sc} \cdot \delta_{co} \cdot c_E} \right]^{-1/n} \cdot V_{ce}$$

With a constant relative sea-level rise the system will evolve to a volume which differs from the equilibrium volume but is constant in time, the so-called dynamic equilibrium volume (V_{ce}^*). From equation (3.14) also follows that with increasing relative sea-level rise V_{ce}^* becomes infinitely large and a critical relative sea-level rise can be defined, where the system is no longer capable to follow the sea-level rise:

$$1 - \frac{d\zeta}{dt} \cdot \frac{\delta_{co} + w_{sc} \cdot A_c}{w_{sc} \cdot \delta_{co} \cdot c_E} = 0 \longrightarrow \left(\frac{d\zeta}{dt} \right)_{critical} = \frac{w_{sc} \cdot \delta_{co} \cdot c_E}{\delta_{co} + w_{sc} \cdot A_c} \quad (3.15)$$

Combining equations (3.14) and (3.15) gives a formulation for the relative change of volume against the ratio of relative sea-level rise and the critical sea-level rise:

$$\frac{V_{ce}^*}{V_{ce}} = 1 - \left(\frac{\frac{d\zeta}{dt}}{\frac{d\zeta}{dt}_{critical}} \right)^{-1/n} \quad (3.16)$$

3.3.3 Test-run

A model-run can be done with some fictitious data (see Table 3-1):

Table 3-1: Element characteristics for a fictitious tidal inlet, 1-element model

Element	Area $10^7[\text{m}^2]$	Volume $10^7[\text{m}^3]$	w_s $10^{-4}[\text{m/s}]$	$\delta_{\rightarrow \text{ow}}$ $[\text{m}^3/\text{s}]$	cE $10^{-4}[-]$	Tidal Range [m]	Pres. SLR [mm/y]
Channel	5	7.5	0.5	1500	2.0	2	0.0

The results of the test-run are shown in Figure 3.2:

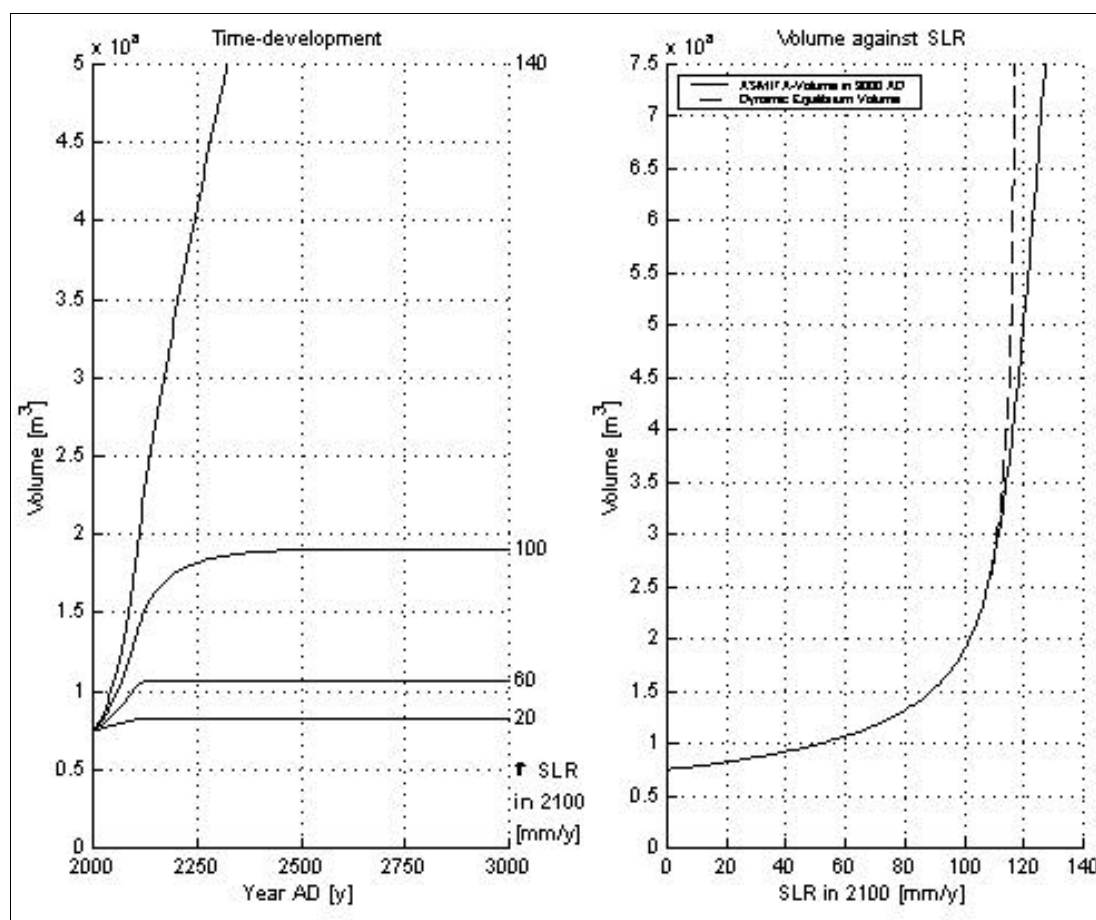


Figure 3.2: Test-run with 1-element ASMITA-model

The test-run shows that with increasing sea-level rise the volume of the channel increases and for small sea-level rises the channel reaches the dynamic equilibrium state ca. 50 years after the sea-level rise is on his maximum value in 2100. But for sea-level rises of about 100 mm/y the time to evolve to the dynamic equilibrium state takes much longer and above a certain level the channels remains increasing in volume, this level is defined as the critical sea-level rise (see equation (3.15)):

$$\left. \frac{d\zeta}{dt} \right|_{critical} = 118.3 \text{ mm/y} \quad (3.17)$$

3.3.4 Conclusion

With a constant sea-level rise the element tends to a dynamic equilibrium state. But with increasing sea-level rise there exist a limit where the system is no longer capable to follow the sea-level rise and the system will drown. For values lower then the critical sea-level rise the dynamic equilibrium state can be described by the ratio of sea-level rise and critical sea-level rise.

3.4 2-element model

3.4.1 Introduction

The next step is an expansion of the model with the tidal flats (see Figure 3.3) The tidal flats are assumed to be separated from the outside world by the channels. And it is thus assumed that there is only diffuse transport between the tidal flats and the channel and between the channel and the outside world.

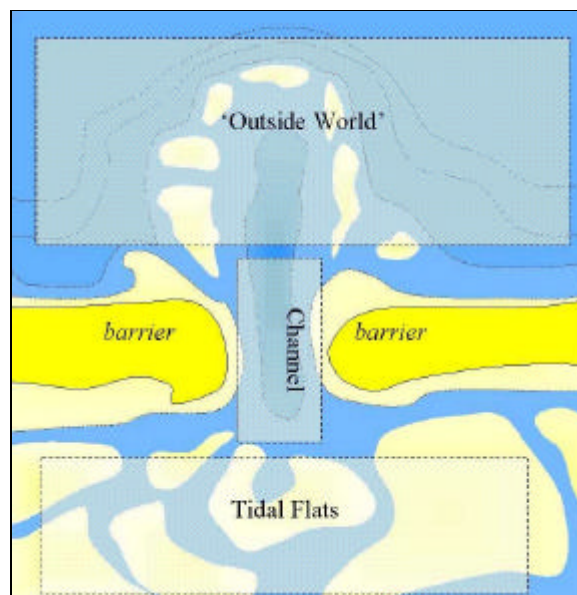


Figure 3.3: Two element model, Tidal Flats and Channel

3.4.2 Model set-up

The morphological development in this 2-element model is analogously to the 1-element model. And the set-up will follow section 3.3, starting with the relations for the equilibrium volumes (see Section 2.4):

$$\begin{aligned} V_{fe} &= f \cdot A_b \cdot H \\ V_{ce} &= f \cdot V_{ctv} \end{aligned} \quad (3.18)$$

For the relation between the local and global equilibrium concentration applies:

$$\begin{aligned} c_{fe} &= c_E \cdot \left(\frac{V_f}{V_{fe}} \right)^n \\ c_{ce} &= c_E \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} \end{aligned} \quad (3.19)$$

As V_f is defined as a 'dry'-volume n is positive in contrast with the negative value for the channel-relation, the absolute value is for both formulations the same and is determined by the sediment transport formula (see sub-section 3.2.1).

The rate of volume changes are given by:

$$\begin{aligned} \frac{dV_f}{dt} &= -A_f \cdot \frac{dz}{dt} + w_{sf} \cdot A_f \cdot (c_f - c_{fe}) \\ \frac{dV_c}{dt} &= A_c \cdot \frac{dz}{dt} - w_{sc} \cdot A_c \cdot (c_c - c_{ce}) \end{aligned} \quad (3.20)$$

These volume changes have to be fed by the diffusive transport in order to fulfil the mass-balances:

$$\begin{aligned} d_{cf} \cdot (c_c - c_f) &= w_{sf} \cdot A_f \cdot (c_f - c_{fe}) \\ d_{co} \cdot (c_E - c_c) - d_{cf} \cdot (c_c - c_f) &= w_{sc} \cdot A_c \cdot (c_c - c_{ce}) \end{aligned} \quad (3.21)$$

Based on the model equations (equations (3.19),(3.20) and (3.21)) the volume change for both elements can be written as (see Appendix A1):

$$\begin{aligned} \frac{dV_f}{dt} &= A \cdot \left(\frac{V_f}{V_{fe}} \right)^n + B \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + E - A_f \cdot \frac{d\zeta}{dt} \\ \frac{dV_c}{dt} &= C \cdot \left(\frac{V_f}{V_{fe}} \right)^n + D \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + F + A_c \cdot \frac{d\zeta}{dt} \end{aligned} \quad (3.22)$$

The difference with the 1-element model is obvious, in the 2-element model the morphological development of an element is also dependent of the development of the other element. This dynamic interaction also influences the dynamic equilibrium situation. For the dynamic equilibrium situation the volume-changes of the tidal flats and channels have to be zero ($\frac{dV_f}{dt} = 0$ and $\frac{dV_c}{dt} = 0$). Based on equation (3.22) the solution for V_{fe}^* and V_{ce}^* becomes then (see Appendix A1):

$$\begin{aligned} V_{fe}^* &= \left[1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f}{\delta_{cf}} + \frac{A_f + A_c}{\delta_{co}} + \frac{1}{w_{sf}} \right)^{1/n} \right] \cdot V_{fe} \\ V_{ce}^* &= \left[1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f + A_c}{\delta_{co}} + \frac{1}{w_{sc}} \right)^{-1/n} \right] \cdot V_{ce} \end{aligned} \quad (3.23)$$

This shows a considerable analogy with equation (3.14), V_{ce}^* has the same relationship with the relative sea-level rise, only the critical relative sea-level rise is also dependent of the area of the tidal flats. V_{fe}^* can also be related to a critical relative sea-level rise as well, but as n is positive for dry volumes V_{fe}^* decreases instead of increases with increasing relative sea-level rise. The solutions for the critical relative sea-level rise regarding the tidal flats and the channels are:

$$\begin{aligned} \left(\frac{d\zeta}{dt} \right)_{critical, f} &= \frac{c_E}{\frac{1}{w_{sf}} + \frac{A_c + A_f}{\delta_{co}} + \frac{A_f}{\delta_{cf}}} \\ \left(\frac{d\zeta}{dt} \right)_{critical, c} &= \frac{w_{sf} \cdot \delta_{co} \cdot c_E}{\delta_{co} + w_{sf} \cdot (A_c + A_f)} \end{aligned} \quad (3.24)$$

3.4.3 Test-run

In order to compare the development of the two elements with increasing relative sea-level rise against the 1-element model a test-run has been done (see Table 3-2).

Table 3-2: Element characteristics for a fictitious tidal inlet, 2-element model

Element	Area 10^7 [m ²]	Volume 10^7 [m ³]	w_s 10^{-4} [m/s]	$\delta_{\rightarrow f}$ [m ³ /s]	$\delta_{\rightarrow c}$ [m ³ /s]	$\delta_{\rightarrow ow}$ [m ³ /s]	cE 10^{-4} [-]	Tidal Range [m]	Pres. SLR [mm/y]
Tidal Flat	5	7.5	1.0		1000		2.0	2	2.0
Channel	5	7.5	0.5	1000		1500	2.0	2	2.0

The results of the test-run correspond with the results of the 1-element model (see Figure 3.2 and Figure 3.4).

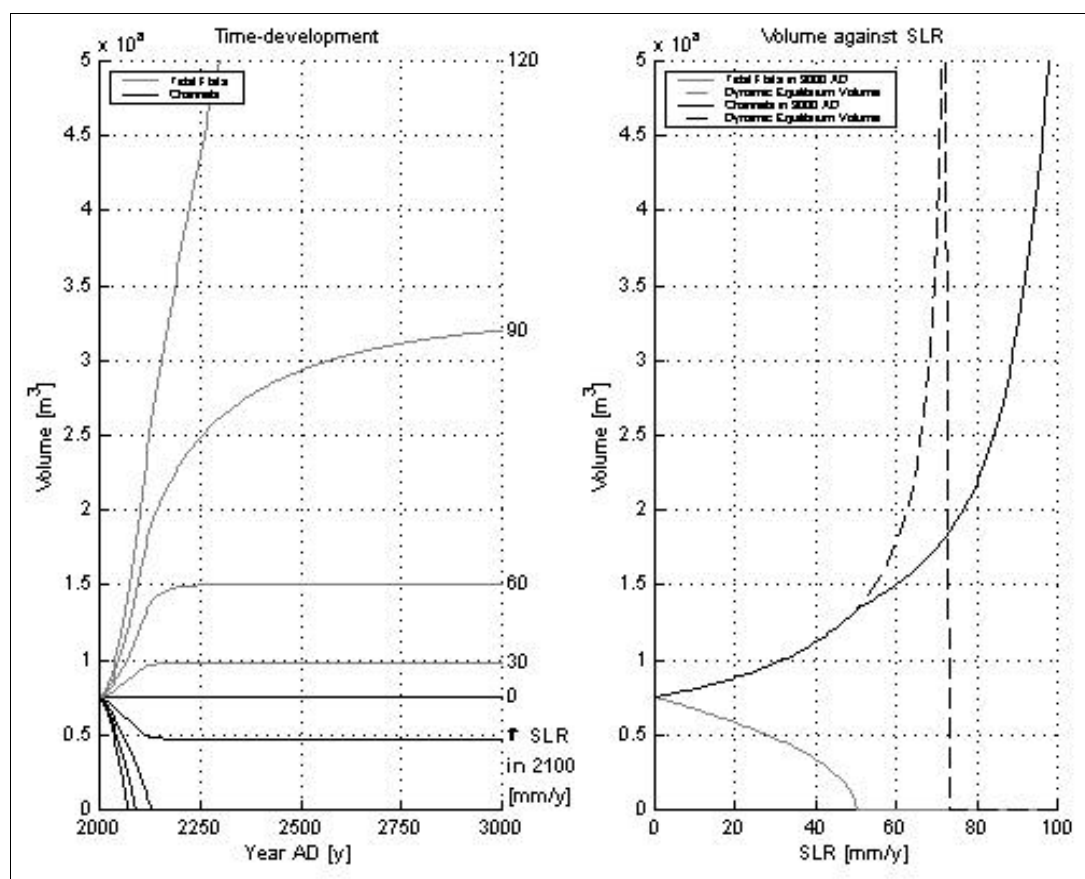


Figure 3.4: Comparison of 2-element ASMITA and dynamic equilibrium volume

The channel volume increases with increasing sea-level rise, but on the other hand the volume of the tidal flats decreases. The difference between increase and decrease is influenced by the definition of channel as a ‘wet’ volume and tidal flats as ‘dry’ volume (see also the sign of the power in equation (3.23)). The 2-element model also predicts a lower critical sea-level rise for both channel and tidal flats, this comes back in the values of the critical sea-level rise:

$$\left(\frac{d\zeta}{dt} \right)_{critical,c} = 72.8 \text{ mm/y}$$

$$\left(\frac{d\zeta}{dt} \right)_{critical,f} = 49.6 \text{ mm/y}$$
(3.25)

As the value of the critical sea-level rise for the tidal flats is lower than for the channels this value is determined for the system, a sea-level rise higher than the critical value will result in a drowning of the flats and the behaviour of the channels will differ from the prediction based on the dynamic equilibrium volume. This can be explained by the fact that the formulation used for dynamic equilibrium situation (see equation (3.22)) allows ‘negative volumes’ and the ASMITA-model replaces negative values by zero, this causes the differences between the two solutions.

3.4.4 Conclusion

Analogously to the 1-element model the two elements of the system tend to a dynamic equilibrium state. For both elements the dynamic equilibrium state can be described by the ratio of sea-level rise and critical sea-level rise. The difference with the 1-element model lies in the interaction between the two elements, which is reflected in the formulation of the critical sea-level rise. The value of the critical sea-level rise for the tidal flats is lower than the value of the channel and therefore the critical point of the system is determined by the tidal flats. With a sea-level rise higher than the critical value the tidal flats will drown and the channels will increase in volume, but the increase of volume is not as big as the dynamic equilibrium volume predicts.

3.5 3-element model

3.5.1 Introduction

The last expansion of the model is adding the ebb-tidal delta as the third element (see Figure 3.1). As the ebb-tidal delta lies at the sea-side of the channel, the channel loses his connection with the outside world and the ebb-tidal delta takes over the function. Transports are possible between tidal flats and channel, between channel and ebb-tidal delta and between ebb-tidal delta and the outside world.

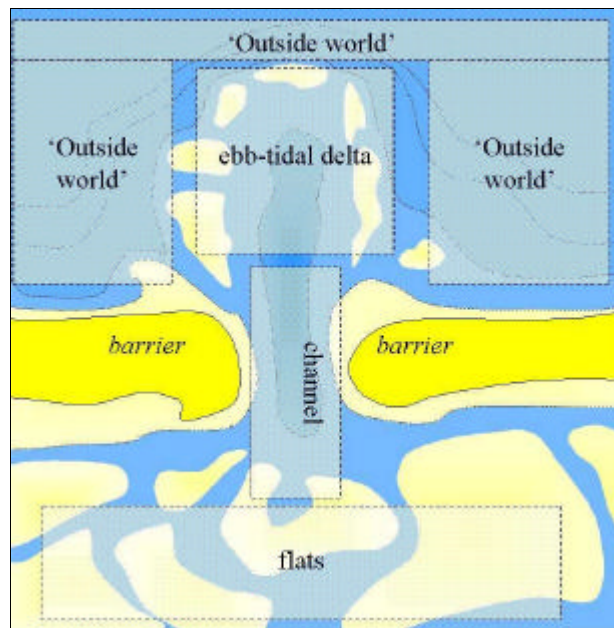


Figure 3.5: Three element model, Tidal Flats, Channel and Ebb-tidal delta

3.5.2 Model set-up

For the three elements the same model set-up will be done, starting with the equilibrium relations for element-volumes:

$$V_{fe} = f_b A_b H g$$

$$V_{ce} = f_{ctv} V_{ctv} g \quad (3.26)$$

$$V_{de} = f_{ctv} V_{ctv} g$$

The local equilibrium concentration is determined by:

$$\begin{aligned}
 c_{fe} &= c_E \cdot \left(\frac{V_f}{V_{fe}} \right)^n \\
 c_{ce} &= c_E \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} \\
 c_{de} &= c_E \cdot \left(\frac{V_d}{V_{de}} \right)^n
 \end{aligned} \tag{3.27}$$

Mentioning that V_f and V_d area defined as ‘dry’-volume and thus n is positive in contrast with the negative value for the channel-relation.

The rate of volume changes are given by:

$$\begin{aligned}
 \frac{dV_f}{dt} &= -A_f \cdot \frac{dz}{dt} + w_{sf} \cdot A_f \cdot (c_f - c_{fe}) \\
 \frac{dV_c}{dt} &= A_c \cdot \frac{dz}{dt} - w_{sc} \cdot A_c \cdot (c_c - c_{ce}) \\
 \frac{dV_d}{dt} &= -A_d \cdot \frac{dz}{dt} + w_{sd} \cdot A_d \cdot (c_d - c_{de})
 \end{aligned} \tag{3.28}$$

In order to fulfil the mass-balances for all elements:

$$\begin{aligned}
 d_{cf} \cdot (c_c - c_f) &= w_{sf} \cdot A_f \cdot (c_f - c_{fe}) \\
 d_{cd} \cdot (c_d - c_c) - d_{cf} \cdot (c_c - c_f) &= w_{sc} \cdot A_c \cdot (c_c - c_{ce}) \\
 d_{do} \cdot (c_E - c_d) - d_{cd} \cdot (c_d - c_c) &= w_{sd} \cdot A_d \cdot (c_d - c_{de})
 \end{aligned} \tag{3.29}$$

Solving equations (3.27), (3.28) and (3.29) leads to the general solution (see Appendix A2):

$$\begin{aligned}
 \frac{dV_f}{dt} &= A \cdot \left(\frac{V_f}{V_{fe}} \right)^n + B \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + C \cdot \left(\frac{V_d}{V_{de}} \right)^n + J - A_f \cdot \frac{d\zeta}{dt} \\
 \frac{dV_c}{dt} &= D \cdot \left(\frac{V_f}{V_{fe}} \right)^n + E \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + F \cdot \left(\frac{V_d}{V_{de}} \right)^n + K + A_c \cdot \frac{d\zeta}{dt} \\
 \frac{dV_d}{dt} &= G \cdot \left(\frac{V_f}{V_{fe}} \right)^n + H \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + I \cdot \left(\frac{V_d}{V_{de}} \right)^n + L - A_d \cdot \frac{d\zeta}{dt}
 \end{aligned} \tag{3.30}$$

This solution is analogous to the solution of the 2-element model, only the dynamic interaction between the elements has increased by adding an element to the model. For the dynamic equilibrium situation the volume-changes have to be zero ($\frac{dV_f}{dt} = 0$, $\frac{dV_c}{dt} = 0$ and $\frac{dV_d}{dt} = 0$). Using equation (3.30) to derive V_{fe}^* , V_{ce}^* and V_{de}^* gives (see Appendix A2):

$$\begin{aligned}
 V_{fe}^* &= \left[1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f}{\delta_{cf}} + \frac{A_f + A_c}{\delta_{cd}} + \frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sf}} \right)^{1/n} \right] \cdot V_{fe} \\
 V_{ce}^* &= \left[1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f + A_c}{\delta_{co}} + \frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sc}} \right)^{-1/n} \right] \cdot V_{ce} \\
 V_{de}^* &= \left[1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sd}} \right)^{1/n} \right] \cdot V_{de}
 \end{aligned} \tag{3.31}$$

The solution is analogous to the solution of the 2-element model. The volumes defined as ‘dry’ volumes (V_{fe}^* and V_{de}^*) decrease with increasing sea-level rise and the ‘wet’ channel volume (V_{ce}^*) increases.

By adding an extra element in the model, the interaction between the element increases which is also reflected in the critical sea-level rise:

$$\begin{aligned} \left(\frac{d\zeta}{dt} \right)_{critical, f} &= \frac{c_E}{\frac{A_f}{\delta_{cf}} + \frac{A_f + A_c}{\delta_{cd}} + \frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sf}}} \\ \left(\frac{d\zeta}{dt} \right)_{critical, c} &= \frac{c_E}{\frac{A_f + A_c}{\delta_{cd}} + \frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sc}}} \\ \left(\frac{d\zeta}{dt} \right)_{critical, d} &= \frac{w_{sd} \cdot \delta_{co} \cdot c_E}{\delta_{do} + w_{sd} \cdot (A_c + A_f + A_d)} \end{aligned} \quad (3.32)$$

Considering the critical sea-level rise it is important to see that the element the closest to the outside world (the ebb-tidal delta) is less sensitive for sea-level rise than the elements further away (in the tidal basin). The reason for that is that the sediment needed to maintain the equilibrium state of the element has to be transported over a longer distance. This makes the tidal flats the most vulnerable part tending to drag other elements of the system along with them and the value of the critical sea-level rise of the tidal flats is thus determined for the value of the critical sea-level rise of the whole system.

3.5.3 Test-run

The development of the three elements with increasing relative sea-level rise has been investigated with a test-run, with same tidal range and present relative sea-level rise as in the 2-element model (see Table 3-2).

Table 3-3: Element characteristics for a fictitious tidal inlet, 3-element model

Element	Area 10 ⁷ [m ²]	Volume 10 ⁷ [m ³]	w _s 10 ⁻⁴ [m/s]	δ _{→f} [m ³ /s]	δ _{→c} [m ³ /s]	δ _{→d} [m ³ /s]	δ _{→ow} [m ³ /s]	cE 10 ⁻⁴ [-]
Tidal Flat	5	7.5	1.0		1000			2.0
Channel	5	7.5	0.5	1000		1500		2.0
Ebb-tidal Delta	5	7.5	0.1		1500		1500	2.0

The test-input gives the following development for the three elements (see Figure 3.6):

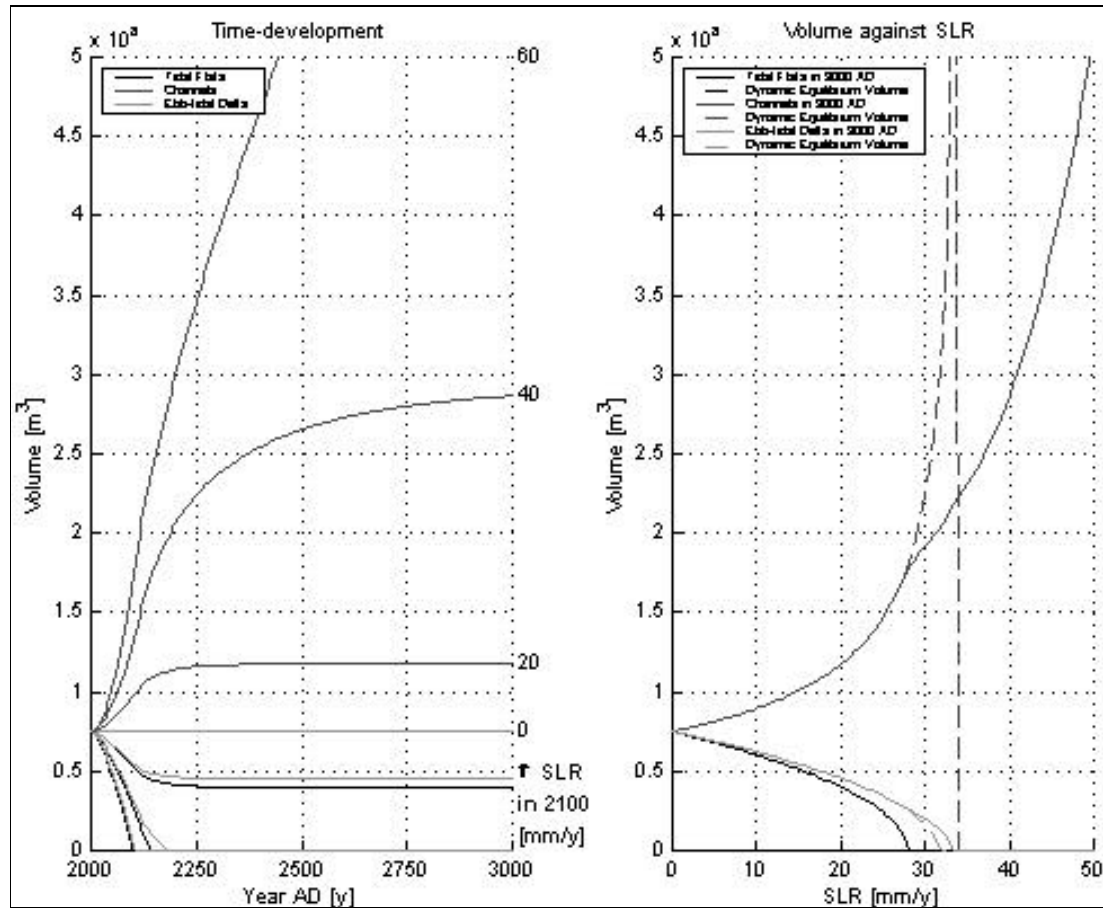


Figure 3.6: Computation of Dynamic Equilibrium Volume

The development of the three elements is analogous to the development in the 2-element model, an $1/n$ -power relation between the ratio of the relative sea-level rise and critical relative sea-level rise and the development of the dynamic equilibrium volume. But the critical relative sea-level rise is much smaller than the critical relative sea-level rises in the 1 and 2 element models (see Equations (3.17) and (3.17)):

$$\frac{d\zeta_{critical,c}}{dt} = 33.8 \text{ mm/y}$$

$$\frac{d\zeta_{critical,f}}{dt} = 27.8 \text{ mm/y} \quad (3.33)$$

$$\frac{d\zeta_{critical,d}}{dt} = 31.5 \text{ mm/y}$$

Another difference is, that the time too reach the equilibrium state for 3-element model takes much longer (see Figure 3.4 and Figure 3.6), this is due to the increased interaction between the elements

3.5.4 Conclusion

The 3-element model has the same trend in morphological development as the 2-element model, 'dry' volumes decrease with increasing sea-level rise and 'wet' volumes increases. The dynamic equilibrium state is also related to a critical sea-level rise; only the relation between the critical value and the areas has been changed. The addition of an element to the system has increased the interaction between the elements and the increased dynamics result in a higher predicted vulnerability for the tidal inlet and an increase of time needed to reach the equilibrium state.

3.6 Linearization of model

3.6.1 Introduction

In the previous sections the model has been set-up and the dynamic equilibrium situation is derived. But it is more important to know what the development of the tidal inlet in the first 100 to 200 years will be instead of the end-situation. As the model consists of a system of non-linear differential equations, the model can not be translated directly to a function of time. There are two ways to compute the time-development, the first method is a numerical computation for 100 or 200 years, where the old volumes are used to calculate the volume-changes (see equation (3.30)). The second approach is to linearize the differential equations and then derive the solution of the linearized differential equations. In this section the linearization of the model will be discussed, starting with the 1-element model.

3.6.2 1-element model

Starting with the same model as stated in Section 3.3, the morphological change can be expressed by:

$$\frac{dV_c}{dt} = A_c \cdot \frac{dz}{dt} - \frac{w_{sc} \cdot A_c \cdot d_{co} \cdot c_E}{d_{co} + w_{sc} \cdot A_c} \left[1 - \left(\frac{V_c}{V_{ce}} \right)^{-n} \right] \quad (3.34)$$

Using the Taylor series expansion to simplify this non-linear equation, neglecting second and higher order terms, the volume change around $V_c = V_{ce}$ is given by:

$$\frac{dV_c}{dt} = A_c \cdot \frac{dz}{dt} + \frac{n \cdot w_{sc} \cdot A_c \cdot d_{co} \cdot c_E}{V_{ce} \cdot (d_{co} + w_{sc} \cdot A_c)} \cdot (V_c - V_{ce}) \quad (3.35)$$

This a combination of one homogeneous differential equation and two particular equations:

$$\begin{aligned}\frac{dV_c}{dt} - l \cdot V_c &= 0 \\ \frac{dV_c}{dt} - l \cdot V_c &= -l \cdot V_{ce} \\ \frac{dV_c}{dt} - l \cdot V_c &= A_c \cdot \frac{dz}{dt}\end{aligned}\tag{3.36}$$

with:

$$l = \frac{n \cdot w_{sc} \cdot A_c \cdot d_{co} \cdot c_E}{V_{ce} \cdot (d_{co} + w_{sc} \cdot A_c)}\tag{3.37}$$

The solutions of the homogeneous and the first particular equations are:

$$\begin{aligned}V_c &= C_0 \cdot e^{l \cdot t} \\ V_c &= V_{ce}\end{aligned}\tag{3.38}$$

Where C_0 is determined by the initial value of V_c .

The second particular equation is depended on the relative sea-level rise as function of the time. With a constant relative sea-level rise the solution is:

$$V_c = -\frac{A_c}{\lambda} \cdot \left[\frac{d\zeta}{dt} \right]_{const.}\tag{3.39}$$

Which gives a total solution of:

$$V_c = V_{ce} + C_0 \cdot e^{\lambda \cdot t} - \frac{A_c}{\lambda} \cdot \left[\frac{d\zeta}{dt} \right]_{const.}\tag{3.40}$$

Assuming the present state is in a morphological dynamic equilibrium the initial value is given by:

$$\begin{aligned}
 V_{c,present} &= \lim_{t \rightarrow \infty} V_c = V_{ce} + C_0 \cdot e^{\lambda \cdot t} - \frac{A_c}{\lambda} \cdot \left(\frac{d\zeta}{dt} \right)_{present} = V_{ce} - \frac{A_c}{\lambda} \cdot \left(\frac{d\zeta}{dt} \right)_{present} \\
 V_{c,present} &= V_{ce} + C_0 \cdot e^{\lambda \cdot 0} - \frac{A_c}{\lambda} \cdot \left(\frac{d\zeta}{dt} \right)_{const.} \Leftrightarrow V_{ce} - \frac{A_c}{\lambda} \cdot \left(\frac{d\zeta}{dt} \right)_{present} \\
 C_0 &= \frac{A_c}{\lambda} \cdot \left(\frac{d\zeta}{dt} \right)_{const.} - \left(\frac{d\zeta}{dt} \right)_{present}
 \end{aligned} \tag{3.41}$$

The total solution then becomes:

$$V_c = V_{ce} - \frac{A_c}{\lambda} \cdot \left(\frac{d\zeta}{dt} \right)_{const.} - \left(\frac{d\zeta}{dt} \right)_{const.} - \left(\frac{d\zeta}{dt} \right)_{present} \cdot e^{\lambda \cdot t} \tag{3.42}$$

Comparing the solution of equation (3.42) with the results of the dynamic equilibrium solution (see sub-section 3.3.2) the error of the linearizing of the differential equation can be estimated:

$$\begin{aligned}
 V_{ce}^* &= \left(1 - \frac{\left(\frac{d\zeta}{dt} \right)_{scen.}}{\left(\frac{d\zeta}{dt} \right)_{critical}} \right)^{-\frac{1}{n}} \cdot V_{ce} \\
 \lim_{t \rightarrow \infty} V_c &= V_{ce} - \frac{A_c}{\lambda} \cdot \left(\frac{d\zeta}{dt} \right)_{scen.} = \left(1 + \frac{1}{n} \cdot \frac{\left(\frac{d\zeta}{dt} \right)_{scen.}}{\left(\frac{d\zeta}{dt} \right)_{critical}} \right) \cdot V_{ce}
 \end{aligned} \tag{3.43}$$

Equation (3.43) shows that the linearized solution linear increases with increasing sea-level rise and there is no upper limit to the sea-level rise (see Figure 3.7).

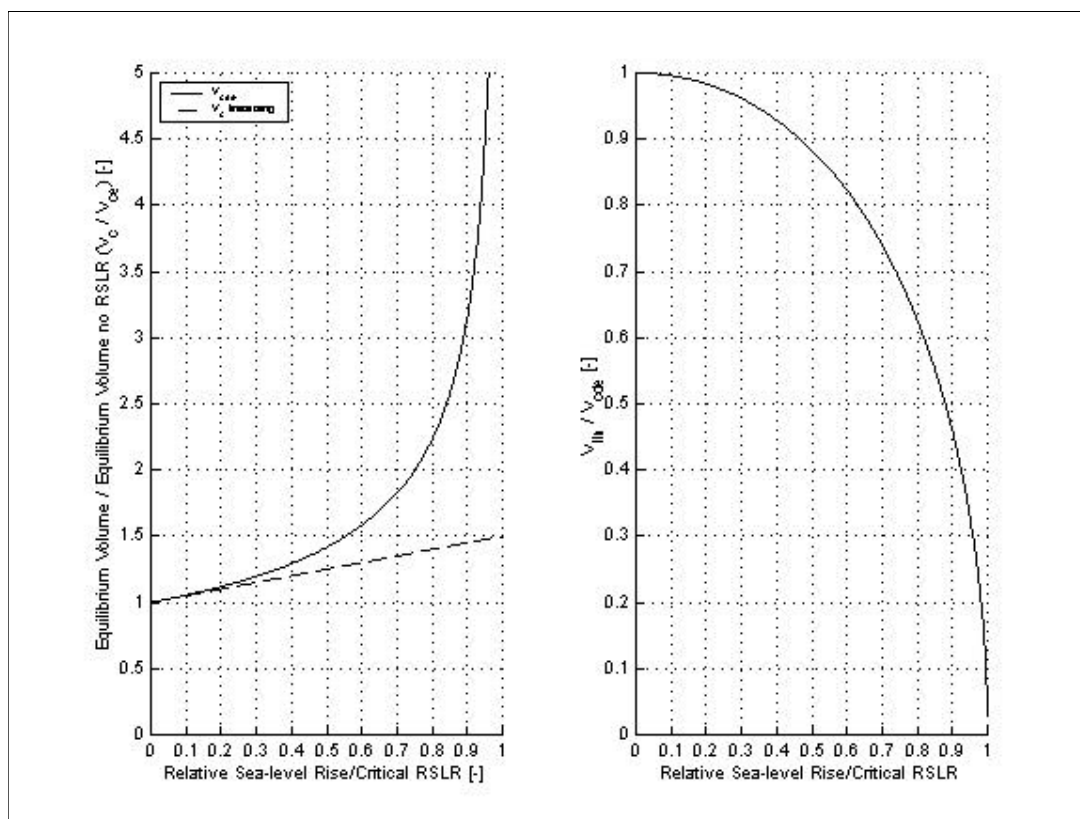


Figure 3.7: Difference between analytical solution of V_{cde} and the linearising of model

The linearized equation gives good results with small sea-level rises, but with increasing sea-level rise the linearization is no longer valid. As this study is focused on the influences of increasing sea-level rise, the linearization will not give the desired results. Besides that, it appeared that the linearized system of 3 differential equations (belonging to the 3-element model) could not be solved analytically and have to be solved numerically.

3.7 Conclusion

As the ASMITA-model is a 'behaviour-oriented' model, the morphological development of the tidal inlet tends to equilibrium state. The dynamic equilibrium state is determined by the ratio of the relative sea level rise and the critical relative sea-level rise. This development is independent of the numbers of elements, but the predicted value of the critical relative sea-level rise is sensitive for the kind of model used. Putting more elements in the model gives more dynamic interaction in the system resulting in a lower prediction of the critical sea-level rise.

Using the linearization of the ASMITA-model gives good results with small sea-level rises, but close to the critical sea-level rise the influences of higher order terms are clear. And for the 3-element-model it is even too difficult to give an analytical linearized solution. Therefore it is better to use a numerical method with the non-linearized equations.

4 Data-analysis

4.1 Introduction

In this chapter the data available will be compared with the data needed as input for the model (see Chapter 3). First an overview of the global data-sets will be given in section 4.2, then in section 4.3 the translation of the global data to the modelling data will be done.

4.2 Global data-sets

4.2.1 Coastal-segmentation

The coastal-segmentation is the base of the DIVA-tool (Dynamic Interactive Vulnerability Assessment). All data needed to model will be put in this data-base. The base of the coastal-segmentation is the world-vector-shoreline, a data-set, divided in line-segments, which represents the shoreline with a scale of 1:250.000. The world vector shoreline is divided in about 10.000 segments, this is done based on administrative units, population density and coast-type. All attributes (e.g. wave height or people per km², etc.) will be same for one segment.

The direct coastal-erosion will be done for the segment as whole, but the indirect erosion (in tidal basins) has to be solved separately, as the tidal basins are not a part of the world vector shoreline. For that purpose about 200 tidal areas in the world were detected and they were put in the database as an attribute to the corresponding segment (see Figure 4-1). When the modelling is done for a segment, the indirect erosion is calculated for the tidal areas in that segment and is added to the direct erosion of that segment.



Figure 4-1: Locations of the tidal inlets in the world

4.2.2 Etopo2

Etopo2 is a world-wide data-set based on xyz-points, with a resolution of 2 arc-minutes. This means a longitudinal distance of ± 3.7 km (2 miles) at the equator and 2.5-3.0 km for latitudes in Europe, the latitudinal distance is ± 3.7 km all over the world. This is a rather coarse resolution in relation to the area of the tidal inlets (with a complex morphological environment), so it's hardly possible to give a good estimate of the area of the individual elements, required for computation with the 3-element model.

As a test-case the Etopo2-data-set is used to estimate the area and volume of the Dutch Wadden Sea as a whole (area = $2.75 \cdot 10^9$ m² and volume = $40.24 \cdot 10^9$ m³, this means an average depth of 14.65m). Available data-sets shows us that the estimate of the area ($2.87 \cdot 10^9$ m²) is rather good, but the average depth differs from what the measurements (3.62 m) show (see Appendix B). Therefore Etopo2 will only provide accurate-enough values of the basin areas in contradiction to the values of the volume, they have to be determined by other means.

4.2.3 LOICZ

The result of the LOICZ-project (Land-Ocean Interactions in the Coastal Zone) is a data-set with characteristics of coastal and offshore areas. The data valuable for the indirect erosion are tidal range, wave height and sediment type (see Table 4-1).

Table 4-1: Valuable parameters from the LOICZ-data-set

order	Variable name	Description of variable
9	Wave height	Wave height in meters. Greatest height with a frequency of 3% or more. Reference ID 8
11	Tidal range	Tidal range class. 1(tide less), 2 (<2m), 3 (2-4m), 4 (4-8m), 5(>8m). Reference ID 4
17	Dominant Soil texture	Dominant soil texture. 0(ocean), 1 (coarse), 2(medium/coarse), 3(medium), 4(fine/medium), 5(fine), 6(ice), 7(organic). Reference ID 5

4.2.4 Charts

With help of charts available (e.g. the Bosatlas and other maps) the number of inlets belonging to a tidal area is counted (e.g. for the Dutch Wadden Sea five inlets are counted and five more for the Eastern Wadden Sea (Germany)). This information is needed to give an estimation of the average tidal basin area per inlet.

4.2.5 Conclusion

As there are not many data available the ASMITA-model has to be adapted. This can be done in two ways, the first way is to use a 1-element model with the basin area as element and the second way is a 3-element model where the elements are derived from the tidal basin area.

In the first method the dynamic interaction in the tidal area, which is known to be important for the morphological development (see Sections 3.3 and 3.5), will not be taken into account. The second method requires a subdivision of the tidal basin area into areas of the three elements. Therefore the existing equilibrium relations have to be used (see Section 2.4).

In order to keep the dynamic interaction in the modelling the algorithm will be based on the 3-element model. Besides that the 3-element model has the advantage that the user of the DIVA-tool can improve the results by replacing the input-values, derived from the equilibrium relations, by measured values. As the DIVA-tool user will not be allowed to change the algorithm, the only improvement that can be made at the 1-element model is an improvement of the values of the tidal basin area.

4.3 Translation global to modelling data

4.3.1 Geometric data

To make an estimate of the volumes and areas of the three elements the equilibrium relations from the literature will be used (see Section 2.4). First the data from Etopo2 and Loicz has to be adapted for the use in the equilibrium relations:

$$A_{basin} = A_{calc} / n_{inlet} \quad (4.1)$$

where:

$$\begin{aligned} A_{basin} &= \text{Average tidal basin area [m}^2\text{]} \\ A_{calc} &= \text{Total area calculated with Etopo2 [m}^2\text{]} \\ n_{inlet} &= \text{Number of inlets belonging to the tidal area [-]} \end{aligned}$$

The average tidal basin area is a measure for the tidal flat area:

$$\begin{aligned} A_{flat} &= A_{basin} - 2.5 \cdot 10^{-5} \cdot A_{basin}^{1.5} \\ \text{with:} & \\ A_{flat} &> 0.1 \cdot A_{basin} \end{aligned} \quad (4.2)$$

As the tidal flats and the channels together form the tidal basin, the area of the channels is defined by the tidal flat area and the basin area:

$$A_{channel} = A_{basin} - A_{flat} = 2.5 \cdot 10^{-5} \cdot A_{basin}^{1.5}$$

with:

$$A_{channel} < 0.9 \cdot A_{basin}$$
(4.3)

In order to get the tidal prism, at first the tidal flat volume has to be determined, therefore an average flat-height is needed. The coefficient in the relation (α_{fe}) is set to 0.5 as the relation Eysink derived for the Wadden Sea (see sub-section 2.4.3) appeared to be not valid for the global area-data:

$$H_{flat} = 0.5 \cdot H_{tidal}$$
(4.4)

Where the H_{tidal} comes from the Loicz-data (see Table 4-1). In this data-set only a tidal range-class is given, but the model uses one value, thus the mean tidal range has to be derived from the tidal range class (see Table 4-2)

Table 4-2: Translation from tidal range classes in Loicz to mean tidal range

Class	Range	H_{tidal}
1	Tideless	0.25
2	<2m	1.25
3	2-4m	3
4	4-8m	6
5	>8m	9

The volume of the flats equals the product of area and average height:

$$V_{flat} = A_{flat} \cdot H_{flat} = 0.5 \cdot H_{tidal} \cdot [A_b - 2.5 \cdot 10^{-5} \cdot A_b^{1.5}]$$
(4.5)

The volume of the flat gives together with the product of basin area and tidal range the tidal prism:

$$V_{tidal} = A_{basin} \cdot H_{tidal} - V_{flat}$$
(4.6)

The channel volume and the ebb-tidal delta volume are both dependent of the tidal prism:

$$V_{channel} = 6.5 \cdot 10^{-5} \cdot V_{tidal}^{1.5}$$
(4.7)

$$V_{delta} = a_{WA} \cdot V_{tidal}^{1.23}$$

Where α_{WA} is dependent on the wave climate. In the Loicz-data the significant wave-height (3% of the waves are higher than this value) is given (see Table 4-1), these values have to be translated to energy classes, which gives a value for α_{WA} (see Table 4-3).

Table 4-3: Translation from significant wave height from the Loicz-data to α_{WA}

H_{wave}	Wave Climate	α_{WA}
1	Low energy Coast	$8.64 \cdot 10^{-3}$
2-3	Moderate energy Coast	$6.44 \cdot 10^{-3}$
4-5	High energy Coast	$5.33 \cdot 10^{-3}$

The only geometric parameter not defined by an equilibrium relation is the ebb-tidal delta area (see Section 2.4). Therefore available data-sets from the Wadden Sea have been used to estimate a relation between the area and the tidal prism (see Figure 4-2).

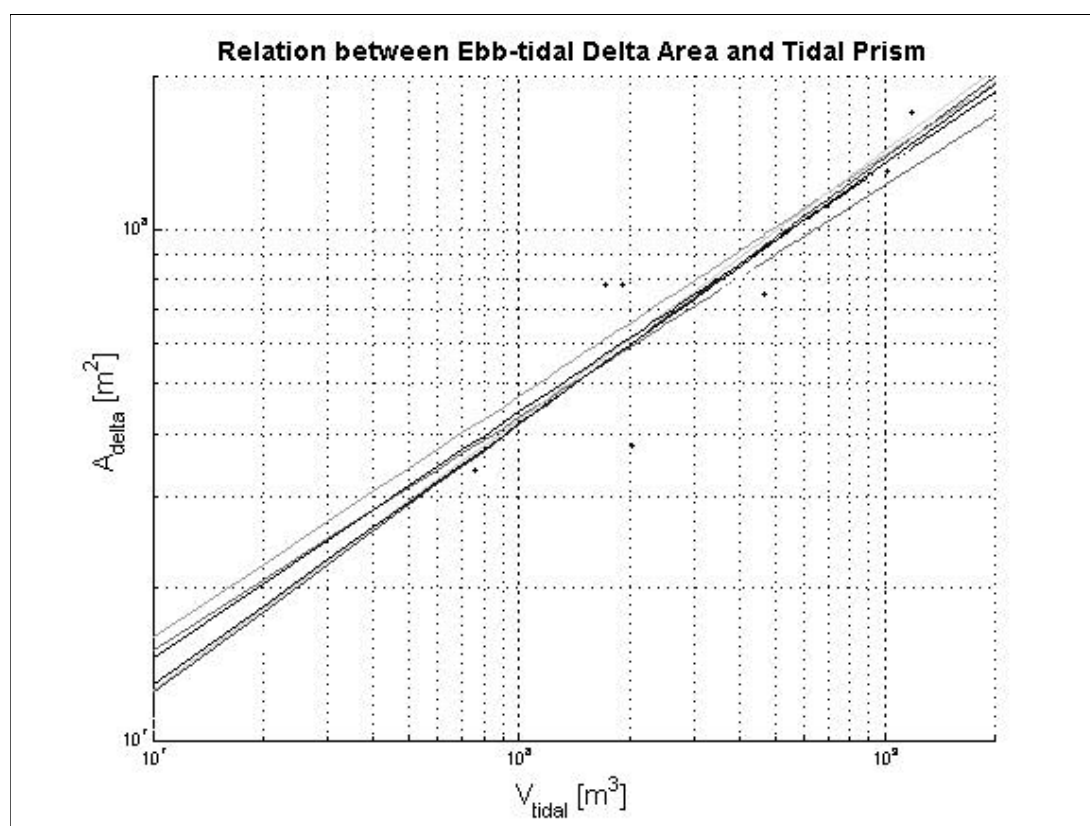


Figure 4-2: Relation between tidal prism and the area of ebb-tidal delta, with sensitivity-analysis

The relation derived from this analysis is:

$$A_{delta} = 3.46 \cdot 10^3 \cdot V_{tidal}^{0.51} \quad (4.8)$$

All the areas and volumes of the three elements, needed for the algorithm, have been derived and also the relation for the average tidal flat-height area is known, which is needed for the translation of calculated volume-loss into land-loss of the tidal flats.

4.3.2 Coefficients

Most coefficients are mainly determined by the type of sediment. In the coastal-segmentation the sediment type is divided in four classes based on the Loicz-data (see Table 4-4).

Table 4-4: Coastal type-classes available in Coastal-Segmentation

Class	Coastal Type
1	Sandy coastal stretches
2	Unrodible or limited erosional coasts
3	Muddy coasts
4	Very fine sediment coasts e.g. corals/mangroves

For the computation of direct and indirect erosion the model will only look at the segments with sandy coastal stretches as coastal type. Therefore it is not possible to vary the coefficients based on different sediment types.

Overall equilibrium concentration (c_E)

The overall equilibrium concentration determines the availability of sediment in the outside world. The concentration is scaled in that way that it gives information about cubic metres bottom per cubic metres water instead of kilograms sediment per cubic metres water:

$$c_E = \frac{c_{sed}}{\rho \cdot (1 - \epsilon_p)} \quad (4.9)$$

with:

c_E	=	Overall equilibrium concentration [-]
c_{sed}	=	Concentration sediment in water [kg/m ³]
ρ	=	Density of sediment [kg/m ³]
ϵ_p	=	Porosity of bottom-layer [-]

As there is no variety in the sediment-type and there is no knowledge of sediment-availability all over the world, the value of c_E will be given by the values used in the Wadden Sea-models ($2 \cdot 10^{-4}$).

Horizontal diffusion (d)

Tidal asymmetry leads to a net sediment-transport during a tidal period. In the ASMITA-concept this net-transport is described by a diffusion phenomenon. The diffusion coefficient (δ) represents the tide-residual exchange capacity between two elements.

The diffusion coefficient originates from the mass-balance equation and is also used in Estmorf (Wang and Karssen, 1992). In this model the horizontal exchange rate between tidal flat and channel is described by:

$$F = D \cdot h \cdot \frac{c_f - c_c}{L} \quad (4.10)$$

with:

F	=	Horizontal sediment flux per unit width [m ² /s]
D	=	Dispersion coefficient [m ² /s]
h	=	Time-averaged water depth [m]
L	=	Distance between centres of flats and channel [m]
c _f	=	Sediment-concentration in tidal flat area [-]
c _c	=	Sediment-concentration in channels [-]

Integrating F over the total width gives the total sediment flux:

$$T = D \cdot A_{cross} \cdot \frac{c_f - c_c}{L} \quad (4.11)$$

with:

T	=	Total horizontal sediment flux [m ³ /s]
A _{cross}	=	Cross-section between tidal flats and channel [m]

In ASMITA the sediment transport is described by:

$$T = d_{cf} \cdot \left| c_f - c_c \right| \quad (4.12)$$

As equation (4.11) and (4.12) representing the same transport they must be equal and that gives a relationship for the diffusion coefficient:

$$d = \frac{D \cdot A_{cross}}{L} \quad (4.13)$$

This means the coefficient depends on the cross-section the sediment-transport is passing through and the average distance between the two elements (distance between the centres). The dispersion coefficient D represents the tide-residual sediment transport capacity, which is dependent on the sediment-type, the corresponding fall velocity and the tide averaged velocity. As there will be no sediment-variation and the tide-averaged velocity is constant when the system is in a morphological equilibrium (Escoffier, 1940), the assumption can be made that D has a constant value.

To estimate the values for the dispersion coefficients the optimised diffusion coefficients from the field data on the Zouterkamperlaag, regarding the closure of the Lauwerszee, can be used. These coefficients have to be scaled with the factor A_{cross}/L to derive the dispersion coefficient. The cross-sectional area is determined by the tidal volume passing the cross-section (see Subsection 2.4.1):

$$A_{\text{MSL}} \sim \alpha_A \cdot V_{\text{ctv}} \quad (4.14)$$

For the channel the volume equals the tidal prism, the tidal volume passing the ebb-tidal delta can be estimated by the tidal prism and for the tidal flats the volume equals:

$$V_{t,f} = A_f \cdot H_{\text{tidal}} - V_f \quad (4.15)$$

For the diffusion-length can be assumed that it is related to the area of the elements. The length-scale for the diffusion in the basin can be estimated by the square-root of the basin area, the same value holds for the diffusion between the channel and the ebb-tidal delta. The length-scale for the ebb-tidal delta can be estimated by the square-root of the area of the delta.

The total solution for the three diffusion coefficients then becomes:

$$\begin{aligned} \delta_{cf} &= \frac{D'_1 \cdot [A_f \cdot H_{\text{tidal}} - V_f]}{\sqrt{A_b}} \\ \delta_{cd} &= \frac{D'_2 \cdot [A_b \cdot H_{\text{tidal}} - V_f]}{\sqrt{A_b}} \\ \delta_{do} &= \frac{D'_3 \cdot [A_b \cdot H_{\text{tidal}} - V_f]}{\sqrt{A_d}} \end{aligned} \quad (4.16)$$

where D' is determined by the dispersion coefficient (D), and the coefficient in the relation between cross-sectional area and tidal prism:

$$D' \sim \alpha_A \cdot D \quad (4.17)$$

The values of D' will be derived from model-calibration based on field data on the Zoutkamperlaag regarding the closure of the Lauwerszee (van Goor, 2001). These values corresponds with earlier calibrations for the Zouterkamperlaag (Buisman, 1997). The scaling method gives based on the calibration values for D' (see Table 4-5):

Table 4-5: Calibrated Diffusion Coefficients for Zouterkamperlaag

Zoutkamperlaag				Tidal Range = 2.24
Element	Area [m ²]	Volume [m ³]	δ [m ³ /s]	D' [m/s]
Flat	7.83E+07	7.62E+07	840	8000
Channel	4.12E+07	1.52E+08	1290	6365
Delta	7.80E+07	1.19E+08	1060	4225

Vertical exchange (w_s)

The vertical exchange coefficient represents the net vertical exchange per unit per second. The vertical exchange is not the same as the fall velocity although they have the same dimension. This parameter covers all kinds of processes involving erosion and sedimentation, and acts as the long-term residual change in sediment-amount in the element. The vertical exchange of the ebb-tidal delta is influenced by the waves, which can stir up sediment. Therefore the exchange rate of the ebb-tidal delta will be smaller than at the tidal flats where the wave climate is much calmer, but on the other hand the sediment in tidal flats is finer, which slows the sediment exchange.

Previous studies used values between 10^{-5} and 10^{-4} m/s (Buisman, 1997, Van Goor, 2001 and Kragtwijk, 2001). In this study the different exchange rates will be:

$$\begin{aligned}
 w_{s,flat} &= 1 \cdot 10^{-4} \text{ m/s} \\
 w_{s,channel} &= 5 \cdot 10^{-5} \text{ m/s} \\
 w_{s,delta} &= 1 \cdot 10^{-5} \text{ m/s}
 \end{aligned}
 \tag{4.18}$$

n-parameter

This parameter is used in the relation between volume-variation of the equilibrium volume and the local equilibrium concentration. This parameter is related to the non-linear relation between sediment transport and mean velocity, and a value of 2 is in compliance with the third power most commonly used in sediment transport formula (Buisman, 1997, Van Goor, 2001 and Kragtwijk, 2001).

4.4 Conclusion

Available global data-sets are not detailed enough for a computation with the 3-element model. Surface of the tidal area, number of inlets, mean tidal range and significant wave height are the only parameters derived from global data-sets. In order to keep the morphological dynamics in the algorithm the data will be extended to three elements by means of equilibrium relations known from previous studies and available in literature. The coefficients needed in the algorithm will be derived from calibrated ASMITA-model-runs with Wadden Sea data-sets.

An advantage of the 3-element model is that, as the input-values in the DIVA-tool can be changed by the user, the results of the 3-element model will improve. The user probably possesses more detailed data or is willing to measure the data needed. The possibilities to improve the results when the computation will be done with the 1-element model are much smaller as the user will not be able to improve the algorithm itself.

5 Long-term Modelling

5.1 Introduction

The data-analysis (see the previous Chapter 4) showed us that the global data-sets are not detailed enough for the use in the 3-element model. In order to keep the dynamic interaction between the elements in the algorithm the data will be extended from tidal basin area to 3-element data based on the equilibrium relations (see Section 4.3).

As there are detailed data of the Wadden Sea tidal inlets (see Figure 5-1) a 3-element computation is done and some improvements are made at the basic ASMITA-model concerning modelling with increasing sea-level rise (see Section 5.2). The results of the modelling will be used to validate the simplifications in the algorithm (see Section 5.3).

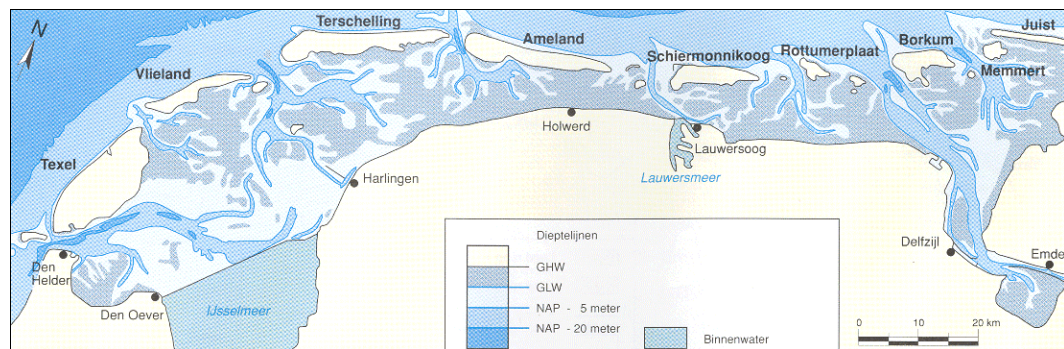


Figure 5-1: Barrier Islands of the Dutch Wadden Sea

5.2 ASMITA-modelling

5.2.1 ASMITA-model data

For the Dutch Wadden Sea Inlets detailed data was collected and therefore one of these tidal inlets is used (see Table 5-1 and Appendix B). To choose one of the inlets some considerations have to be made. For good modelling of the effects of sea-level rise the inlet should have been in a morphological equilibrium for the last decades. But the human interference in the Wadden Sea has been radical last century. The closure of the former Zuiderzee (IJsselmeer, 1932) and the Lauwerszee (1969) affected the respectively the western (Marsdiep and Vlie) and the eastern (Pinkegat and Zouterkamperlaag) Dutch Wadden Sea inlets.

Table 5-1: Tidal inlets of the Dutch Wadden Sea (West → East) and their main characteristics

Tidal Inlet Basin	Basin area [km ²]	Tidal Range [m]	Tidal prism [10 ⁶ m ³]
Marsdiep	656	1.65	1015
Eierlandse gat	161	1.65	205
Vlie	719	1.90	1190
Amelander Zeegat/Borndiep	269	2.15	475
Pinkegat	52	2.15	80
Zoutkamperlaag - Present	123	2.25	195
Zoutkamperlaag - Before Closure	230	2.25	305
Eijerlanderbalg	35	2.40	48
Lauwers	128	2.45	210
Schild	31	2.45	42
Eems-Dollard	467	2.70	1095

Nevertheless the Amelander Zeegat (between Terschelling and Ameland, also known as the Borndiep) has been relatively stable for the last decades (see Table 5-2).

Table 5-2: Development of Amelander Zeegat last century (Biegel, 1993)

Year:	1926	1950	1973	1978	1984	Average	Standard Deviation
Basin Area [km ²]	270	284	278	276	269	275.4	6.1
Tidal Range [m]	2.039	2.083	2.126	2.137	2.147	2.106	0.045

The relative stable situation makes the Amelander Zeegat (AZ) useful for the ASMITA-model. For the 3-element modelling more detailed information of the elements of the tidal inlet is needed (see Table 5-3).

Table 5-3: Element characteristics of Amelander Zeegat (Biegel, 1993)

Element	Area 10 ⁷ [m ²]	Volume 10 ⁸ [m ³]	w _s 10 ⁻⁴ [m/s]	δ _{→f} [m ³ /s]	δ _{→c} [m ³ /s]	δ _{→d} [m ³ /s]	δ _{→ow} [m ³ /s]	cE 10 ⁻⁴ [-]	Pres. SLR [mm/y]
Tidal Flat	16.5	1.07	1.0		1000			2.0	1.7
Channel	10.3	2.98	0.5	1000		1500		2.0	1.7
Ebb-tidal delta	7.47	1.21	0.1		1500		1500	2.0	1.7

5.2.2 Basic model

First a model run has been made with the basic ASMITA-model. The results are presented in two ways (see Figure 5-2): the relative loss of tidal flats against time for the short-term development and also the relative loss against relative sea-level rise (relative sea-level rise divided by the critical relative sea-level rise) after 2500 years for the long-term development (system is presumed to be close to his equilibrium). The relative loss is defined as the quotient of the modelled volume of the tidal flats and the present volume, in order to give the best view of the actual loss.

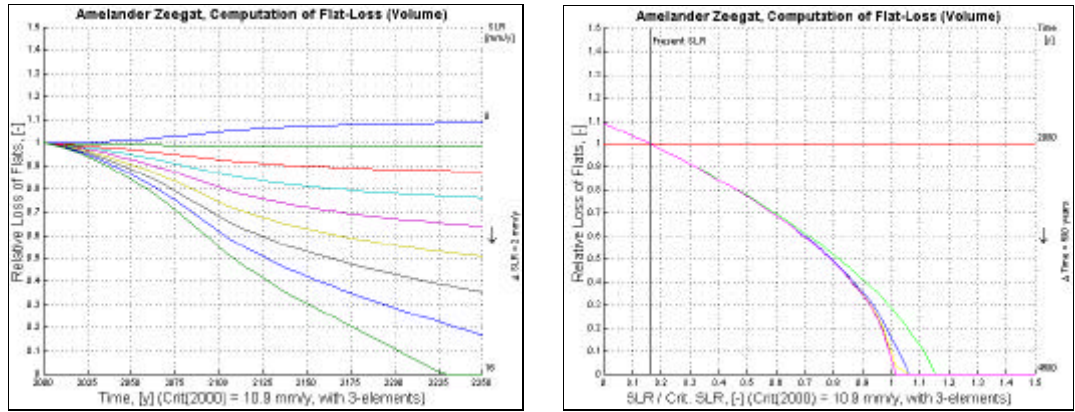


Figure 5-2: Influence of relative sea-level rise on the tidal flats of Ameland Zeegat with ASMITA-model

The results are comparable with the outcome of sub-section 3.5.3. The differences is the way of presentation, the figures are relative to their present volume instead of relative to their static equilibrium volume (see equations 3.31 and 3.32):

$$\frac{V_{f,dyn.eq.}}{V_{f,pres}} = \frac{V_e \cdot \left[1 - \left(\frac{d\zeta}{dt} \right)_{critical}^{-1} \cdot \left(\frac{d\zeta}{dt} \right)^{1/n} \right]}{V_e \cdot \left[1 - \left(\frac{d\zeta}{dt} \right)_{critical}^{-1} \cdot \left(\frac{d\zeta}{dt} \right)_{pres}^{1/n} \right]} = \frac{\left(\frac{d\zeta}{dt} \right)_{critical} - \left(\frac{d\zeta}{dt} \right)^{1/n}}{\left(\frac{d\zeta}{dt} \right)_{critical} - \left(\frac{d\zeta}{dt} \right)_{pres}^{1/n}} \quad (5.1)$$

where 'RSLR_{critical}' stands for the critical relative sea-level rise (see sub-section 3.5.2):

$$\left(\frac{d\zeta}{dt} \right)_{critical} = \frac{c_E}{\frac{A_f}{\delta_{cf}} + \frac{A_b}{\delta_{dc}} + \frac{A_{tot}}{\delta_{do}} + \frac{1}{w_{sf}}} = \frac{2.0 \cdot 10^{-4}}{[1.9 + 2.1 + 2.6 + 0.12]} = 10.8 \text{ mm/y} \quad (5.2)$$

Combining equation (5.1), (5.2) and a present relative sea-level rise of 1.7 mm/y gives:

$$\frac{V_{f,dyn.eq.}}{V_{f,pres}} = \sqrt[1/n]{119 - 0.109 \cdot \frac{dz}{dt}} \quad (5.3)$$

This corresponds with the results of the long-term development (see Figure 5-2).

5.2.3 Adaptation to variable area

The ASMITA-model is based on a fixed area size, this implies modelling with vertical boundaries. With small volume changes this is a good approach but when the model predicts drowning due to accelerated relative sea-level rise the changes in area can play an important role. This means the area has to follow the morphological change of the tidal flats, therefore the area is calculated as the quotient of volume and average flat height (see equations 2.6 and 2.7):

$$A_{flat} = \frac{V_{flat}}{H_{flat}} = \frac{V_{flat}}{a_{fe} \cdot H_{tidal}} = \frac{V_{flat}}{(0.41 - 0.24 \cdot 10^{-9} \cdot A_{basin}) \cdot H_{tidal}} \quad (5.4)$$

As the area of the tidal basin does not change, the loss of flat area has to be compensated by increase of the channel area.

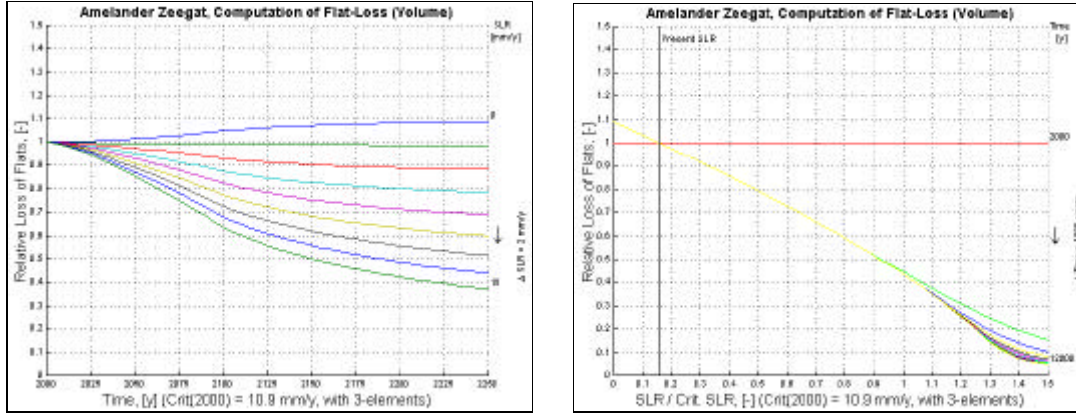


Figure 5-3: ASMITA-model with adaptation of area change

The difference between the adaptation and the basic model is a higher critical relative sea-level rise (see Figure 5-3). For small relative sea-level rise the difference is negligible, but close to total drowning the critical relative sea-level rise changes. This is logic consequence of flat loss, a constant size of the basin and a constant total area (see equation (5.2)):

$$\lim_{A_f \rightarrow 0} \left[\frac{d\zeta}{dt} \right]_{critical} = \frac{2.0 \cdot 10^{-4}}{[0.0 + 2.1 + 2.6 + 0.12]} = 151 \text{ mm/y} \approx 1.4 \cdot \left[\frac{d\zeta}{dt} \right]_{critical} \quad (5.5)$$

ASMITA-modelling with the variable area also showed an increase in relative sea-level rise of 1.4 times the standard relative sea-level rise (see Figure 5-3).

5.2.4 Expansion of Tidal Basin

The Wadden Sea coast is well defended by dikes, so there is no expansion of the tidal area possible (area basin is constant). But in case of a non-defended hinterland expansion is possible, in order to predict the influence of expansion the ASMITA-model should be adapted (modelling with expansion also means modelling with variable area (see Section 5.2.3)). The expansion is then related to the sea-level-rise:

$$\begin{aligned} \frac{dA_b}{dt} &= \frac{L_{coast}}{slope} \cdot \frac{d\zeta}{dt} = \frac{\sqrt{A_b}}{slope} \cdot \frac{d\zeta}{dt} \\ \text{with: } L_{coast} &\approx \sqrt{A_b} \\ \frac{dV_f}{dt} &= \frac{\sqrt{A_b}}{slope} \cdot \frac{d\zeta}{dt} \cdot H_{tidal} + \frac{d\zeta}{dt} \end{aligned} \quad (5.6)$$

A test-case on the Ameland Zeegat with a slope of the hinterland of 1 to 200 (vertically 1 m means 200 m horizontally) has been carried out (see Figure 5-4).

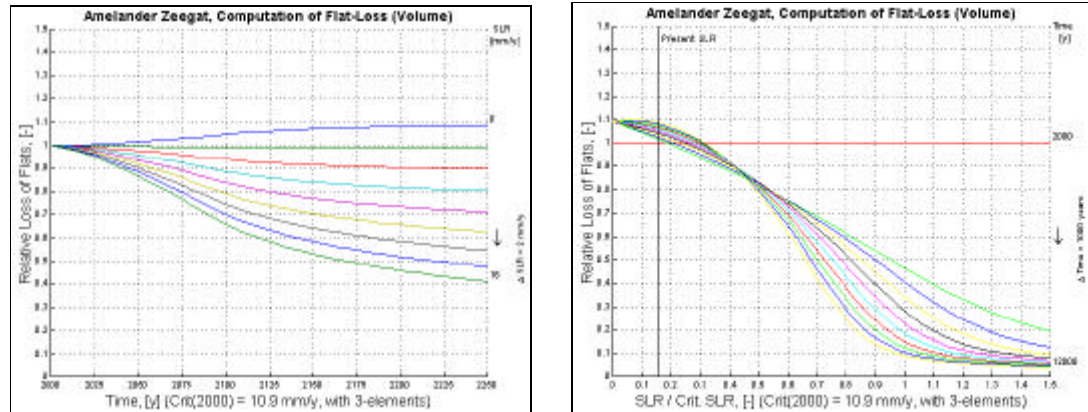


Figure 5-4: ASMITA-model with expansion of tidal area

Again for lower relative sea-level rise rates and on the short-term the difference with the basic model is small. For high relative sea-level rise rates the drowning is smaller than in case of only a variable area, this is due to migration of the tidal flats to the hinterland (the loss of flats in original basin is compensated by area-gain).

On the long-term unlimited gain of area causes drowning for all rates of relative sea-level rise. Again the definition of critical relative sea-level rise explains the reason of the drowning (see equation (5.2)):

$$\lim_{t \rightarrow \infty} [RSLR_{critical} \cdot AZ] = \frac{2.0 \cdot 10^{-4}}{0 + 2.1 + \frac{a \cdot t}{d_{cf}} + 2.6 + \frac{a \cdot t}{d_{do}} + 0.12} = 0 \text{ mm/y} \quad (5.7)$$

where:

$$\begin{aligned} \alpha &= \text{Rate of expansion [1/m]} \\ t &= \text{Time [y]} \end{aligned}$$

The rate of expansion is determined by the rate of relative sea-level rise, the slope of the hinterland and the length of coast, where the area expands. :

$$\alpha = \frac{d\zeta/dt}{\text{slope}} \cdot L_{coast} \xrightarrow{SLR=2.0 \text{ mm/y}} 6.55 \cdot 10^3 \text{ m}^2/\text{y} \quad (5.8)$$

where:

$$\begin{aligned} \text{slope} &= \text{Slope of hinterland, taken as } 1/200 \text{ [-]} \\ L_{coast} &= \text{Length of expansion (assuming a square-form basin } L_{coast} \approx \sqrt{A_b} \text{)} \end{aligned}$$

Combining equation (5.7) and (5.8) gives us the time where the critical relative sea-level rise equals the 2.0 mm/y (present sea-level rise):

$$t = \frac{\frac{2.0 \cdot 10^{-4}}{365 \cdot 1000} - (0.0 + 2.1 + 2.6 + 0.12)}{\frac{6.55 \cdot 10^3}{365} \cdot \left(\frac{1}{12.96 \cdot 10^7} + \frac{1}{12.96 \cdot 10^7} \right)} = 313.4 \cdot 10^3 \text{ y} \quad (5.9)$$

This is a long period of time, but it means that the system never will reach a dynamic equilibrium situation, in spite of the assumption that nowadays the system is in a dynamic equilibrium. Therefore a simple algorithm with a time-development to a dynamic equilibrium situation is no longer valid for long-term prediction with expansion.

5.3 Algorithm

As stated before this project will be part of a research to the influences of climate change to socio-economic environment of the coasts. To fit in the DIVA-model (Dynamic Interactive Vulnerability Assessment) the algorithm has to handle with a certain input, has to produce a specified output and the computational effort should be minimised.

5.3.1 Input from DIVA

At first, the time-span of the model will be from 1995 to 2100 AD with a discrete time-step of 5 years and this may be extended to 2500 AD with time-steps of 50 years. For all time-steps the model will produce a relative rise or fall of the sea-level (m). This relative sea-level change is not necessarily continuous rising or falling, so the algorithm can not work with a constant sea-level rise (m/y) as used in the computation of the dynamic equilibrium volume and in the solution with exponential decay (see Section 3.6). This implies also that the algorithm has to consist of a numerical computation which will use the old volumes to calculate the new volumes (Euler Implicit-method).

5.3.2 Base-equations

As stated in Section 3.6 it is not possible to solve the 3-element model into 3 functions of volume-development against time. Besides that the relative sea-level rise, variable in time, requires a numerical approach.

Therefore the normal ASMITA-model should satisfy. But the model will take too much computation time, as it calculates all base-equations. This means that the system of all 9 equations should be turned into a system of 3 equations. This results in (see equation 3.30 and Appendix A2):

$$\begin{pmatrix} dV_f \\ dV_c \\ dV_d \end{pmatrix} \cdot \Delta t = \begin{pmatrix} M_1 & M_2 & M_3 \\ M_5 & M_6 & M_7 \\ M_9 & M_{10} & M_{11} \end{pmatrix} \cdot \begin{pmatrix} \frac{V_f \cdot \Delta t - 1}{V_{fe}} \\ \frac{V_c \cdot \Delta t - 1}{V_{ce}} \\ \frac{V_d \cdot \Delta t - 1}{V_{de}} \end{pmatrix} + \begin{pmatrix} M_4 \\ M_8 \\ M_{12} \end{pmatrix} \cdot \Delta t + \Delta \zeta \cdot \begin{pmatrix} -A_f \\ -A_c \\ -A_d \end{pmatrix} \quad (5.10)$$

with the values of the system-matrix M dependent of w_{si} , δ_{ij} and A_i (see Appendix C).

For each time-step the new volumes have to be calculated, which will be used in the next time-step (see equation (5.10)), valid for all volumes:

$$V_i \cdot \Delta t = V_i \cdot \Delta t - 1 + dV_i \cdot \Delta t \quad (5.11)$$

5.3.3 Output to DIVA

The end-result of the model will be in terms of money (costs and benefits). This can be expressed in two ways, the first way is to calculate the value-loss of the nature due to changing in the tidal area (loss of feeding-place for birds and resting place for seals). The second is the price of keeping the nature in or restoring it to the present state. To estimate the costs the algorithm therefore has to produce values of land-loss (m^2) and sediment-volume-loss (m^3), which later in the model can be converted into terms of money.

The change of land-area is determined by the change of volume of the tidal flats:

$$dA_f \cdot \Delta t = \frac{dV_f}{H_{flat}} \cdot n_{inlets} \quad (5.12)$$

The second output required is the sediment-change in the system. This consists of two parts, the sediment amount the system demands from the adjacent coast ('sand hunger') and the relative change of the volumes of the elements according to the present state.

The sediment-demand can be calculated by comparing the new state with the present state and the change due to relative sea-level rise:

$$dV_{coast \rightarrow inlet} \cdot \Delta t = \Delta \zeta \cdot (A_f + A_c + A_d) + dV_f - dV_c + dV_d \cdot n_{inlets} \quad (5.13)$$

And the amount of sediment that has to be supplied in order to keep or restore the present state is defined by the change in volumes:

$$dV_{suppletion} \cdot \Delta t = dV_c - dV_f - dV_d \cdot n_{inlets} \quad (5.14)$$

5.3.4 Method

If variable area and expansion will be taken to account this means that the values of M are changing with each area-change. For the DIVA-model it means that the algorithm should consist of a minimum of 2 extra equations to compute the area change, 3 equations to recalculate the diffusion coefficient (see sub-section 4.3.2) and 12 equations to recalculate M above the normal equations. This will of course increase the computation time too much (an increase of about 3 times), and this results in a computation with fixed area.

The algorithm will then consist of the following procedure:

1. Calculating initial and boundary conditions (see Section 4.3 and Appendix C)
2. Computation of volume change per time-step (3 equations, see (5.10))
3. Recalculating the volumes per time-step (3 equations, see (5.11))
4. Giving output per time-step (3 equations, see (5.12), (5.13) and (5.14))

This gives about 50 computational lines to define the initial and boundary conditions and 9 equations per time-step and per tidal area to calculate the land-loss and the sediment-loss.

5.3.5 Results

To check the results of the algorithm we will first do a test-run with the basic ASMITA-model with a relative sea-level rise of 6 mm/y (see Figure 5-5).

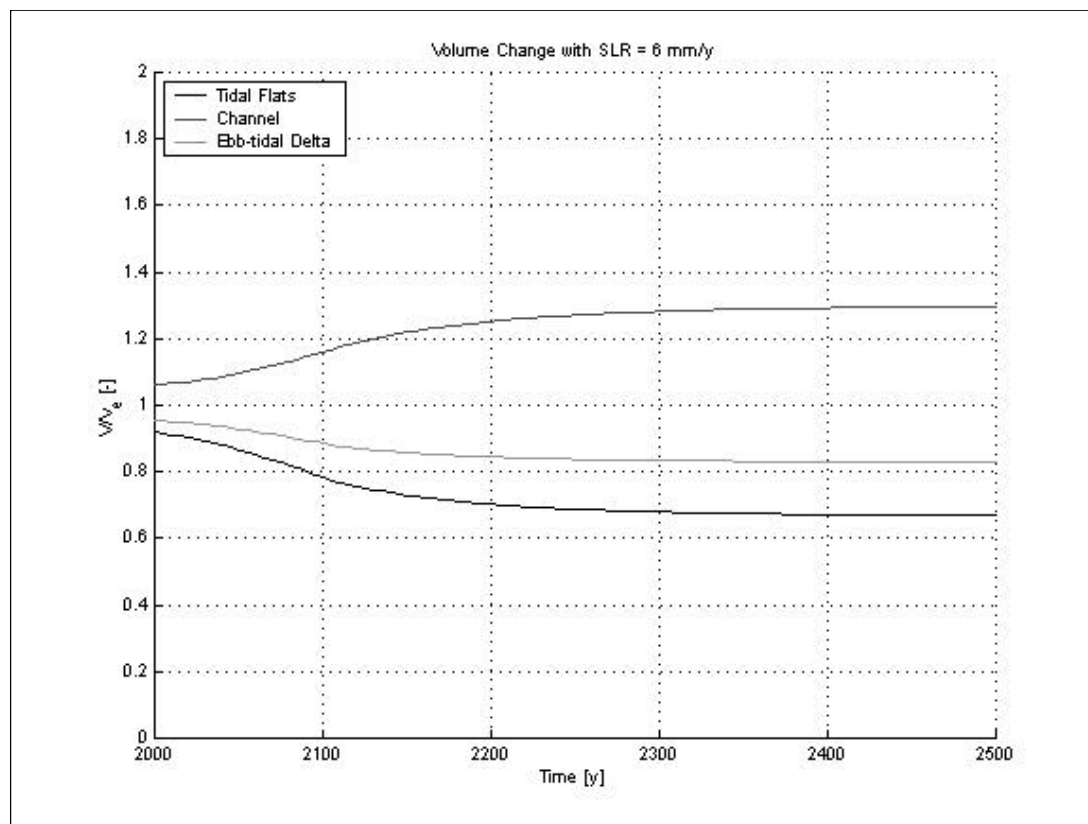


Figure 5-5: Results for basic ASMITA with Amelanders Zeegat-data

The first test will be the computation of the algorithm itself. Therefore a run is done with the detailed data of the Ameland Zeegat as input (see Figure 5-6).

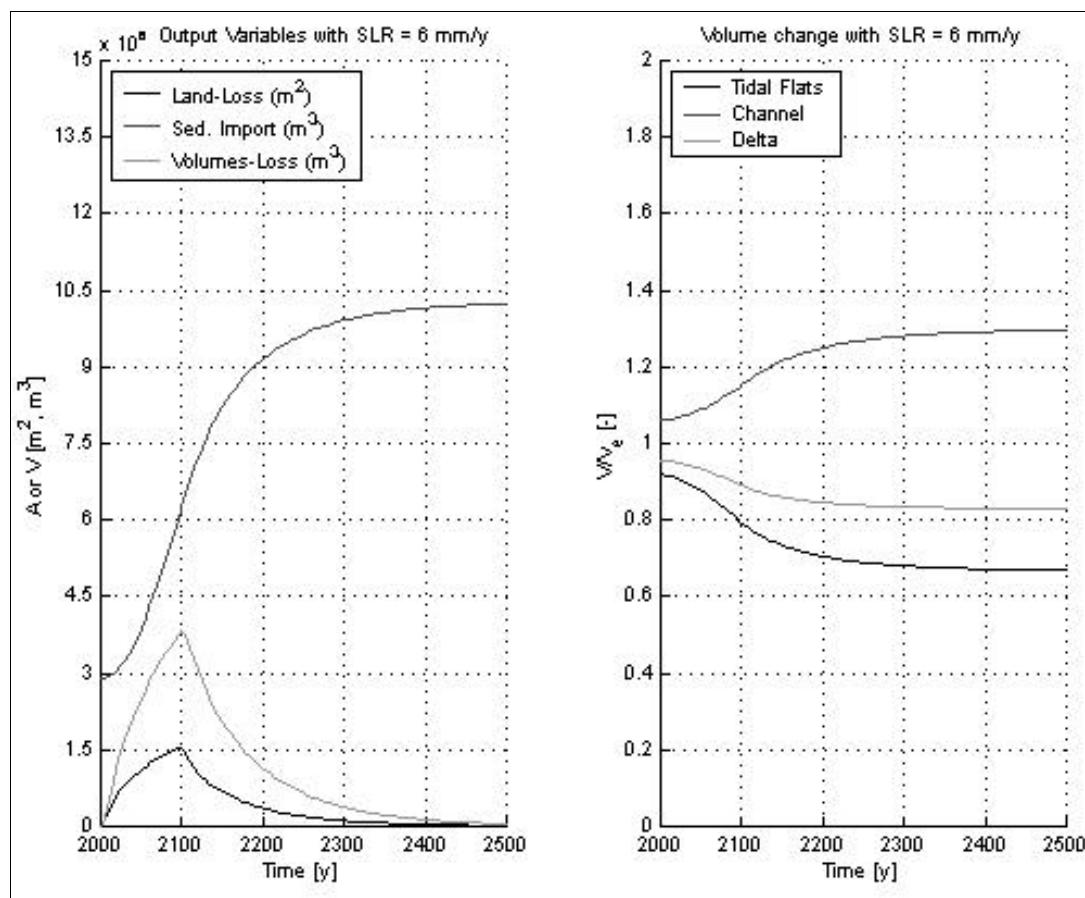


Figure 5-6: Results algorithm with input of Ameland Zeegat

Comparing the two results it can be seen that the outcome is the same in the algorithm as in the model. This is logic as the algorithm is just a rewriting of the ASMITA-model and no simplifications are made in the basic model.

The next step is to check the relations used to translate the data into the model. A run has been made with the only input from Ameland Zeegat is Basin Area, Mean Tidal Range and the α_{WA} (see Section 4.3). The error in the translation can then be derived from the difference between the results of the run and the results from the run with all data (see Figure 5-5 and Figure 5-6).

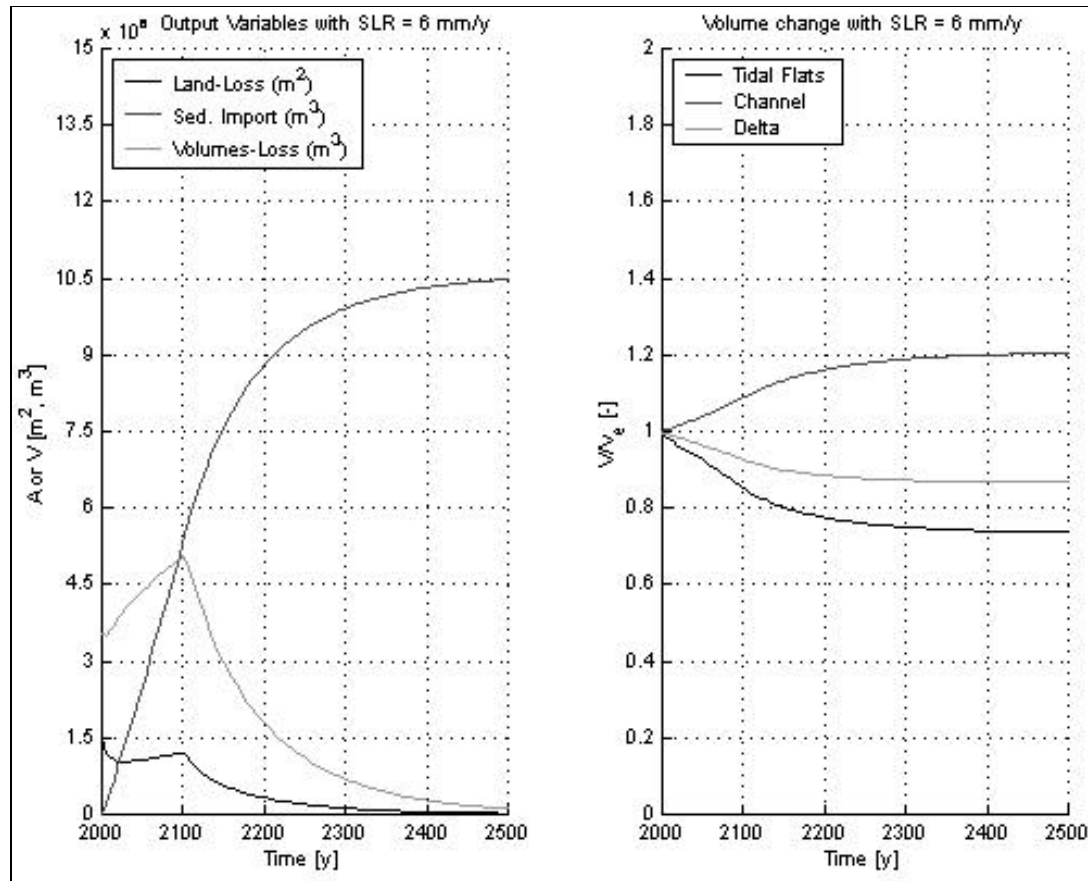


Figure 5-7: Results algorithm based on only basin area-input of Amelander Zeegat

The results are different and can be explained by the equilibrium relations. The value of the areas are very accurate but the values of the volume are even 1.5 to 2 times bigger (see Table 5-4).

Table 5-4: The results of the test with only basin area compared to a full input-run

	Data of AZ	Relations	Difference
Af	1.65E+08	1.58E+08	96%
Ac	1.03E+08	1.10E+08	106%
Ad	7.47E+07	8.50E+07	114%
Vfe	1.17E+08	1.70E+08	146%
Vce	2.80E+08	5.32E+08	190%
Vde	1.27E+08	2.50E+08	197%

The last step is the results of the Wadden Sea compared to the results of the run with the simplified Amelander Zeegat (see Figure 5-7 and Figure 5-8).

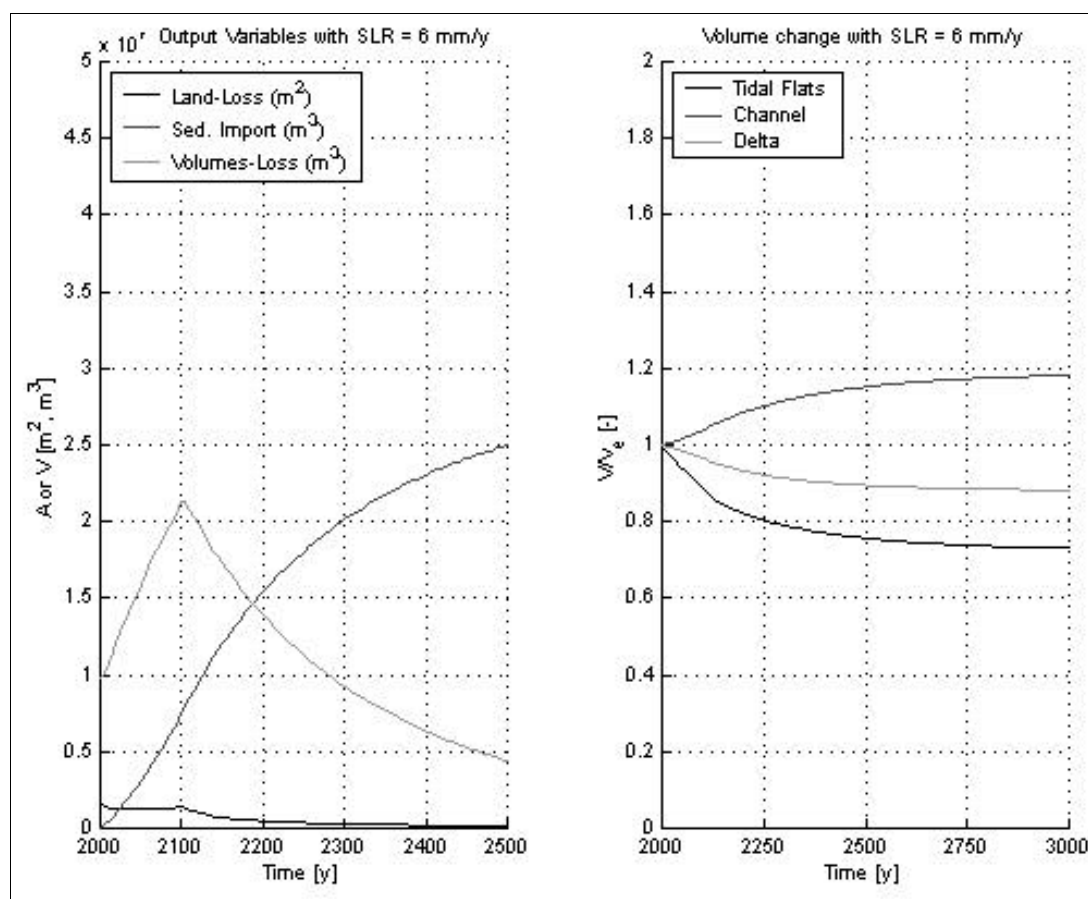


Figure 5-8: Results of algorithm based on the Wadden Sea

The absolute difference between the results of the computation with the average tidal basin area of the Wadden Sea and the results of the computation with the tidal basin area of the Amelander Zeegat are large (output of Wadden Sea is 4 times output of Amelander Zeegat). This can be explained by the large differences in the average tidal basin area size (respectively $78.6 \cdot 10^7$ and $26.8 \cdot 10^7$).

But the relative changes in volume show similarities, only the development of the Wadden Sea takes more time. The reason for the similarity is the fact that the translation from tidal basin area is the same for all inlets and therefore the differences in results are relatively small.

5.3.6 Global results

The algorithm can be used to model the data from the whole world (see Appendix C). To predict the sea-level rise a linear rise between a present sea-level rise (for all inlets 2.0 mm/y is taken) and a scenario in 2100 (set to 6.0 mm/y for all inlets) is assumed.

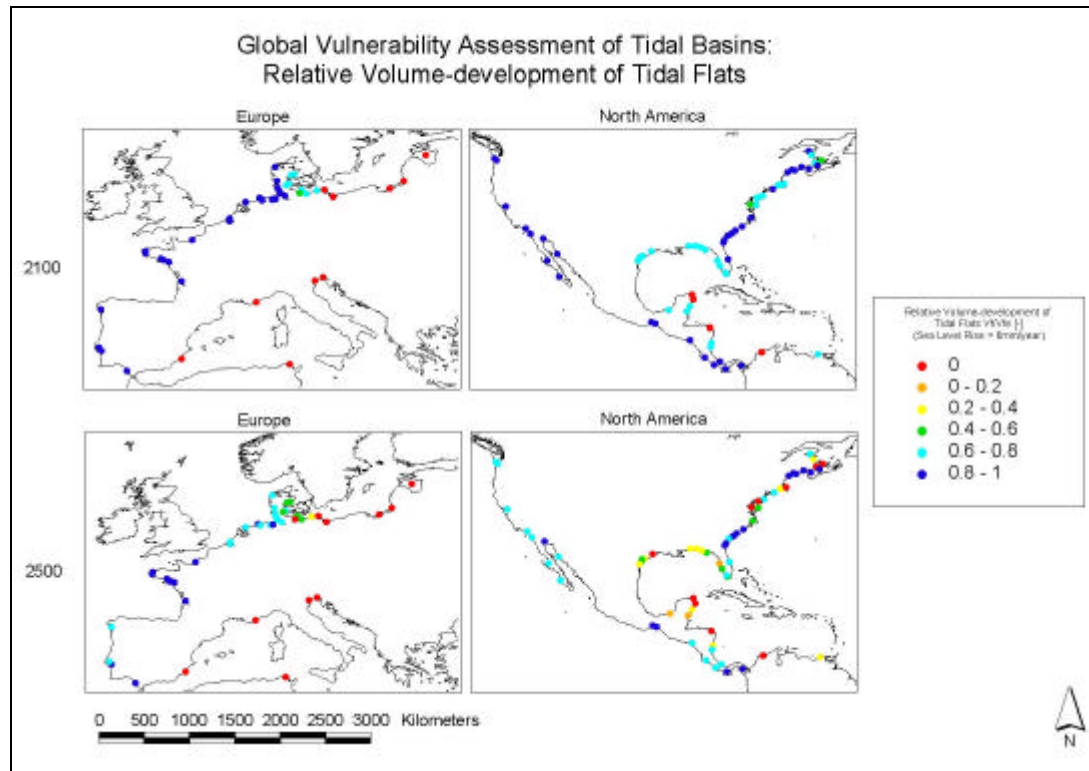


Figure 5-9: Relative volume development of tidal basins in Europe and North America with a SLR of 6 mm/y

Figure 5-9 shows that the tidal basins in Mediterranean Sea and the Baltic Sea are more vulnerable to relative sea-level, this is due to the presence of a micro tidal range rise (for the rest of the world see Appendix C, 17-23). For the other areas the changes are still small in 2100, and the differences with 2500 are considerable. In 2100 the dynamic equilibrium situation has not yet been reached due to increasing sea-level rise till 2100 and in 2500 the tidal basins are more close to their equilibrium state (see Figure 5-10).

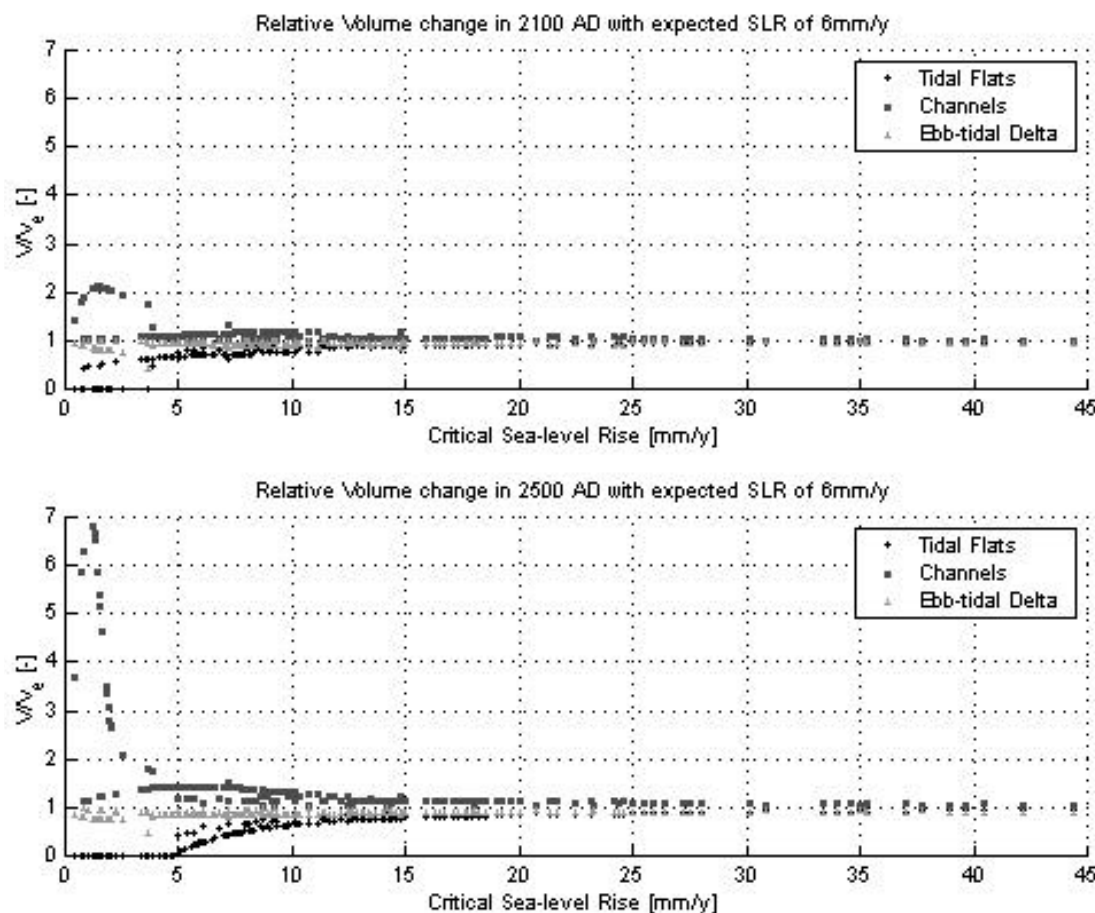


Figure 5-10: Relative volume development against the critical sea-level rise off all tidal inlets

In 2100 we see that the volume changes are relatively low, but in 2500 the volume change of the elements is more conform the theory, tidal areas with a critical sea-level rise below 6 mm/y are completely drowned and areas with a critical sea-level rise higher than 6 mm/y tend to a relative volume according the formula:

$$\frac{V}{V_e} = \sqrt{1 - \left(\frac{d\zeta}{dt} \right)_{critical}^2} \quad (5.15)$$

Figure 5-10 shows again that the tidal flats are determined for the system, for a vulnerability assessment of all tidal areas the development of the tidal flats will therefore be investigated (see Table 5-5).

Table 5-5: Global development of tidal flats

V_f/V_{fe}	number of areas in 2100	number of areas in 2500
0	18	36
<0.1	18	41
<0.2	18	42
<0.3	18	54
<0.4	18	61
<0.5	22	74
<0.6	25	87
<0.7	52	109
<0.8	96	147
<0.9	164	189
<1	204	204

In 2100 18 areas are completely drowned, all these areas have a tidal range class of 1 (see Appendix C). This means that in these areas the tidal prism is too small to import the sediment needed for dealing with the sea-level rise. The rest of the tidal areas did not lose much volume, and they are still tending to the dynamic equilibrium state. In 2500 the areas are more close to the dynamic equilibrium state and more tidal areas have been drowned, these areas have a critical sea-level rise which is lower than the 6 mm/y (see Figure 5-10), the low critical sea-level rise is mainly influenced by the size of the area, the large areas have a lower critical sea-level rise as they needed more sediment to deal with the sea-level rise 1 (see Appendix C).

To investigate the influence of the input parameters, the results are averaged for the wave height classes and the tidal range classes. First the average relative volume change and the standard deviation per Wave Height Class is calculated (see Table 5-6).

Table 5-6: Output of algorithm per wave height class

Wave Height Class	nr. of areas	Vd/Vde [-]	Vc/Vce [-]	Vf/Vfe [-]	Vd/Vde [-]	Vc/Vce [-]	Vf/Vfe [-]
average:		2100	2100	2100	2500	2500	2500
Low energy Coast	20	0.964	1.058	0.806	0.907	1.193	0.566
Moderate energy Coast	86	0.910	1.264	0.643	0.846	1.868	0.456
Moderate energy Coast	73	0.940	1.100	0.803	0.879	1.284	0.615
High energy Coast	16	0.957	1.055	0.801	0.895	1.211	0.532
High energy Coast	9	0.949	1.052	0.902	0.899	1.137	0.819
standard deviation:							
Low energy Coast	20	0.032	0.052	0.150	0.052	0.155	0.359
Moderate energy Coast	86	0.076	0.355	0.321	0.063	1.455	0.310
Moderate energy Coast	73	0.038	0.173	0.174	0.037	0.468	0.299
High energy Coast	16	0.021	0.045	0.167	0.039	0.162	0.408
High energy Coast	9	0.034	0.068	0.099	0.042	0.140	0.175

The results show that the development of the channels and the tidal flats do not differ with different wave height, the standard deviation also shows that the development is not mainly determined by the wave height. The standard deviation of the ebb-tidal delta is low, but the averages do not differ much for the all classes, which means that the development for all deltas is analogous.

Another input-parameter is the tidal range classes. Also for this parameter the relative volumes are averaged and the standard deviation is calculated (see Table 5-7).

Table 5-7: Output of algorithm per tidal range class

Tidal Range Class	nr. of areas	Vd/Vde [-]	Vc/Vce [-]	Vf/Vfe [-]	Vd/Vde [-]	Vc/Vce [-]	Vf/Vfe [-]
average:		2100	2100	2100	2500	2500	2500
Tideless	18	0.802	1.988	0.000	0.758	4.379	0.000
<2m	72	0.922	1.140	0.693	0.845	1.385	0.335
2-4m	76	0.953	1.051	0.866	0.893	1.159	0.728
4-8m	24	0.963	1.026	0.924	0.918	1.089	0.841
>8m	14	0.971	1.018	0.931	0.930	1.076	0.836
standard deviation:							
Tideless	18	0.105	0.178	0.000	0.073	1.711	0.000
<2m	72	0.035	0.047	0.073	0.032	0.085	0.236
2-4m	76	0.021	0.018	0.060	0.019	0.041	0.150
4-8m	24	0.021	0.016	0.065	0.025	0.068	0.183
>8m	14	0.015	0.023	0.081	0.030	0.099	0.245

The influence of the tidal range is big, a low tidal range causes drowning of the tidal flats. This is due to the small tidal prism, which results in small diffusion coefficients (see sub-section 4.3.2), giving low critical sea-level rises. High tidal ranges give high diffusion coefficient resulting in a high critical sea-level rise and thus less loss of tidal flats and ebb-tidal delta volume.

5.4 Conclusion

It would require disproportional computational effort to take variable area and expansion into account. The extra equations, required to recalculate the area-dependent coefficients every time-step, will increase the computation time of the DIVA-model too much. Therefore the basic ASMITA-model is translated into a system of differential equations which will be solved numerically.

The algorithm itself gives the same results as the ASMITA-model, which confirms the theory. The error of translating the data and the inaccuracy of the data are large, but the algorithm gives the same trend in volume-development. Therefore the algorithm should be used more for a qualitative analysis than for the quantitative results. And the user himself can produce better results by adding more detailed data.

The analysis of the tidal inlets in the world showed that the tidal areas in the tidal range class 1 are drowning fast (before 2100), this is because of the low sediment-import rate as a result of a small tidal prism. The rest of the tidal areas do not differ much from the original situation, but the sea-level rise was still increasing till 2100, so the dynamic equilibrium state is not yet reached. In 2500 the tidal inlets are closer to the dynamic equilibrium state and more tidal areas have been drowned. These areas have a critical sea-level rise that is lower than the 6 mm/y and this is mainly influenced by the size of the area. Large areas need more sediment to compensate the loss due to sea-level rise, and they have therefore a lower critical sea-level rise.

6 Conclusions and Recommendations

6.1 Conclusions

6.1.1 Conclusions data-analysis

The degree of the detail of available global data-sets is not high enough to give information of area and volume of the various elements in the tidal inlet (channels, tidal flats and ebb-tidal delta). Surface of the tidal area, number of inlets, mean tidal range and significant wave height are the useful parameters derived from global data-sets. The data is extended to the required three elements by means of equilibrium relations known from previous studies and available in literature. The coefficients needed in the algorithm are derived from calibrated ASMITA-model-runs with Wadden Sea data-sets. The user will be allowed to change these default input-values in the DIVA-tool. As the user probably has more detailed data available or is able to provide the data needed, the modelling results can be improved .

6.1.2 Conclusions algorithm

It would require disproportional computational effort to take a ‘variable area’ and ‘expansion’ into account. The additional equations, required to recalculate the area-dependent coefficients at every time-step, will increase the computation time of the DIVA-tool too much. Therefore the basic ASMITA-model is translated into a system of differential equations which are solved numerically. Besides that the numerical approach is also required by the time-dependent sea-level rise, received as input from the DIVA-tool.

6.1.3 Conclusions global-analysis

The analysis of the tidal inlets in the world showed that the micro-tidal areas (tidal range class 1) will drown before 2100. This is due to a small tidal prism resulting in a low sediment-import rate . As the sea-level rise is still increasing till 2100, the remainder of the tidal areas will not have reached their dynamic equilibrium state. In 2500 the tidal inlets are closer to their dynamic equilibrium state and more tidal areas will have been drowned. These areas have a critical sea-level rise that is lower than the 6 mm/y and this is mainly influenced by the size of the area. Large areas need more sediment to compensate the lose of volume due to sea-level rise, and therefore they have a lower critical sea-level rise.

6.2 Recommendations

As more data-collecting over the whole world will cost too much (both in terms of money and time), the quality of the estimates of the missing parameters can be improved by improving the equilibrium relations needed for the translation of the data.

An investigation of the influences of climate change to other factors than sea-level rise is advisable. It is to be expected that the wave and storm climate will change and maybe the tide will be influenced also, which will have large influence on the tidal inlet as the tidal range is one of the most important factors in the morphological development of a tidal area.

The coefficients in the model (e.g. dispersion and vertical exchange) are determined by model-runs with the detailed Wadden Sea data. Additional model-runs with data from other areas will improve the accuracy of the coefficients.

The user of the DIVA-tool is recommended to collect the data of the area of interest, in order to generate more accurate predictions. We expect that the local organisations have more detailed data-sets at their disposal.

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Appendices

A Maple

A.1 Maple 2-elements

A.1.1 Maple-solution

Using Maple to simplify the base-equations of the 2-element ASMITA-model to two differential equations gives:

Input:

```
opl1 := solve ({dVf=wsf*Af*(cf-cfe)-Af*SLR, dVc=-wsc*Ac*(cc-cce)+Ac*SLR,
dcf*(cc-cf)=wsf*Af*(cf-cfe), dco*(cE-cc)-dcf*(cc-cf)=wsc*Ac*(cc-cce), cfe=cE*Vfu,
cce=cE*Vcu}, {dVf,dVc,cc,cf,cfe,cce});
```

Output:

opl1 :=

1. $dVc = Ac*SLR + cE*((wsc*dco*dcf + wsc*wsf*Af*dco + wsc*wsf*Af*dcf)*Ac*Vcu - Ac*wsc*wsf*Af*dcf*Vfu - Ac*(wsc*dco*dcf + wsc*wsf*Af*dco))/X$
2. $dVf = -Af*SLR + cE*(Ac*wsc*wsf*Af*dcf*Vcu - (wsf*dco*dcf + wsf*wsc*Ac*dcf)*Af*Vfu + wsf*Af*dcf*dco)/X$

$X = dco*dcf + wsc*Ac*dcf + wsf*Af*dco + wsf*Af*dcf + wsf*Af*wsc*Ac$

$Vfu = (Vf/Vfe)^n$

$Vcu = (Vc/Vce)^{-n}$

A.1.2 Resulting system of differential equations

Above solution from Maple can be written as a system of two differential equations of both volumes:

$$\frac{dV_f}{dt} = A \cdot \left(\frac{V_f}{V_{fe}} \right)^n + B \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + E - A_f \cdot \frac{d\zeta}{dt} \quad (A.1)$$

$$\frac{dV_c}{dt} = C \cdot \left(\frac{V_f}{V_{fe}} \right)^n + D \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + F + A_c \cdot \frac{d\zeta}{dt}$$

where the values in the system-matrix are dependent of the geometric data and the coefficients used in the model:

$$\begin{aligned}
 A &= -w_{sf} \cdot A_f \cdot c_E \cdot d_{cf} \cdot \frac{d}{dt} d_{co} + w_{sc} \cdot A_c \cdot \frac{d}{dt} Y \\
 B &= +w_{sf} \cdot A_f \cdot c_E \cdot d_{cf} \cdot \frac{d}{dt} w_{sc} \cdot A_c \cdot \frac{d}{dt} Y \\
 E &= +w_{sf} \cdot A_f \cdot c_E \cdot d_{cf} \cdot \frac{d}{dt} d_{co} \cdot \frac{d}{dt} Y \\
 C &= -w_{sc} \cdot A_c \cdot c_E \cdot \frac{d}{dt} w_{sf} \cdot A_f \cdot d_{cf} \cdot \frac{d}{dt} Y \\
 D &= +w_{sc} \cdot A_c \cdot c_E \cdot \frac{d}{dt} d_{co} \cdot d_{cf} + w_{sf} \cdot A_f \cdot d_{co} + w_{sf} \cdot A_f \cdot d_{cf} \cdot \frac{d}{dt} Y \\
 F &= -w_{sc} \cdot A_c \cdot c_E \cdot \frac{d}{dt} d_{co} \cdot d_{cf} + w_{sf} \cdot A_f \cdot d_{co} \cdot \frac{d}{dt} Y
 \end{aligned} \tag{A.2}$$

$$\frac{1}{Y} = d_{co} \cdot d_{cf} + w_{sc} \cdot A_c \cdot d_{cf} + w_{sf} \cdot A_f \cdot d_{co} + w_{sf} \cdot A_f \cdot d_{cf} + w_{sf} \cdot A_f \cdot w_{sc} \cdot A_c$$

and as the volume changes are zero in equilibrium situation ($V = V_E$), the matrix have to fulfil two conditions:

$$\begin{aligned}
 A' + B' + E' &= w_{sf} \cdot A_f \cdot c_E \cdot d_{cf} \cdot \left[-\frac{d}{dt} d_{co} + w_{sc} \cdot A_c \cdot \frac{d}{dt} \frac{d}{dt} d_{co} + \frac{d}{dt} w_{sc} \cdot A_c \cdot \frac{d}{dt} d_{co} \right] \cdot Y = 0 \\
 C' + D' + F' &= w_{sc} \cdot A_c \cdot c_E \cdot \left[-\frac{d}{dt} w_{sf} \cdot A_f \cdot d_{cf} + \frac{d}{dt} d_{co} \cdot d_{cf} + w_{sf} \cdot A_f \cdot d_{co} + w_{sf} \cdot A_f \cdot d_{cf} \cdot \frac{d}{dt} d_{co} - w_{sf} \cdot A_f \cdot d_{co} \right] \cdot Y = 0
 \end{aligned} \tag{A.3}$$

Equation (A.3) shows that both conditions are fulfilled.

A.1.3 Dynamic Equilibrium Situation

For the dynamic equilibrium situation both volume changes are zero.

Input:

opl1 := solve ({dVf=wsf*Af*(cf-cfe)-Af*SLR, dVc=-wsc*Ac*(cc-cce)+Ac*SLR, dcf*(cc-cf)=wsf*Af*(cf-cfe), dco*(cE-cc)-dcf*(cc-cf)=wsc*Ac*(cc-cce), cfe=cE*Vfu, cce=cE*Vcu, dVf=0,dVc=0}, {Vfu,Vcu,dVf,dVc,cc,cf,cfe,cce});

Output:

opl1 :=

1. Vfu = -(dcf*dco+wsf*Af*dco+wsf*Af*dcf+wsf*Ac*dcf)/cE/wsf/dcf/dco*SLR+1
2. Vcu = -(dco+wsc*Af+wsc*Ac)/wsc/dco/cE*SLR+1

This can be written as:

$$\begin{aligned}
 V_{fe}^* &= \left[1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f}{\delta_{cf}} + \frac{A_f + A_c}{\delta_{co}} + \frac{1}{w_{sf}} \right)^{\frac{1}{n}} \right] \cdot V_{fe} \\
 V_{ce}^* &= \left[1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f + A_c}{\delta_{co}} + \frac{1}{w_{sc}} \right)^{-\frac{1}{n}} \right] \cdot V_{ce}
 \end{aligned} \tag{A.4}$$

A.2 Maple 3-elements

A.2.1 Maple-solution

Using Maple to simplify the base-equations of the 3-element ASMITA-model to three differential equations gives:

Input:

opl1:=solve ({dVf=wsf*Af*(cf-cfe)-Af*SLR, dVc=-wsc*Ac*(cc-cce)+Ac*SLR,
dVd=wsd*Ad*(cd-cde)-Ad*SLR, dcf*(cc-cf)=wsf*Af*(cf-cfe), dcd*(cd-cc)-dcf*(cc-
cf)=wsc*Ac*(cc-cce), ddo*(cE-cd)-dcd*(cd-cc)=wsd*Ad*(cd-cde), cfe=cE*Vfu,
cce=cE*Vcu, cde=cE*Vdu}, {dVf,dVc,dVd,cc,cf,cd,cfe,cce,cde});

Output:

opl1:=

1. $dVf = -Af*SLR + cE*(-Af*(wsf*wsd*Ad*wsc*Ac*dcf + wsf*ddo*dcd*dcf + wsf*wsd*Ad*dcd*dcf + wsf*dcd*wsc*Ac*dcf + wsf*ddo*wsc*Ac*dcf)*Vfu - Af*(-wsf*wsd*Ad*wsc*Ac*dcf - wsf*ddo*wsc*Ac*dcf - wsf*dcd*wsc*Ac*dcf)*Vcu + Af*wsf*wsd*Ad*dcd*dcf*Vdu + Af*wsf*ddo*dcd*dcf)/X$
2. $dVc = Ac*SLR + cE*(Ac*(-wsc*wsd*Ad*wsf*Af*dcf - wsc*dcd*wsf*Af*dcf - wsc*ddo*wsf*Af*dcf)*Vfu + Ac*(wsc*ddo*dcd*wsf*Af + wsc*wsd*Ad*dcd*wsf*Af + wsc*wsd*Ad*wsf*Af*dcf + wsc*dcd*wsf*Af*dcf + wsc*ddo*wsf*Af*dcf + wsc*wsd*Ad*dcd*dcf + wsc*ddo*dcd*dcf)*Vcu + Ac*(-wsc*wsd*Ad*dcd*wsf*Af - wsc*wsd*Ad*dcd*dcf)*Vdu + Ac*(-wsc*ddo*dcd*dcf - wsc*ddo*dcd*wsf*Af))/X$
3. $dVd = -Ad*SLR + cE*(Af*wsf*wsd*Ad*dcd*dcf*Vfu - Ad*(-wsd*dcd*wsc*Ac*dcf - wsd*dcd*wsf*Af*wsc*Ac)*Vcu - Ad*(wsd*dcd*wsf*Af*dcf + wsd*ddo*wsc*Ac*wsf*Af + wsd*ddo*dcd*wsf*Af + wsd*ddo*wsf*Af*dcf + wsd*ddo*dcd*dcf + wsd*dcd*wsf*Af*wsc*Ac + wsd*dcd*wsc*Ac*dcf + wsd*ddo*wsc*Ac*dcf)*Vdu - Ad*(-wsd*ddo*wsc*Ac*dcf - wsd*ddo*wsc*Ac*wsf*Af - wsd*ddo*dcd*dcf - wsd*ddo*wsf*Af*dcf - wsd*ddo*dcd*wsf*Af))/X$

$$X = ddo*wsc*Ac*wsf*Af + dcd*wsc*Ac*wsf*Af + ddo*dcd*wsf*Af + ddo*wsf*Af*dcf + wsd*Ad*dcd*wsf*Af + wsd*Ad*wsf*Af*dcf + wsd*Ad*wsc*Ac*dcf + wsd*Ad*wsc*Ac*wsf*Af + dcd*wsf*Af*dcf + dcd*wsc*Ac*dcf + ddo*dcd*dcf + wsd*Ad*dcd*dcf + ddo*wsc*Ac*dcf$$

$$Vfu = (Vf/Vfe)^n$$

$$Vcu = (Vc/Vce)^{-n}$$

$$Vdu = (Vd/Vde)^n$$

A.2.2 Resulting system of differential equations

The Maple-solution can be written as a system of three differential equations:

$$\begin{aligned}
 \frac{dV_f}{dt} &= A \cdot \left(\frac{V_f}{V_{fe}} \right)^n + B \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + C \cdot \left(\frac{V_d}{V_{de}} \right)^n + J - A_f \cdot \frac{d\zeta}{dt} \\
 \frac{dV_c}{dt} &= D \cdot \left(\frac{V_f}{V_{fe}} \right)^n + E \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + F \cdot \left(\frac{V_d}{V_{de}} \right)^n + K + A_c \cdot \frac{d\zeta}{dt} \\
 \frac{dV_d}{dt} &= G \cdot \left(\frac{V_f}{V_{fe}} \right)^n + H \cdot \left(\frac{V_c}{V_{ce}} \right)^{-n} + I \cdot \left(\frac{V_d}{V_{de}} \right)^n + L - A_d \cdot \frac{d\zeta}{dt}
 \end{aligned} \tag{A.5}$$

A.2.3 Dynamic Equilibrium Situation

The dynamic equilibrium situation can be computed with addition that the volume changes are zero.

Input:

```

opl1:=solve({dVf=wsf*Af*(cf-cfe)-Af*SLR, dVc=-wsc*Ac*(cc-cce)+Ac*SLR,
dVd=wsd*Ad*(cd-cde)-Ad*SLR, dcf*(cc-cf)=wsf*Af*(cf-cfe), dcd*(cd-cc)-dcf*(cc-
cf)=wsc*Ac*(cc-cce), ddo*(cE-cd)-dcd*(cd-cc)=wsd*Ad*(cd-cde), cfe=cE*Vfu,
cce=cE*Vcu, cde=cE*Vdu, dVf=0,dVc=0,dVd=0},
{Vfu,Vcu,Vdu,dVf,dVc,dVd,cc,cf,cd,cfe,cce,cde});

```

Output:

1. $V_{fu} = -(dcd*wsf*Af*dcf+wsf*dcf*dcd*Ac+wsf*dcf*dcd*Ad+ddo*wsf*Af*dcf+wsf*dcf*Ac*ddo+ddo*dcd*wsf*Af+ddo*dcd*dcf)/wsf/cE/ddo/dcd/dcf*SLR+1$
2. $V_{cu} = -(wsc*dcd*Af+wsc*dcd*Ac+wsc*dcd*Ad+wsc*Af*ddo+wsc*Ac*ddo+ddo*dcd)/wsc/dcd/ddo/cE*SLR+1$
3. $V_{du} = -(wsd*Af+wsd*Ac+wsd*Ad+ddo)/wsd/ddo/cE*SLR+1$

The dynamic equilibrium situation can thus be written as:

$$\begin{aligned}
 V_{fe}^* &= \left(1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f}{\delta_{cf}} + \frac{A_f + A_c}{\delta_{cd}} + \frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sf}} \right)^{\frac{1}{n}} \right) \cdot V_{fe} \\
 V_{ce}^* &= \left(1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f + A_c}{\delta_{co}} + \frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sc}} \right)^{-\frac{1}{n}} \right) \cdot V_{ce} \\
 V_{de}^* &= \left(1 - \frac{d\zeta}{dt} \cdot \frac{1}{c_E} \cdot \left(\frac{A_f + A_c + A_d}{\delta_{do}} + \frac{1}{w_{sd}} \right)^{\frac{1}{n}} \right) \cdot V_{de}
 \end{aligned} \tag{A.6}$$

B Data from Wadden Sea

This Appendix contains the measured data-sets from the Wadden Sea. This data-sets are used to verify the results of the data-collection and the results of the algorithm, as this data-set contains detailed enough data that it can be used in the 3-element ASMITA-model.

Table B-1: Data-sets of the Wadden Sea

code	system		year	nodata	MHW	MLW	getijslag	Vmhw	Prism	Vmlw	Amhw	Vc,mlw	Vf,mlw	Af
vo3310	10	marsdiep	1933	0	0.62	-0.92	1.54	3.18E+09	9.12E+08	2.27E+09	6.12E+08	2.27E+09	3.07E+07	1.15E+08
vo4810	10		1948	0	0.66	-0.90	1.56	3.18E+09	9.74E+08	2.21E+09	6.40E+08	2.21E+09	2.59E+07	9.82E+07
vo7110	10		1971	0	0.71	-0.88	1.59	3.18E+09	9.96E+08	2.18E+09	6.55E+08	2.18E+09	4.68E+07	1.25E+08
vo7510	10		1975	0	0.72	-0.88	1.60	3.16E+09	9.99E+08	2.17E+09	6.57E+08	2.17E+09	5.03E+07	1.29E+08
vo8110	10		1981	0	0.74	-0.87	1.61	3.23E+09	1.01E+09	2.22E+09	6.56E+08	2.22E+09	4.08E+07	1.21E+08
mean last 3					0.72	-0.88	1.60	3.19E+09	1.00E+09	2.19E+09	6.56E+08	2.19E+09	4.60E+07	1.25E+08
marsdiep	year	Ach	Af+nod	Af/Ab	Ad	Vd	code	Vmhw	Prism	Vmlw	Amhw	Af	Afc	Af/Ab
	1933	4.97E+08	1.15E+08	0.19		6.50E+08	vo3310	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1948	5.42E+08	9.82E+07	0.15		6.02E+08	vo4810	1.00	1.07	0.97	1.05	0.86	0.86	0.82
	1971	5.30E+08	1.25E+08	0.19		5.09E+08	vo7110	1.00	1.09	0.96	1.07	1.09	1.09	1.02
	1975	5.29E+08	1.29E+08	0.20			vo7510	1.00	1.09	0.96	1.07	1.12	1.12	1.04
	1981	5.36E+08	1.21E+08	0.18	1.31E+08	4.89E+08	vo8110	1.02	1.11	0.98	1.07	1.05	1.05	0.98
mean last 3		5.31E+08		0.19		4.99E+08								
code	system		year	nodata	MHW	MLW	getijslag	Vmhw	Prism	Vmlw	Amhw	Vc,mlw	Vf,mlw	Af
vo3420	20	eijerlandsche gat	1934	0	0.62	-0.92	1.54	2.85E+08	2.07E+08	7.85E+07	1.64E+08	7.85E+07	4.64E+07	1.13E+08
vo4920	20		1949	0	0.66	-0.90	1.56	2.89E+08	2.00E+08	8.82E+07	1.54E+08	8.82E+07	4.10E+07	9.72E+07
vo7120	20		1971	0	0.71	-0.88	1.59	2.93E+08	1.89E+08	1.04E+08	1.52E+08	1.04E+08	5.33E+07	1.01E+08
vo7620	20		1976	0	0.72	-0.88	1.60	3.05E+08	2.01E+08	1.04E+08	1.62E+08	1.04E+08	5.75E+07	1.09E+08
vo8220	20		1982	0	0.74	-0.87	1.61	3.14E+08	2.03E+08	1.11E+08	1.60E+08	1.11E+08	5.42E+07	1.06E+08
mean last 3					0.72	-0.88	1.60	3.04E+08	1.97E+08	1.06E+08	1.58E+08	1.06E+08	5.50E+07	1.05E+08
eijerlandsche gat	year	Ach	Af+nod	Af/Ab	Ad	Vd	code	Vmhw	Prism	Vmlw	Amhw	Af	Afc	Af/Ab
	1934	5.12E+07	1.13E+08	0.69	3.78E+07	1.11E+08	vo3420	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1949	5.72E+07	9.72E+07	0.63	3.78E+07		vo4920	1.01	0.97	1.12	0.94	0.86	0.86	0.91
	1971	5.11E+07	1.01E+08	0.66	3.78E+07	1.28E+08	vo7120	1.03	0.91	1.33	0.93	0.89	0.89	0.96
	1976	5.26E+07	1.09E+08	0.67	3.78E+07	1.33E+08	vo7620	1.07	0.97	1.33	0.98	0.96	0.96	0.98
	1982	5.43E+07	1.06E+08	0.66	3.78E+07	1.35E+08	vo8220	1.10	0.98	1.41	0.97	0.94	0.94	0.96
mean last 3		5.27E+07		0.67	3.78E+07	1.32E+08								

code	system		year	nodata	MHW	MLW	getijslag	Vmhw	Prism	Vmlw	Amhw	Vc,mlw	Vf,mlw	Af
vo3330	30	vlie	1933	0	0.71	-1.00	1.71	2.53E+09	1.15E+09	1.38E+09	7.40E+08	1.38E+09	1.14E+08	2.64E+08
vo5130	30		1951	0	0.75	-1.01	1.77	2.41E+09	1.12E+09	1.29E+09	7.15E+08	1.29E+09	1.39E+08	2.66E+08
vo7230	30		1972	0	0.80	-1.04	1.84	2.40E+09	1.16E+09	1.24E+09	7.15E+08	1.24E+09	1.54E+08	3.21E+08
vo7730	30		1977	0	0.81	-1.04	1.85	2.38E+09	1.15E+09	1.23E+09	7.13E+08	1.23E+09	1.67E+08	3.34E+08
vo8330	30		1983	0	0.83	-1.05	1.87	2.44E+09	1.18E+09	1.26E+09	7.19E+08	1.26E+09	1.65E+08	3.23E+08
mean last 3					0.81	-1.04	1.85	2.41E+09	1.16E+09	1.24E+09	7.16E+08	1.24E+09	1.62E+08	3.26E+08
vlie	year	Ach	Af+nod	Af/Ab			code	Vmhw	Prism	Vmlw	Amhw	Af	Afc	Af/Ab
	1933	4.76E+08	2.64E+08	0.36		4.16E+08	vo3330	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1951	4.50E+08	2.66E+08	0.37			vo5130	0.95	0.98	0.93	0.97	1.01	1.01	1.04
	1972	3.94E+08	3.21E+08	0.45		3.70E+08	vo7230	0.95	1.01	0.90	0.97	1.22	1.22	1.26
	1977	3.79E+08	3.34E+08	0.47		3.63E+08	vo7730	0.94	1.00	0.89	0.96	1.26	1.26	1.31
	1983	3.96E+08	3.23E+08	0.45	1.70E+08	3.55E+08	vo8330	0.96	1.03	0.91	0.97	1.23	1.23	1.26
mean last 3		3.89E+08		0.46		3.63E+08								

code	system		year	nodata	MHW	MLW	getijslag	Vmhw	Prism	Vmlw	Amhw	Vc,mlw	Vf,mlw	Af
vo2640	40	borndiep	1926	0	0.76	-1.28	2.04	7.16E+08	4.30E+08	2.87E+08	2.70E+08	2.87E+08	1.20E+08	1.75E+08
vo5040	40		1950	0	0.84	-1.25	2.08	7.65E+08	4.56E+08	3.09E+08	2.84E+08	3.09E+08	1.36E+08	1.81E+08
vo7340	40		1973	0	0.91	-1.22	2.13	7.69E+08	4.61E+08	3.07E+08	2.78E+08	3.07E+08	1.29E+08	1.83E+08
vo7840	40		1978	0	0.93	-1.21	2.14	7.65E+08	4.65E+08	3.00E+08	2.76E+08	3.00E+08	1.26E+08	1.80E+08
vo8440	40		1984	0	0.95	-1.20	2.15	7.68E+08	4.70E+08	2.98E+08	2.69E+08	2.98E+08	1.07E+08	1.65E+08
mean last 3					0.93	-1.21	2.14	7.67E+08	4.66E+08	3.02E+08	2.74E+08	3.02E+08	1.20E+08	1.76E+08
borndiep	year	Ach	Af+nod	Af/Ab	Ad	Vd	code	Vmhw	Prism	Vmlw	Amhw	Af	Afc	Af/Ab
	1926	9.52E+07	1.75E+08	0.65	7.47E+07	1.14E+08	vo2640	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1950	1.03E+08	1.81E+08	0.64	7.47E+07	1.63E+08	vo5040	1.07	1.06	1.08	1.05	1.04	1.04	0.98
	1973	9.49E+07	1.83E+08	0.66	7.47E+07		vo7340	1.07	1.07	1.07	1.03	1.05	1.05	1.02
	1978	9.69E+07	1.80E+08	0.65	7.47E+07	1.41E+08	vo7840	1.07	1.08	1.05	1.02	1.03	1.03	1.00
	1984	1.03E+08	1.65E+08	0.62	7.47E+07	1.21E+08	vo8440	1.07	1.09	1.04	1.00	0.95	0.95	0.95
mean last 3		9.83E+07		0.64	7.47E+07	1.31E+08								

code	system		year	nodata	MHW	MLW	getijslag	Vmhw	Prism	Vmlw	Amhw	Vc,mlw	Vf,mlw	Af
vo2750a	50	pinkegat	1927	0	0.87	-1.36	2.23	1.52E+08	1.10E+08	4.21E+07	5.97E+07	4.21E+07	2.30E+07	3.67E+07
vo4950a	50		1949	0	0.90	-1.33	2.23	1.18E+08	8.97E+07	2.83E+07	5.38E+07	2.83E+07	3.06E+07	3.67E+07
vo5750a	50		1957	0	0.91	-1.32	2.23	1.15E+08	9.13E+07	2.34E+07	5.61E+07	2.34E+07	3.41E+07	4.18E+07
vo6750a	50		1967	8.10E+03	0.93	-1.31	2.23	1.17E+08	9.82E+07	1.85E+07	5.85E+07	1.85E+07	3.25E+07	4.14E+07
vo7050a	50		1970	3.75E+03	0.93	-1.30	2.23	9.98E+07	8.13E+07	1.85E+07	4.96E+07	1.85E+07	2.96E+07	3.81E+07
vo7550a	50		1975	0	0.94	-1.30	2.23	9.46E+07	7.91E+07	1.55E+07	4.84E+07	1.55E+07	2.91E+07	3.64E+07
vo7950a	50		1979	0	0.95	-1.29	2.24	9.60E+07	7.99E+07	1.61E+07	4.72E+07	1.61E+07	2.56E+07	3.48E+07
vo8250a	50		1982	4.08E+05	0.95	-1.29	2.23	9.80E+07	7.95E+07	1.85E+07	4.84E+07	1.85E+07	2.87E+07	3.81E+07
vo8750a	50		1987	7.50E+03	0.96	-1.28	2.23	9.33E+07	7.64E+07	1.70E+07	4.77E+07	1.70E+07	3.03E+07	3.78E+07
mean last 3					0.95	-1.28	2.23	9.58E+07	7.86E+07	1.72E+07	4.78E+07	1.72E+07	2.82E+07	3.69E+07
pinkegat	year	Ach	Af+nod	Af/Ab	Ad		code	Vmhw	Prism	Vmlw	Amhw	Af	Afc	Af/Ab
	1927	2.30E+07	3.67E+07	0.61			vo2750a	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1949	1.72E+07	3.67E+07	0.68			vo4950a	0.05	0.08	0.02	0.08	0.11	0.11	1.11
	1957	1.44E+07	4.18E+07	0.74			vo5750a	0.05	0.08	0.02	0.08	0.13	0.13	1.21
	1967	1.72E+07	4.14E+07	0.71			vo6750a	0.05	0.09	0.02	0.08	0.12	0.12	1.15
	1970	1.15E+07	3.81E+07	0.77			vo7050a	0.04	0.07	0.02	0.07	0.11	0.11	1.25
	1975	1.21E+07	3.64E+07	0.75			vo7550a	0.04	0.07	0.01	0.07	0.11	0.11	1.22
	1979	1.24E+07	3.48E+07	0.74			vo7950a	0.04	0.07	0.01	0.07	0.10	0.10	1.20
	1982	1.04E+07	3.85E+07	0.79			vo8250a	0.04	0.07	0.02	0.07	0.11	0.12	1.28
	1987	9.89E+06	3.78E+07	0.79			vo8750a	0.04	0.07	0.01	0.07	0.11	0.11	1.29
mean last 3		1.09E+07		0.77										

code	system		year 1979	nodata	MHW	MLW	getijslag	Vmhw	Prism	Vmlw	Amhw	Vc,mlw	Vf,mlw	Af
vo2760a	60	zoutkamper- laag	1927	0	0.94	-1.51	2.45	5.51E+08	3.41E+08	2.09E+08	2.18E+08	2.09E+08	1.92E+08	1.59E+08
vo4960a	60		1949	0	0.97	-1.43	2.40	5.35E+08	3.16E+08	2.19E+08	2.14E+08	2.19E+08	1.96E+08	1.56E+08
vo5760a	60	actual boundaries	1957	1.05E+05	0.98	-1.40	2.38	5.48E+08	3.18E+08	2.30E+08	2.04E+08	2.30E+08	1.67E+08	1.46E+08
vo6760a	60		1967	8.10E+03	0.99	-1.37	2.36	5.47E+08	3.21E+08	2.26E+08	2.08E+08	2.26E+08	1.71E+08	1.51E+08
vo7060a	60		1970	6.38E+05	0.94	-1.33	2.28	3.51E+08	1.78E+08	1.73E+08	1.09E+08	1.73E+08	7.05E+07	7.17E+07
vo7560a	60		1975	1.36E+06	0.95	-1.32	2.27	3.45E+08	1.85E+08	1.61E+08	1.12E+08	1.61E+08	6.92E+07	6.98E+07
vo7960a	60		1979	1.65E+06	0.96	-1.30	2.26	3.38E+08	1.85E+08	1.53E+08	1.12E+08	1.53E+08	6.71E+07	6.99E+07
vo8260a	60		1982	3.13E+06	0.96	-1.29	2.25	3.43E+08	1.88E+08	1.55E+08	1.16E+08	1.55E+08	7.41E+07	7.61E+07
vo8760a	60		1987	3.38E+06	0.96	-1.28	2.24	3.43E+08	1.91E+08	1.52E+08	1.19E+08	1.52E+08	7.62E+07	7.83E+07
mean last 3					0.96	-1.29	2.25	3.41E+08	1.88E+08	1.53E+08	1.16E+08	1.53E+08	6.41E+07	7.48E+07
zoutkamper- laag actual boundaries	year 1979	Ach	Af+nod	Af/Ab	Ad	Vd	code	Vmhw	Prism	Vmlw	Amhw	Af	Afc	Af/Ab
	1927	5.86E+07	1.59E+08	0.73			vo2760a	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1949	5.79E+07	1.56E+08	0.73			vo4960a	0.70	0.68	0.73	0.77	0.87	0.87	1.00
	1957	5.81E+07	1.46E+08	0.71			vo5760a	0.72	0.68	0.77	0.74	0.81	0.81	0.98
	1967	5.71E+07	1.51E+08	0.73			vo6760a	0.71	0.69	0.75	0.75	0.84	0.84	0.99
	1970	3.74E+07	7.23E+07	0.66	7.80E+07	1.45E+08	vo7060a	0.46	0.38	0.58	0.39	0.40	0.40	0.90
	1975	4.22E+07	7.12E+07	0.62	7.80E+07	1.35E+08	vo7560a	0.45	0.40	0.54	0.41	0.39	0.40	0.85
	1979	4.17E+07	7.16E+07	0.63	7.80E+07	1.36E+08	vo7960a	0.44	0.40	0.51	0.40	0.39	0.40	0.86
	1982	4.02E+07	7.93E+07	0.65	7.80E+07	1.26E+08	vo8260a	0.45	0.40	0.52	0.42	0.42	0.44	0.90
	1987	4.12E+07	8.16E+07	0.66	7.80E+07	1.19E+08	vo8760a	0.45	0.41	0.51	0.43	0.44	0.45	0.90
mean last 3		4.10E+07		0.65										

code	system		year	nodata	MHW	MLW	getijslag	Vmhw	Prism	Vmlw	Amhw	Vc,mlw	Vf,mlw	Af
vor2760a	60	zoutkamper- laag	1927	0	0.94	-1.51	2.45	5.35E+08	3.26E+08	2.09E+08	2.05E+08	2.09E+08	1.75E+08	1.47E+08
vor4960a	60		1949	0	0.97	-1.43	2.40	5.20E+08	3.01E+08	2.19E+08	2.01E+08	2.19E+08	1.81E+08	1.43E+08
vor5760a	60		1957	0	0.98	-1.40	2.38	5.43E+08	3.14E+08	2.30E+08	1.98E+08	2.30E+08	1.59E+08	1.40E+08
vor6760a	60	fixed boundaries	1967	0	0.99	-1.37	2.36	5.32E+08	3.06E+08	2.26E+08	1.97E+08	2.26E+08	1.59E+08	1.40E+08
vor7060a	60		1970	6.40E+05	0.94	-1.33	2.28	3.48E+08	1.75E+08	1.73E+08	1.07E+08	1.73E+08	6.78E+07	6.92E+07
vor7560a	60		1975	5.21E+05	0.95	-1.32	2.27	3.38E+08	1.78E+08	1.60E+08	1.06E+08	1.60E+08	6.35E+07	6.41E+07
vor7960a	60		1979	5.67E+05	0.96	-1.30	2.26	3.31E+08	1.78E+08	1.53E+08	1.06E+08	1.53E+08	6.17E+07	6.46E+07
vor8260a	60		1982	3.43E+05	0.96	-1.29	2.25	3.27E+08	1.73E+08	1.55E+08	1.06E+08	1.55E+08	6.48E+07	6.63E+07
vor8760a	60		1987	6.55E+05	0.96	-1.28	2.24	3.23E+08	1.72E+08	1.51E+08	1.05E+08	1.51E+08	6.32E+07	6.51E+07
mean last 3					0.96	-1.29	2.25	3.27E+08	1.74E+08	1.53E+08	1.06E+08	1.53E+08	6.50E+07	6.53E+07
zoutkamper- laag fixed boundaries	year	Ach	Af+nod	Af/Ab	Ad	Vd	code	Vmhw	Prism	Vmlw	Amhw	Af	Afc	Af/Ab
	1927	5.80E+07	1.47E+08	0.72			vor2760a	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	1949	5.78E+07	1.43E+08	0.71			vor4960a	0.97	0.92	1.05	0.98	0.97	1.00	0.99
	1957	5.81E+07	1.40E+08	0.71			vor5760a	1.02	0.96	1.10	0.97	0.96	0.98	0.99
	1967	5.68E+07	1.40E+08	0.71			vor6760a	0.99	0.94	1.08	0.96	0.96	0.98	0.99
	1970	3.73E+07	6.99E+07	0.65	7.80E+07	1.45E+08	vor7060a	0.65	0.54	0.83	0.52	0.47	0.49	0.91
	1975	4.22E+07	6.47E+07	0.60	7.80E+07	1.35E+08	vor7560a	0.63	0.54	0.77	0.52	0.44	0.45	0.84
	1979	4.16E+07	6.51E+07	0.61	7.80E+07	1.36E+08	vor7960a	0.62	0.55	0.73	0.52	0.44	0.46	0.85
	1982	3.92E+07	6.67E+07	0.63	7.80E+07	1.26E+08	vor8260a	0.61	0.53	0.74	0.52	0.45	0.47	0.88
	1987	4.00E+07	6.57E+07	0.62	7.80E+07	1.19E+08	vor8760a	0.60	0.53	0.72	0.51	0.44	0.46	0.86
mean last 3		4.02E+07		0.62										

C Algorithm

This appendix describes the algorithm. The algorithm will exist of a system of 3 differential equations (function of volume in time), which will be solved numerically:

$$\begin{pmatrix} dV_f/dt \\ dV_c/dt \\ dV_d/dt \end{pmatrix} = \begin{pmatrix} M_1 & M_2 & M_3 \\ M_5 & M_6 & M_7 \\ M_9 & M_{10} & M_{11} \end{pmatrix} \cdot \begin{pmatrix} \frac{V_f b_t - 1}{V_{fe}} \\ \frac{V_c b_t - 1}{V_{ce}} \\ \frac{V_d b_t - 1}{V_{de}} \end{pmatrix} + \begin{pmatrix} M_4 \\ M_8 \\ M_{12} \end{pmatrix} \cdot \Delta t + \Delta \zeta \cdot \begin{pmatrix} -A_f \\ A_c \\ -A_d \end{pmatrix} \quad (C.1)$$

with the values of the system-matrix M dependent of w_{si} , δ_{ij} and A_i :

Table C-1: Values of the coefficients in system-matrix

$M1 = -wAf * cE * dcf / X * (ddo * dcd + dcd * wAc + ddo * wAc + wAd * dcd + wAd * wAc)$
$M2 = wAf * cE * dcf / X * (dcd * wAc + wAc * ddo + wAc * wAd)$
$M3 = wAf * cE * dcf / X * (wAd * dcd)$
$M4 = wAf * cE * dcf / X * (ddo * dcd)$
$M5 = -wAc * cE / X * (dcd * dcf * wAf + wAf * ddo * dcf + wAf * wAd * dcf)$
$M6 = wAc * cE / X * (ddo * dcd * wAf + wAd * dcd * wAf + wAd * dcd * dcf + ddo * dcd * dcf + dcd * dcf * wAf + ddo * dcf * wAf + wAd * dcf * wAf)$
$M7 = -wAc * cE / X * (wAd * dcd * dcf + wAd * dcd * wAf)$
$M8 = -wAc * cE / X * (ddo * dcd * dcf + ddo * dcd * wAf)$
$M9 = wAd * cE / X * (dcd * dcf * wAf)$
$M10 = wAd * cE / X * (dcd * wAf * wAc + dcd * dcf * wAc)$
$M11 = -wAd * cE / X * (dcd * wAf * wAc + dcd * dcf * wAc + dcd * dcf * wAf + ddo * dcf * wAf + wAc * ddo * dcf + wAc * ddo * wAf + ddo * dcd * dcf + ddo * dcd * wAf)$
$M12 = wAd * cE / X * (ddo * dcd * dcf + ddo * dcd * wAf + wAc * ddo * dcf + ddo * dcf * wAf + wAc * ddo * wAf)$

with the help-variables:

Table C-2: Help-variables of coefficients in system-matrix

$wAf = wsf * Af$
$wAc = wsc * Ac$
$wAd = wsd * Ad$
$X = dcd * wAf * wAc + wAd * dcd * dcf + wAd * wAc * wAf + wAd * wAc * dcf + wAd * dcf * wAf + wAd * dcd * wAf + dcd * dcf * wAf + dcd * dcf * wAc + wAc * ddo * dcf + wAc * ddo * wAf + ddo * dcf * wAf + ddo * dcd * dcf + ddo * dcd * wAf$

For each time-step the new volumes have to be calculated:

$$V_i b_{t+g} = V_i b_t - 1 + dV_i b_{t+g} \quad (C.2)$$

The new volumes will be used to calculate the volume changes next time-step. This procedure will be done for all time-steps.

Table C-3: Results of the algorithm for all tidal areas in the world in 2100 AD

nr.	Name	First Country	Wet Area [m ²]	nr. Inlets [-]	Wave Height [m]	Tidal Class [-]	Critical SLR [mm/y]	V _d /V _{de} [-]	V _c /V _{ce} [-]	V _f /V _{fe} [-]	Land Loss [m ²]	Sand from Coast [m ³]	Suppletion needed [m ³]
1	tidra	mauratania	2.34E+08	2	2	3	21.37	0.919	1.070	0.900	1.70E+07	7.18E+07	7.53E+07
2	timiris	mauratania	2.75E+08	1	2	3	17.09	0.939	1.059	0.895	1.69E+07	5.18E+07	1.03E+08
3	saloum	senegal	1.92E+08	3	2	3	24.54	0.909	1.075	0.904	1.48E+07	7.90E+07	5.50E+07
4	gambia	gambia	7.83E+08	1	2	3	12.65	0.965	1.039	0.885	2.71E+07	7.02E+07	3.29E+08
5	casamance	senegal	6.04E+08	1	2	3	13.65	0.959	1.044	0.888	2.61E+07	6.60E+07	2.49E+08
6	cacheu	guinee-bassau	2.34E+08	1	2	3	17.86	0.935	1.061	0.896	1.50E+07	4.87E+07	8.52E+07
7	monsoa	guinee-bassau	5.50E+08	3	2	3	19.06	0.929	1.065	0.897	3.73E+07	1.32E+08	1.92E+08
8	corubal	guinee-bassau	1.40E+09	2	2	3	13.07	0.963	1.041	0.886	5.39E+07	1.37E+08	5.84E+08
9	cacine	guinea	7.56E+08	2	2	3	11.63	0.935	1.082	0.845	6.04E+07	1.24E+08	2.71E+08
10	nunez	guinea	7.56E+08	3	2	2	8.28	0.897	1.169	0.735	1.21E+08	1.67E+08	2.19E+08
11	pongo	guinea	4.53E+08	3	2	2	9.72	0.883	1.176	0.754	7.74E+07	1.27E+08	1.16E+08
12	sangarea	guinea	2.89E+08	2	2	2	9.85	0.882	1.177	0.755	4.94E+07	8.25E+07	7.28E+07
13	freetown	sierra leone	7.56E+08	1	2	2	5.81	0.936	1.128	0.696	7.19E+07	8.97E+07	2.69E+08
14	bonthe	sierra leone	6.59E+08	2	2	2	7.60	0.906	1.161	0.726	9.87E+07	1.27E+08	2.03E+08
15	lagos	nigeria	2.47E+08	1	3	2	8.33	0.896	1.169	0.736	3.96E+07	5.53E+07	7.13E+07
16	forcados	nigeria	2.89E+08	1	3	2	7.94	0.901	1.165	0.731	4.47E+07	5.97E+07	8.62E+07
17	niger1	nigeria	3.16E+08	2	3	2	9.58	0.884	1.176	0.752	5.37E+07	8.69E+07	8.17E+07
18	niger2	nigeria	2.61E+08	2	3	2	10.16	0.880	1.177	0.759	4.49E+07	7.78E+07	6.42E+07
19	niger3	nigeria	5.50E+08	2	3	2	8.06	0.900	1.166	0.732	8.62E+07	1.17E+08	1.62E+08
20	cross	nigeria	1.84E+09	2	3	3	8.85	0.961	1.058	0.828	7.65E+07	1.63E+08	7.37E+08
21	wouri	cameroon	1.99E+09	1	2	3	9.08	0.981	1.025	0.863	2.72E+07	8.28E+07	8.68E+08
22	muni	equatorial guinee	1.87E+09	1	2	3	9.33	0.981	1.026	0.865	2.52E+07	8.21E+07	8.13E+08
23	gabon	gabon	1.52E+09	1	2	3	10.16	0.978	1.029	0.871	1.97E+07	7.96E+07	6.62E+08
24	zaire	zaire	7.42E+08	1	2	2	5.85	0.935	1.129	0.697	7.18E+07	8.91E+07	2.64E+08
25	FALSE	south africa	1.17E+09	1	4	2	5.04	0.946	1.109	0.675	5.52E+07	1.08E+08	4.35E+08
26	inhambane	mozambique	1.10E+08	1	1	3	21.69	0.923	1.070	0.902	7.96E+06	3.30E+07	3.68E+07
27	bazaruto	mozambique	3.30E+08	2	1	3	19.59	0.933	1.065	0.899	2.25E+07	7.94E+07	1.18E+08
28	beira	mozambique	2.61E+08	1	1	4	30.15	0.963	1.024	0.949	7.94E+06	4.24E+07	1.23E+08

29	antonio_enes	mozambique	1.92E+08	2	3	4	37.00	0.936	1.033	0.948	7.59E+06	6.48E+07	7.95E+07
30	masirah	oman	1.13E+09	2	2	3	13.94	0.957	1.045	0.889	5.09E+07	1.30E+08	4.61E+08
31	ghubbat	oman	6.59E+08	1	2	3	13.31	0.961	1.042	0.887	2.67E+07	6.74E+07	2.74E+08
32	khorr_al_uheid	united arab emirates	2.06E+08	1	1	3	18.47	0.938	1.062	0.898	1.35E+07	4.36E+07	7.64E+07
33	bahrein	bahrein	9.88E+09	2	1	3	6.12	0.992	1.017	0.835	1.63E+08	1.77E+08	4.30E+09
34	al_kuwait	kuwait	5.22E+08	1	1	4	25.51	0.976	1.018	0.947	1.19E+07	4.98E+07	2.52E+08
35	umm_qasr	iraq	9.07E+08	2	1	4	26.43	0.974	1.019	0.948	2.23E+07	9.70E+07	4.35E+08
36	qeshm	iran	1.48E+09	2	1	3	12.85	0.971	1.040	0.886	5.41E+07	1.30E+08	6.30E+08
37	miani_hor	pakistan	7.01E+08	1	3	3	13.07	0.963	1.041	0.886	2.70E+07	6.84E+07	2.92E+08
38	kori_kreek	india	9.89E+08	2	3	5	25.86	0.970	1.019	0.947	2.34E+07	1.07E+08	4.68E+08
39	kutch	india	7.47E+09	1	3	5	14.11	0.996	1.003	0.942	4.37E+07	6.17E+07	3.46E+09
40	mutur	sri lanka	1.92E+08	1	2	2	9.02	0.889	1.174	0.745	3.21E+07	4.84E+07	5.22E+07
41	jaffina	sri lanka	5.91E+08	2	2	2	7.88	0.902	1.164	0.730	9.10E+07	1.21E+08	1.77E+08
42	phuket	thailand	1.80E+09	3	2	3	10.10	0.949	1.070	0.837	1.14E+08	2.17E+08	6.89E+08
43	da_nang	vietnam	6.87E+07	2	2	2	14.76	0.861	1.167	0.810	1.11E+07	3.30E+07	1.18E+07
44	hue	vietnam	1.92E+08	2	2	2	11.13	0.874	1.177	0.771	3.33E+07	6.47E+07	4.36E+07
45	ca_ba	vietnam	1.33E+09	2	2	2	6.06	0.931	1.134	0.701	1.41E+08	1.71E+08	4.66E+08
46	chin_chou_wan	china	4.40E+08	1	2	2	6.93	0.916	1.151	0.716	5.94E+07	7.24E+07	1.43E+08
47	anpu	china	2.84E+09	1	2	3	5.66	0.981	1.036	0.787	6.05E+07	1.01E+08	1.20E+09
48	deep_bay	china	2.62E+09	1	2	3	8.07	0.984	1.023	0.855	3.81E+07	8.59E+07	1.14E+09
49	nagoya	japan	3.17E+09	1	2	3	5.39	0.982	1.034	0.782	6.91E+07	1.02E+08	1.34E+09
50	shizuoka	japan	3.05E+09	1	3	2	3.33	0.973	1.075	0.614	1.18E+08	1.26E+08	1.23E+09
51	tokyo	japan	2.23E+09	1	3	2	3.83	0.967	1.085	0.636	8.11E+07	1.20E+08	8.83E+08
52	kritappu	japan	2.75E+08	1	5	2	8.06	0.895	1.168	0.731	4.32E+07	5.97E+07	7.98E+07
53	tokoro	japan	5.22E+08	2	5	2	8.19	0.894	1.169	0.733	8.31E+07	1.16E+08	1.50E+08
54	moskalvo	japan	1.50E+09	2	2	2	5.83	0.935	1.129	0.696	1.44E+08	1.79E+08	5.33E+08
55	cambridge	australia	2.20E+09	1	1	5	23.22	0.994	1.005	0.955	9.96E+06	4.92E+07	1.10E+09
56	collier_bay	australia	6.00E+09	1	1	4	10.69	0.996	1.006	0.916	5.06E+07	6.65E+07	2.73E+09
57	king_sound	australia	8.39E+09	1	1	4	9.24	0.997	1.005	0.910	7.52E+07	6.90E+07	3.77E+09
58	exmouth_bay	australia	3.43E+09	1	2	3	7.18	0.987	1.020	0.847	5.27E+07	8.88E+07	1.50E+09
59	shark_bay	australia	1.52E+10	4	3	3	4.97	0.984	1.031	0.774	3.43E+08	4.18E+08	6.45E+09
60	adelaide	australia	4.67E+08	1	3	3	14.71	0.953	1.049	0.891	2.34E+07	6.16E+07	1.87E+08

61	exmouth_bay	australia	2.65E+09	1	3	3	3.54	0.970	1.079	0.624	9.98E+07	1.24E+08	1.06E+09
62	mornington	australia	1.29E+09	2	3	2	6.12	0.930	1.135	0.702	1.40E+08	1.69E+08	4.50E+08
63	corner_inlet	australia	4.81E+08	2	3	3	17.72	0.935	1.061	0.896	3.07E+07	9.85E+07	1.76E+08
64	90_mile_beach	australia	3.16E+08	1	3	3	16.44	0.942	1.056	0.894	1.86E+07	5.44E+07	1.21E+08
65	fraser_island	australia	3.75E+09	2	3	3	9.31	0.981	1.026	0.865	5.06E+07	1.64E+08	1.63E+09
66	curtis_island	australia	4.81E+08	2	2	1	1.95	0.790	2.043	0.000	2.94E+08	1.39E+08	7.97E+07
67	secretary	new_sealand	4.40E+08	2	5	3	18.16	0.929	1.063	0.896	2.89E+07	9.86E+07	1.55E+08
68	petone	new_sealand	2.47E+08	1	3	4	24.41	0.948	1.036	0.931	1.03E+07	4.70E+07	1.03E+08
69	awamuto	new_sealand	2.75E+08	2	3	4	34.59	0.943	1.030	0.948	1.01E+07	7.46E+07	1.18E+08
70	oackland	new_sealand	5.63E+08	1	3	4	25.02	0.972	1.018	0.946	1.23E+07	5.44E+07	2.68E+08
71	kaipara	new_sealand	1.59E+09	1	3	4	14.36	0.984	1.016	0.915	1.35E+07	6.73E+07	7.33E+08
72	tulcea	romania	5.50E+08	1	1	2	6.45	0.933	1.141	0.709	6.62E+07	7.58E+07	1.90E+08
73	kherson	ukraine	1.37E+09	1	1	2	4.75	0.963	1.101	0.667	4.58E+07	1.05E+08	5.29E+08
74	azov	ukraine	5.91E+10	1	1	2	0.83	0.997	1.018	0.435	3.34E+09	1.59E+08	2.46E+10
75	karkinitzky	ukraine	7.57E+09	1	1	2	2.19	0.989	1.050	0.550	3.41E+08	1.36E+08	3.14E+09
76	misfaq	egypt	4.53E+08	2	2	1	1.99	0.789	2.034	0.000	2.83E+08	1.33E+08	7.40E+07
77	port_said	egypt	1.43E+09	2	2	1	1.31	0.828	2.097	0.000	4.74E+08	2.84E+08	3.44E+08
78	zuetina	libya	6.87E+08	3	2	1	1.98	0.789	2.036	0.000	4.27E+08	2.01E+08	1.12E+08
79	djerba	tunisia	9.62E+08	2	2	1	1.51	0.812	2.107	0.000	4.34E+08	2.28E+08	1.99E+08
80	tunis	tunisia	3.02E+08	1	2	1	1.79	0.797	2.072	0.000	1.71E+08	8.30E+07	5.34E+07
81	venice	italy	8.66E+08	3	2	1	1.82	0.795	2.067	0.000	4.98E+08	2.40E+08	1.51E+08
82	triest	italy	1.24E+08	3	2	1	3.68	0.425	1.748	0.000	1.04E+08	4.53E+07	1.75E+07
83	st_tropez	france	5.50E+07	1	3	4	40.47	0.927	1.038	0.947	2.38E+06	2.53E+07	2.12E+07
84	murcia	spain	1.24E+08	1	2	1	2.48	0.773	1.950	0.000	8.93E+07	4.02E+07	1.80E+07
85	cadiz	spain	1.79E+08	1	3	3	19.19	0.928	1.065	0.898	1.22E+07	4.36E+07	6.23E+07
86	setubal	portugal	2.47E+08	1	3	3	17.59	0.936	1.060	0.896	1.57E+07	4.98E+07	9.10E+07
87	lisboa	portugal	5.22E+08	1	3	3	14.25	0.956	1.047	0.890	2.47E+07	6.35E+07	2.12E+08
88	arosa	portugal	4.40E+08	1	3	3	14.97	0.951	1.050	0.892	2.27E+07	6.05E+07	1.75E+08
89	gironde	france	1.15E+09	1	5	4	20.70	0.981	1.012	0.941	1.03E+07	6.08E+07	5.55E+08
90	loire	france	3.30E+08	1	5	5	38.93	0.966	1.013	0.964	6.41E+06	4.93E+07	1.68E+08
91	vilaine	france	3.85E+08	1	5	5	37.68	0.968	1.012	0.964	7.00E+06	5.07E+07	1.97E+08
92	morbihan	france	3.02E+08	1	5	5	39.63	0.964	1.013	0.964	6.08E+06	4.84E+07	1.53E+08

93	brest	france	5.36E+08	1	5	5	35.03	0.974	1.010	0.964	8.18E+06	5.30E+07	2.76E+08
94	duarnenez	france	5.22E+08	1	5	5	35.23	0.974	1.010	0.964	8.09E+06	5.29E+07	2.69E+08
95	seine	france	2.20E+08	1	3	5	42.18	0.962	1.015	0.965	4.89E+06	4.22E+07	1.12E+08
96	western_scheldt	netherlands	9.07E+08	1	3	3	12.11	0.969	1.037	0.882	2.64E+07	7.24E+07	3.85E+08
97	eastern_scheldt	netherlands	1.09E+09	2	3	3	14.09	0.957	1.046	0.889	5.01E+07	1.28E+08	4.42E+08
98	waddensea	netherlands	3.93E+09	5	3	3	12.64	0.965	1.039	0.885	1.36E+08	3.51E+08	1.65E+09
99	ems	netherlands/germany	7.97E+08	1	3	3	12.58	0.966	1.039	0.884	2.71E+07	7.04E+07	3.36E+08
100	jadebusen	germany	5.08E+08	1	3	3	14.36	0.955	1.047	0.890	2.44E+07	6.31E+07	2.06E+08
101	weser	germany	2.47E+08	1	3	3	17.59	0.936	1.060	0.896	1.57E+07	4.98E+07	9.10E+07
102	eastern_waddensea	germany	1.31E+09	5	3	3	17.33	0.937	1.059	0.895	8.14E+07	2.54E+08	4.84E+08
103	elbe	germany	1.00E+09	1	3	3	8.62	0.963	1.056	0.826	3.64E+07	8.36E+07	4.04E+08
104	heide	germany	2.34E+08	1	3	3	13.40	0.921	1.092	0.851	2.15E+07	5.09E+07	7.68E+07
105	tonning	germany	3.02E+08	1	3	3	12.43	0.929	1.087	0.848	2.60E+07	5.68E+07	1.04E+08
106	halligen	germany	2.64E+09	4	3	3	9.81	0.952	1.067	0.835	1.55E+08	2.98E+08	1.02E+09
107	romo_fano	denmark	1.92E+09	4	3	3	14.59	0.953	1.048	0.891	9.50E+07	2.48E+08	7.74E+08
108	thyboron	denmark	4.67E+08	1	3	3	14.71	0.953	1.049	0.891	2.34E+07	6.16E+07	1.87E+08
109	samso	denmark	6.87E+08	2	3	2	7.51	0.907	1.160	0.725	1.02E+08	1.30E+08	2.13E+08
110	horsens	denmark	3.02E+08	1	2	2	7.82	0.903	1.164	0.729	4.63E+07	6.10E+07	9.12E+07
111	als	denmark	2.20E+08	2	2	2	10.70	0.876	1.178	0.766	3.80E+07	7.02E+07	5.16E+07
112	flensburg	denmark	2.75E+08	1	2	2	8.06	0.900	1.166	0.732	4.31E+07	5.83E+07	8.12E+07
113	fehmar	germany	3.43E+08	2	2	2	9.34	0.886	1.175	0.749	5.80E+07	9.10E+07	9.07E+07
114	travemunde	germany	6.32E+08	1	2	2	3.85	0.900	1.264	0.458	1.27E+08	9.18E+07	2.01E+08
115	wismar	germany	1.92E+08	2	2	2	7.22	0.839	1.310	0.614	5.61E+07	6.30E+07	3.85E+07
116	stralsund	germany	5.36E+08	1	2	2	6.50	0.923	1.143	0.709	6.57E+07	7.86E+07	1.81E+08
117	rugen	germany	9.07E+08	2	2	1	1.55	0.810	2.105	0.000	4.24E+08	2.20E+08	1.83E+08
118	pommerse	poland	1.68E+09	3	2	1	1.43	0.818	2.108	0.000	6.86E+08	3.75E+08	3.66E+08
119	gdansk	polad	2.09E+09	1	2	1	0.85	0.884	1.872	0.000	2.09E+08	2.05E+08	6.89E+08
120	koerishe_haf	russia	2.72E+09	1	2	1	0.75	0.898	1.794	0.000	2.72E+08	2.33E+08	9.26E+08
121	riga	russia	3.66E+10	3	2	1	0.37	0.961	1.423	0.000	3.66E+09	1.63E+09	1.36E+10
122	timan_1	russia	1.92E+08	2	1	2	11.13	0.878	1.175	0.773	3.30E+07	6.27E+07	4.56E+07
123	timan_2	russia	8.52E+08	1	1	2	5.59	0.949	1.122	0.691	7.11E+07	8.95E+07	3.13E+08
124	petsjora	russia	1.51E+10	9	1	2	4.35	0.968	1.094	0.654	5.22E+08	9.84E+08	5.91E+09

125	gaspe	canada	6.97E+09	1	1	5	8.66	0.996	1.006	0.898	7.08E+07	7.22E+07	3.12E+09
126	new_brunswick	canada	8.11E+08	1	1	2	5.68	0.947	1.124	0.693	7.16E+07	8.79E+07	2.96E+08
127	edward_island	canada	1.45E+10	2	4	2	2.24	0.982	1.051	0.553	6.46E+08	2.88E+08	5.97E+09
128	fundy_bay_north	canada	1.61E+09	1	4	5	4.43	0.955	1.096	0.657	5.52E+07	1.17E+08	6.19E+08
129	fundy_bay_south	canada	2.87E+09	1	4	5	12.67	0.988	1.010	0.915	2.44E+07	7.18E+07	1.32E+09
130	fundy_bay_east	canada	1.65E+08	1	4	5	44.44	0.952	1.017	0.964	4.05E+06	4.13E+07	8.10E+07
131	funday_bay_west	canada	1.83E+09	2	4	5	30.88	0.982	1.008	0.962	1.70E+07	1.08E+08	9.44E+08
132	bangor_north	united states	8.11E+08	2	4	4	27.17	0.962	1.021	0.947	2.13E+07	1.08E+08	3.74E+08
133	bangor_south	united states	5.22E+08	2	4	4	30.15	0.953	1.025	0.948	1.62E+07	9.68E+07	2.33E+08
134	august	united states	2.47E+08	2	4	4	35.31	0.938	1.032	0.947	9.39E+06	7.50E+07	1.02E+08
135	cape_kod	united states	1.47E+09	1	4	2	4.61	0.952	1.099	0.662	4.97E+07	1.14E+08	5.62E+08
136	new_bedford	united states	5.50E+08	1	4	2	6.45	0.919	1.143	0.708	6.65E+07	8.18E+07	1.84E+08
137	rode_island	united states	7.01E+08	1	4	2	5.96	0.927	1.132	0.698	7.15E+07	8.99E+07	2.44E+08
138	lon_island	united states	3.57E+08	1	3	3	11.82	0.933	1.083	0.845	2.91E+07	6.06E+07	1.27E+08
139	philadelphia	united states	3.30E+08	3	3	2	10.70	0.876	1.178	0.766	5.70E+07	1.05E+08	7.74E+07
140	delaware_bay	united states	3.12E+09	1	3	2	3.29	0.973	1.074	0.612	1.21E+08	1.27E+08	1.26E+09
141	chincoteague_bay	united states	3.43E+08	2	3	2	9.34	0.886	1.175	0.749	5.80E+07	9.10E+07	9.07E+07
142	chesapeake_bay	united states	1.74E+10	1	3	3	1.49	0.992	1.033	0.496	8.77E+08	1.51E+08	7.24E+09
143	albmarle_pamlico_sound	united states	1.14E+10	6	3	3	6.75	0.975	1.043	0.804	2.23E+08	5.70E+08	4.75E+09
144	cape_fear	united states	6.87E+07	1	3	3	24.17	0.910	1.075	0.904	5.26E+06	2.73E+07	1.99E+07
145	winyah	united states	8.24E+07	1	3	3	23.21	0.913	1.074	0.902	6.23E+06	3.01E+07	2.48E+07
146	charleston	united states	1.79E+08	1	3	3	19.19	0.928	1.065	0.898	1.22E+07	4.36E+07	6.23E+07
147	st_helena_sound	united states	3.02E+08	1	3	3	16.64	0.941	1.057	0.894	1.81E+07	5.36E+07	1.15E+08
148	broad_river	united states	3.30E+08	1	3	3	16.24	0.944	1.055	0.894	1.91E+07	5.52E+07	1.27E+08
149	sepalo_sounds	united states	1.51E+08	1	3	3	20.03	0.924	1.067	0.899	1.06E+07	4.05E+07	5.11E+07
150	simons_sounds	united states	2.20E+08	1	3	3	18.16	0.933	1.062	0.896	1.43E+07	4.75E+07	7.94E+07
151	cape_canaveral	united states	1.11E+09	2	3	3	10.34	0.947	1.072	0.839	7.37E+07	1.41E+08	4.22E+08
152	cape_cable	united states	3.57E+08	1	3	2	7.41	0.908	1.159	0.723	5.21E+07	6.60E+07	1.12E+08
153	everglades_1	united states	1.51E+08	1	3	2	9.72	0.883	1.176	0.754	2.58E+07	4.23E+07	3.86E+07
154	charlotte_harbour	united states	1.02E+09	4	2	2	8.26	0.897	1.168	0.735	1.62E+08	2.24E+08	2.95E+08
155	tampa_bay	united states	1.20E+09	1	2	2	5.00	0.952	1.107	0.674	5.28E+07	1.05E+08	4.50E+08
156	apalchicola_bay	united states	8.66E+08	4	2	2	8.69	0.892	1.172	0.741	1.42E+08	2.06E+08	2.42E+08

157	panama_city	united states	7.28E+08	1	2	2	5.88	0.934	1.130	0.697	7.17E+07	8.85E+07	2.58E+08
158	pensacola_bay	united states	1.36E+09	2	2	2	6.02	0.932	1.133	0.700	1.42E+08	1.73E+08	4.77E+08
159	mobile_bay	united states	1.26E+09	2	2	2	6.16	0.929	1.136	0.703	1.40E+08	1.68E+08	4.39E+08
160	galveston	united states	1.63E+09	1	2	2	4.40	0.960	1.095	0.656	5.63E+07	1.14E+08	6.34E+08
161	mantagorda_bay	united states	1.28E+09	2	2	2	6.14	0.929	1.136	0.703	1.40E+08	1.69E+08	4.44E+08
162	san_antonio_bay	united states	6.46E+08	2	2	2	7.66	0.905	1.162	0.727	9.72E+07	1.26E+08	1.98E+08
163	aransas_bay	united states	8.11E+08	2	2	2	7.12	0.913	1.154	0.719	1.13E+08	1.40E+08	2.60E+08
164	corpus_christi_bay	united states	8.66E+08	1	2	2	5.56	0.941	1.122	0.690	7.10E+07	9.43E+07	3.14E+08
165	laguna_de_terminos	mexico	2.69E+09	2	3	2	4.79	0.955	1.102	0.668	8.94E+07	2.18E+08	1.03E+09
166	holbox_lagoons	mexico	3.98E+08	1	3	1	1.62	0.805	2.098	0.000	2.00E+08	1.01E+08	7.70E+07
167	cozumel	mexico	1.54E+09	2	2	1	1.28	0.831	2.091	0.000	4.72E+08	2.93E+08	3.81E+08
168	ascension_bay	mexico	5.08E+08	1	2	2	6.61	0.921	1.146	0.711	6.41E+07	7.69E+07	1.70E+08
169	chetumal	belize	3.16E+09	3	2	2	5.21	0.947	1.113	0.681	1.90E+08	3.03E+08	1.17E+09
170	caratasca_lagune	honduras	8.66E+08	1	2	1	1.22	0.836	2.079	0.000	2.29E+08	1.53E+08	2.25E+08
171	rio_grande_delta	nicaragua	5.36E+08	1	2	2	6.50	0.923	1.143	0.709	6.57E+07	7.86E+07	1.81E+08
172	el_buff	nicaragua	1.92E+08	2	2	2	11.13	0.874	1.177	0.771	3.33E+07	6.47E+07	4.36E+07
173	san_san_lagune	panama	1.94E+09	4	2	3	14.56	0.954	1.048	0.891	9.54E+07	2.49E+08	7.80E+08
174	isla_salamanca	colombia	5.36E+08	2	3	1	1.87	0.793	2.057	0.000	3.17E+08	1.51E+08	9.15E+07
175	restinga_laguna	venezuela	7.56E+08	1	2	2	5.81	0.936	1.128	0.696	7.19E+07	8.97E+07	2.69E+08
176	rio_mearim_estuary	brasil	4.25E+09	1	2	4	12.40	0.993	1.007	0.921	3.34E+07	6.74E+07	1.95E+09
177	central_bahia	brasil	1.59E+09	2	2	3	12.58	0.966	1.039	0.884	5.42E+07	1.41E+08	6.71E+08
178	guaratiba_bay	brasil	2.51E+09	2	3	2	4.92	0.953	1.105	0.672	9.38E+07	2.14E+08	9.51E+08
179	paranagua_bay	brasil	1.21E+09	1	3	2	4.98	0.952	1.107	0.674	5.16E+07	1.06E+08	4.56E+08
180	tubarao_lagoon	brasil	7.14E+08	2	3	2	7.41	0.908	1.159	0.723	1.04E+08	1.32E+08	2.23E+08
181	peixe	brasil	1.37E+10	1	3	2	1.66	0.990	1.038	0.511	6.69E+08	1.49E+08	5.68E+09
182	rio_negro	argentina	3.60E+10	1	4	2	1.05	0.994	1.023	0.457	1.95E+09	1.62E+08	1.50E+10
183	baya_blanco	argentina	2.54E+09	1	3	4	3.61	0.970	1.081	0.627	9.49E+07	1.23E+08	1.02E+09
184	rio_colorado	argentina	1.72E+09	1	3	4	17.97	0.987	1.010	0.936	1.10E+07	6.02E+07	8.21E+08
185	rio_deseado	argentina	1.65E+08	1	4	4	33.33	0.943	1.029	0.948	5.85E+06	4.18E+07	7.02E+07
186	isla_puna	ecuador	3.81E+09	2	2	2	4.11	0.964	1.090	0.646	1.35E+08	2.34E+08	1.49E+09
187	rio_chone	ecuador	1.51E+08	1	2	4	33.94	0.945	1.029	0.948	5.42E+06	3.86E+07	6.56E+07
188	rio_santiago	ecuador	3.85E+08	1	2	4	27.52	0.965	1.021	0.948	1.03E+07	5.07E+07	1.80E+08

189	panama_bay	panama	7.97E+08	1	2	4	14.86	0.970	1.030	0.906	2.21E+07	6.62E+07	3.48E+08
190	rio_san_pablo	panama	6.87E+08	2	2	4	22.47	0.956	1.032	0.930	2.57E+07	1.04E+08	2.95E+08
191	armuelles	costa rica	1.13E+09	1	2	3	11.34	0.973	1.033	0.878	2.21E+07	7.55E+07	4.85E+08
192	piedras	costa rica	2.39E+09	1	2	3	8.40	0.983	1.024	0.858	3.40E+07	8.49E+07	1.04E+09
193	fonseca_gulf	honduras	2.73E+09	1	2	3	7.93	0.985	1.022	0.854	4.00E+07	8.64E+07	1.19E+09
194	mar_muerto	mexico	2.47E+08	1	3	3	17.59	0.936	1.060	0.896	1.57E+07	4.98E+07	9.10E+07
195	lugana_superior	mexico	2.20E+08	1	3	3	18.16	0.933	1.062	0.896	1.43E+07	4.75E+07	7.94E+07
196	tiburon	mexico	1.03E+09	2	2	3	14.30	0.955	1.047	0.890	4.91E+07	1.27E+08	4.18E+08
197	baja_california	mexico	2.75E+08	2	2	4	28.02	0.935	1.043	0.932	1.32E+07	7.57E+07	1.06E+08
198	magdalena_bay	mexico	2.31E+09	4	2	3	10.23	0.948	1.071	0.838	1.49E+08	2.86E+08	8.79E+08
199	sebastian_vizcaino_bay	mexico	1.09E+09	1	2	3	11.47	0.972	1.033	0.879	2.32E+07	7.50E+07	4.66E+08
200	san_diego	united states	3.57E+08	1	3	3	15.88	0.946	1.054	0.893	2.01E+07	5.67E+07	1.39E+08
201	santa_monica	united states	3.57E+08	1	3	3	15.88	0.946	1.054	0.893	2.01E+07	5.67E+07	1.39E+08
202	san_fransisco	united states	2.69E+09	1	3	3	7.98	0.985	1.022	0.854	3.93E+07	8.62E+07	1.17E+09
203	colombia_river	united states	6.87E+08	1	4	3	13.15	0.958	1.042	0.886	2.69E+07	7.10E+07	2.83E+08
204	willapa_bay	united states	7.01E+08	1	4	3	13.07	0.958	1.042	0.886	2.70E+07	7.13E+07	2.89E+08

Table C-4: Results of the algorithm for all tidal areas in the world in 2500 AD

nr.	Name	First Country	Wet Area [m ²]	nr. Inlets [-]	Wave Height [m]	Tidal Class [-]	Critical SLR [mm/y]	V _d /V _{de} [-]	V _c /V _{ce} [-]	V _f /V _{fe} [-]	Land Loss [m ²]	Sand from Coast [m ³]	Suppletion needed [m ³]
1	tidra	mauratania	2.34E+08	2	2	3	21.37	0.843	1.212	0.770	2.59E+07	8.85E+08	1.22E+08
2	timiris	mauratania	2.75E+08	1	2	3	17.09	0.488	1.781	0.000	3.08E+07	8.32E+08	2.28E+08
3	saloum	senegal	1.92E+08	3	2	3	24.54	0.905	1.074	0.923	2.01E+07	8.41E+08	7.70E+07
4	gambia	gambia	7.83E+08	1	2	3	12.65	0.884	1.118	0.869	5.72E+07	1.59E+09	1.15E+09
5	casamance	senegal	6.04E+08	1	2	3	13.65	0.884	1.119	0.867	5.39E+07	1.38E+09	7.80E+08
6	cacheu	guinee-bassau	2.34E+08	1	2	3	17.86	0.884	1.122	0.861	2.65E+07	7.41E+08	1.77E+08
7	monsoa	guinee-bassau	5.50E+08	3	2	3	19.06	0.906	1.077	0.916	6.24E+07	1.86E+09	3.63E+08
8	corubal	guinee-bassau	1.40E+09	2	2	3	13.07	0.836	1.278	0.679	1.13E+08	2.99E+09	1.95E+09
9	cacine	guinea	7.56E+08	2	2	3	11.63	0.789	1.529	0.411	1.15E+08	2.06E+09	6.45E+08
10	nunez	guinea	7.56E+08	3	2	2	8.28	0.836	1.278	0.679	2.14E+08	2.22E+09	4.30E+08
11	pongo	guinea	4.53E+08	3	2	2	9.72	0.836	1.278	0.679	1.20E+08	1.48E+09	1.89E+08
12	sangarea	guinea	2.89E+08	2	2	2	9.85	0.884	1.128	0.851	7.56E+07	9.47E+08	1.17E+08
13	freetown	sierra leone	7.56E+08	1	2	2	5.81	0.835	1.289	0.663	1.78E+08	1.61E+09	8.49E+08
14	bonthe	sierra leone	6.59E+08	2	2	2	7.60	0.835	1.289	0.663	1.90E+08	1.82E+09	4.47E+08
15	lagos	nigeria	2.47E+08	1	3	2	8.33	0.884	1.129	0.848	7.00E+07	7.29E+08	1.39E+08
16	forcados	nigeria	2.89E+08	1	3	2	7.94	0.763	2.076	0.000	8.26E+07	8.21E+08	1.79E+08
17	niger1	nigeria	3.16E+08	2	3	2	9.58	0.906	1.078	0.912	8.41E+07	1.02E+09	1.35E+08
18	niger2	nigeria	2.61E+08	2	3	2	10.16	0.834	1.304	0.640	6.71E+07	8.73E+08	1.00E+08
19	niger3	nigeria	5.50E+08	2	3	2	8.06	0.906	1.079	0.910	1.57E+08	1.58E+09	3.31E+08
20	cross	nigeria	1.84E+09	2	3	3	8.85	0.898	1.097	0.887	1.66E+08	3.58E+09	2.59E+09
21	wouri	cameroon	1.99E+09	1	2	3	9.08	0.833	1.314	0.626	5.90E+07	2.35E+09	4.17E+09
22	muni	equatorial guinee	1.87E+09	1	2	3	9.33	0.833	1.318	0.619	5.44E+07	2.30E+09	3.84E+09
23	gabon	gabon	1.52E+09	1	2	3	10.16	0.883	1.135	0.837	4.20E+07	2.13E+09	2.95E+09
24	zaire	zaire	7.42E+08	1	2	2	5.85	0.833	1.318	0.619	1.77E+08	1.59E+09	8.25E+08
25	FALSE	south africa	1.17E+09	1	4	2	5.04	0.906	1.079	0.908	1.57E+08	2.12E+09	1.61E+09
26	inhambane	mozambique	1.10E+08	1	1	3	21.69	0.832	1.323	0.612	1.21E+07	4.18E+08	6.03E+07
27	bazaruto	mozambique	3.30E+08	2	1	3	19.59	0.883	1.137	0.834	3.73E+07	1.13E+09	2.21E+08
28	beira	mozambique	2.61E+08	1	1	4	30.15	0.916	1.059	0.932	1.56E+07	7.91E+08	3.40E+08

29	antonio_enes	mozambique	1.92E+08	2	3	4	37.00	0.907	1.080	0.907	1.23E+07	8.44E+08	1.45E+08
30	masirah	oman	1.13E+09	2	2	3	13.94	0.832	1.331	0.599	1.04E+08	2.65E+09	1.40E+09
31	ghubbat	oman	6.59E+08	1	2	3	13.31	0.832	1.331	0.599	5.56E+07	1.45E+09	8.90E+08
32	khore_al_uheid	united arab emirates	2.06E+08	1	1	3	18.47	0.883	1.139	0.830	2.34E+07	6.67E+08	1.55E+08
33	bahrein	bahrein	9.88E+09	2	1	3	6.12	0.883	1.139	0.830	3.87E+08	5.82E+09	2.48E+10
34	al_kuwait	kuwait	5.22E+08	1	1	4	25.51	0.883	1.140	0.829	2.46E+07	1.14E+09	9.21E+08
35	umm_qasr	iraq	9.07E+08	2	1	4	26.43	0.831	1.343	0.580	4.59E+07	2.14E+09	1.51E+09
36	qeshm	iran	1.48E+09	2	1	3	12.85	0.883	1.142	0.823	1.13E+08	3.00E+09	2.21E+09
37	miani_hor	pakistan	7.01E+08	1	3	3	13.07	0.830	1.356	0.559	5.64E+07	1.50E+09	9.76E+08
38	kori_kreek	india	9.89E+08	2	3	5	25.86	0.883	1.144	0.820	4.84E+07	2.32E+09	1.62E+09
39	kutch	india	7.47E+09	1	3	5	14.11	0.918	1.058	0.931	9.34E+07	2.12E+09	2.20E+10
40	mutur	sri lanka	1.92E+08	1	2	2	9.02	0.883	1.144	0.820	5.28E+07	5.97E+08	9.25E+07
41	jaffina	sri lanka	5.91E+08	2	2	2	7.88	0.883	1.144	0.820	1.69E+08	1.67E+09	3.73E+08
42	phuket	thailand	1.80E+09	3	2	3	10.10	0.761	2.667	0.000	2.36E+08	4.19E+09	2.02E+09
43	da_nang	vietnam	6.87E+07	2	2	2	14.76	0.761	2.687	0.000	1.35E+07	2.93E+08	1.43E+07
44	hue	vietnam	1.92E+08	2	2	2	11.13	0.883	1.146	0.817	4.66E+07	6.79E+08	6.27E+07
45	ca_ba	vietnam	1.33E+09	2	2	2	6.06	0.866	1.202	0.745	3.36E+08	2.97E+09	1.40E+09
46	chin_chou_wan	china	4.40E+08	1	2	2	6.93	0.883	1.146	0.815	1.25E+08	1.12E+09	3.58E+08
47	anpu	china	2.84E+09	1	2	3	5.66	0.760	2.796	0.000	1.48E+08	2.86E+09	6.05E+09
48	deep_bay	china	2.62E+09	1	2	3	8.07	0.830	1.370	0.534	8.40E+07	2.56E+09	5.87E+09
49	nagoya	japan	3.17E+09	1	2	3	5.39	0.899	1.103	0.871	1.72E+08	2.96E+09	6.93E+09
50	shizuoka	japan	3.05E+09	1	3	2	3.33	0.883	1.147	0.814	3.05E+08	3.29E+09	6.01E+09
51	tokyo	japan	2.23E+09	1	3	2	3.83	0.883	1.147	0.814	2.23E+08	2.87E+09	4.01E+09
52	kritappu	japan	2.75E+08	1	5	2	8.06	0.883	1.147	0.814	7.85E+07	7.94E+08	1.62E+08
53	tokoro	japan	5.22E+08	2	5	2	8.19	0.829	1.372	0.530	1.49E+08	1.53E+09	2.97E+08
54	moskalvo	japan	1.50E+09	2	2	2	5.83	0.829	1.373	0.528	3.54E+08	3.20E+09	1.67E+09
55	cambridge	australia	2.20E+09	1	1	5	23.22	0.883	1.148	0.811	1.87E+07	1.58E+09	6.28E+09
56	collier_bay	australia	6.00E+09	1	1	4	10.69	0.910	1.080	0.900	1.08E+08	2.31E+09	1.68E+10
57	king_sound	australia	8.39E+09	1	1	4	9.24	0.829	1.376	0.523	1.72E+08	2.45E+09	2.39E+10
58	exmouth_bay	australia	3.43E+09	1	2	3	7.18	0.908	1.081	0.899	1.19E+08	2.76E+09	8.10E+09
59	shark_bay	australia	1.52E+10	4	3	3	4.97	0.758	3.090	0.000	8.85E+08	1.25E+10	3.46E+10
60	adelaide	australia	4.67E+08	1	3	3	14.71	0.884	1.149	0.808	4.70E+07	1.18E+09	5.24E+08

61	exmouth_bay	australia	2.65E+09	1	3	3	3.54	0.829	1.381	0.512	2.65E+08	3.10E+09	5.03E+09
62	mornington	australia	1.29E+09	2	3	2	6.12	0.829	1.381	0.512	3.31E+08	2.91E+09	1.33E+09
63	corner_inlet	australia	4.81E+08	2	3	3	17.72	0.829	1.381	0.512	5.44E+07	1.51E+09	3.70E+08
64	90_mile_beach	australia	3.16E+08	1	3	3	16.44	0.829	1.386	0.502	3.49E+07	9.16E+08	2.84E+08
65	fraser_island	australia	3.75E+09	2	3	3	9.31	0.757	3.335	0.000	1.09E+08	4.60E+09	7.72E+09
66	curtis_island	australia	4.81E+08	2	2	1	1.95	0.829	1.389	0.497	2.94E+08	1.39E+09	1.07E+08
67	secretary	new_sealand	4.40E+08	2	5	3	18.16	0.757	3.504	0.000	4.99E+07	1.43E+09	3.10E+08
68	petone	new_sealand	2.47E+08	1	3	4	24.41	0.920	1.056	0.928	1.93E+07	7.83E+08	2.44E+08
69	awamuto	new_sealand	2.75E+08	2	3	4	34.59	0.866	1.212	0.723	1.75E+07	1.08E+09	2.44E+08
70	oackland	new_sealand	5.63E+08	1	3	4	25.02	0.829	1.391	0.492	2.56E+07	1.23E+09	9.76E+08
71	kaipara	new_sealand	1.59E+09	1	3	4	14.36	0.884	1.151	0.804	2.76E+07	1.95E+09	3.53E+09
72	tulcea	romania	5.50E+08	1	1	2	6.45	0.884	1.152	0.801	1.49E+08	1.29E+09	5.32E+08
73	kherson	ukraine	1.37E+09	1	1	2	4.75	0.829	1.398	0.478	1.37E+08	2.23E+09	2.11E+09
74	azov	ukraine	5.91E+10	1	1	2	0.83	0.829	1.400	0.473	5.91E+09	1.51E+10	1.54E+11
75	karkinitzky	ukraine	7.57E+09	1	1	2	2.19	0.921	1.056	0.928	7.57E+08	4.67E+09	1.78E+10
76	misfaq	egypt	4.53E+08	2	2	1	1.99	0.884	1.152	0.799	2.83E+08	1.32E+09	9.48E+07
77	port_said	egypt	1.43E+09	2	2	1	1.31	0.829	1.403	0.464	4.74E+08	2.91E+09	1.39E+09
78	zuetina	libya	6.87E+08	3	2	1	1.98	0.901	1.105	0.862	4.27E+08	2.00E+09	1.45E+08
79	djerba	tunisia	9.62E+08	2	2	1	1.51	0.829	1.407	0.455	4.34E+08	2.34E+09	5.84E+08
80	tunis	tunisia	3.02E+08	1	2	1	1.79	0.866	1.218	0.708	1.71E+08	8.43E+08	9.14E+07
81	venice	italy	8.66E+08	3	2	1	1.82	0.829	1.407	0.455	4.98E+08	2.44E+09	2.44E+08
82	triest	italy	1.24E+08	3	2	1	3.68	0.885	1.153	0.795	1.04E+08	4.14E+08	1.73E+07
83	st_tropez	france	5.50E+07	1	3	4	40.47	0.885	1.153	0.795	3.45E+06	2.86E+08	3.31E+07
84	murcia	spain	1.24E+08	1	2	1	2.48	0.867	1.220	0.703	8.93E+07	3.80E+08	1.87E+07
85	cadiz	spain	1.79E+08	1	3	3	19.19	0.923	1.054	0.927	2.03E+07	6.09E+08	1.17E+08
86	setubal	portugal	2.47E+08	1	3	3	17.59	0.912	1.080	0.893	2.79E+07	7.72E+08	1.93E+08
87	lisboa	portugal	5.22E+08	1	3	3	14.25	0.758	4.631	0.000	5.02E+07	1.26E+09	6.23E+08
88	arosa	portugal	4.40E+08	1	3	3	14.97	0.912	1.080	0.892	4.51E+07	1.14E+09	4.77E+08
89	gironde	france	1.15E+09	1	5	4	20.70	0.829	1.418	0.425	2.07E+07	1.67E+09	2.55E+09
90	loire	france	3.30E+08	1	5	5	38.93	0.830	1.424	0.404	1.30E+07	9.38E+08	5.48E+08
91	vilaine	france	3.85E+08	1	5	5	37.68	0.886	1.156	0.784	1.44E+07	1.01E+09	6.82E+08
92	morbihan	france	3.02E+08	1	5	5	39.63	0.917	1.077	0.892	1.23E+07	8.97E+08	4.85E+08

93	brest	france	5.36E+08	1	5	5	35.03	0.760	5.150	0.000	1.68E+07	1.17E+09	1.08E+09
94	duarnenez	france	5.22E+08	1	5	5	35.23	0.887	1.156	0.781	1.67E+07	1.16E+09	1.04E+09
95	seine	france	2.20E+08	1	3	5	42.18	0.887	1.156	0.781	9.62E+06	7.39E+08	3.21E+08
96	western_scheldt	netherlands	9.07E+08	1	3	3	12.11	0.887	1.156	0.780	5.59E+07	1.71E+09	1.43E+09
97	eastern_scheldt	netherlands	1.09E+09	2	3	3	14.09	0.762	5.371	0.000	1.03E+08	2.59E+09	1.32E+09
98	waddensea	netherlands	3.93E+09	5	3	3	12.64	0.887	1.156	0.779	2.86E+08	7.95E+09	5.79E+09
99	ems	netherlands/germany	7.97E+08	1	3	3	12.58	0.915	1.077	0.890	5.72E+07	1.60E+09	1.18E+09
100	jadebusen	germany	5.08E+08	1	3	3	14.36	0.888	1.156	0.777	4.95E+07	1.24E+09	5.97E+08
101	weser	germany	2.47E+08	1	3	3	17.59	0.831	1.433	0.366	2.79E+07	7.72E+08	1.93E+08
102	eastern_waddensea	germany	1.31E+09	5	3	3	17.33	0.888	1.156	0.776	1.47E+08	4.01E+09	1.05E+09
103	elbe	germany	1.00E+09	1	3	3	8.62	0.920	1.076	0.890	7.97E+07	1.87E+09	1.47E+09
104	heide	germany	2.34E+08	1	3	3	13.40	0.888	1.156	0.776	3.68E+07	7.26E+08	1.50E+08
105	tonning	germany	3.02E+08	1	3	3	12.43	0.927	1.051	0.926	4.73E+07	8.79E+08	2.26E+08
106	halligen	germany	2.64E+09	4	3	3	9.81	0.927	1.050	0.926	3.27E+08	5.92E+09	3.12E+09
107	romo_fano	denmark	1.92E+09	4	3	3	14.59	0.832	1.435	0.352	1.91E+08	4.81E+09	2.19E+09
108	thyboron	denmark	4.67E+08	1	3	3	14.71	0.832	1.435	0.352	4.70E+07	1.18E+09	5.24E+08
109	samso	denmark	6.87E+08	2	3	2	7.51	0.888	1.156	0.774	1.98E+08	1.87E+09	4.78E+08
110	horsens	denmark	3.02E+08	1	2	2	7.82	0.834	1.435	0.347	8.68E+07	8.50E+08	1.94E+08
111	als	denmark	2.20E+08	2	2	2	10.70	0.832	1.437	0.344	5.47E+07	7.58E+08	7.68E+07
112	flensburg	denmark	2.75E+08	1	2	2	8.06	0.870	1.227	0.669	7.85E+07	7.90E+08	1.66E+08
113	fehmar	germany	3.43E+08	2	2	2	9.34	0.765	5.877	0.000	9.26E+07	1.09E+09	1.54E+08
114	travemunde	germany	6.32E+08	1	2	2	3.85	0.918	1.076	0.888	2.35E+08	1.50E+09	5.14E+08
115	wismar	germany	1.92E+08	2	2	2	7.22	0.889	1.156	0.772	8.55E+07	6.36E+08	5.97E+07
116	stralsund	germany	5.36E+08	1	2	2	6.50	0.870	1.228	0.666	1.46E+08	1.29E+09	4.93E+08
117	rugen	germany	9.07E+08	2	2	1	1.55	0.871	1.228	0.662	4.24E+08	2.26E+09	5.08E+08
118	pommerse	poland	1.68E+09	3	2	1	1.43	0.890	1.156	0.769	6.86E+08	3.84E+09	1.24E+09
119	gdansk	polad	2.09E+09	1	2	1	0.85	0.834	1.440	0.304	2.09E+08	2.24E+09	3.90E+09
120	koerishe_haf	russia	2.72E+09	1	2	1	0.75	0.805	1.771	0.000	2.72E+08	2.63E+09	5.31E+09
121	riga	russia	3.66E+10	3	2	1	0.37	0.835	1.441	0.301	3.66E+09	2.07E+10	8.40E+10
122	timan_1	russia	1.92E+08	2	1	2	11.13	0.835	1.441	0.298	4.66E+07	6.76E+08	6.62E+07
123	timan_2	russia	8.52E+08	1	1	2	5.59	0.892	1.155	0.765	1.82E+08	1.71E+09	1.05E+09
124	petsjora	russia	1.51E+10	9	1	2	4.35	0.872	1.228	0.654	1.51E+09	2.21E+10	2.51E+10

125	gaspe	canada	6.97E+09	1	1	5	8.66	0.835	1.441	0.288	1.59E+08	2.54E+09	1.93E+10
126	new_brunswick	canada	8.11E+08	1	1	2	5.68	0.836	1.441	0.282	1.80E+08	1.66E+09	9.74E+08
127	edward_island	canada	1.45E+10	2	4	2	2.24	0.891	1.155	0.762	1.45E+09	9.53E+09	3.33E+10
128	fundy_bay_north	canada	1.61E+09	1	4	5	4.43	0.893	1.154	0.762	1.61E+08	2.50E+09	2.55E+09
129	fundy_bay_south	canada	2.87E+09	1	4	5	12.67	0.893	1.154	0.762	4.96E+07	2.28E+09	7.24E+09
130	fundy_bay_east	canada	1.65E+08	1	4	5	44.44	0.836	1.442	0.271	7.56E+06	6.35E+08	2.03E+08
131	funday_bay_west	canada	1.83E+09	2	4	5	30.88	0.891	1.155	0.761	3.39E+07	2.82E+09	4.39E+09
132	bangor_north	united states	8.11E+08	2	4	4	27.17	0.771	6.508	0.000	4.35E+07	2.13E+09	1.17E+09
133	bangor_south	united states	5.22E+08	2	4	4	30.15	0.837	1.441	0.260	3.15E+07	1.65E+09	6.08E+08
134	august	united states	2.47E+08	2	4	4	35.31	0.898	1.151	0.761	1.58E+07	1.01E+09	1.99E+08
135	cape_kod	united states	1.47E+09	1	4	2	4.61	0.838	1.441	0.254	1.47E+08	2.39E+09	2.24E+09
136	new_bedford	united states	5.50E+08	1	4	2	6.45	0.838	1.441	0.251	1.49E+08	1.32E+09	5.04E+08
137	rode_island	united states	7.01E+08	1	4	2	5.96	0.838	1.441	0.248	1.73E+08	1.55E+09	7.42E+08
138	lon_island	united states	3.57E+08	1	3	3	11.82	0.838	1.441	0.248	5.49E+07	9.90E+08	2.95E+08
139	philadelphia	united states	3.30E+08	3	3	2	10.70	0.773	6.649	0.000	8.21E+07	1.14E+09	1.15E+08
140	delaware_bay	united states	3.12E+09	1	3	2	3.29	0.895	1.152	0.757	3.12E+08	3.32E+09	6.18E+09
141	chincoteague_bay	united states	3.43E+08	2	3	2	9.34	0.895	1.152	0.757	9.26E+07	1.09E+09	1.54E+08
142	chesapeake_bay	united states	1.74E+10	1	3	3	1.49	0.895	1.152	0.756	1.74E+09	7.02E+09	4.37E+10
143	albmarle_pamlico_sound	united states	1.14E+10	6	3	3	6.75	0.895	1.152	0.756	5.18E+08	1.49E+10	2.16E+10
144	cape_fear	united states	6.87E+07	1	3	3	24.17	0.905	1.123	0.802	7.24E+06	2.95E+08	2.83E+07
145	winyah	united states	8.24E+07	1	3	3	23.21	0.842	1.438	0.228	8.85E+06	3.40E+08	3.67E+07
146	charleston	united states	1.79E+08	1	3	3	19.19	0.843	1.436	0.211	2.03E+07	6.09E+08	1.17E+08
147	st_helena_sound	united states	3.02E+08	1	3	3	16.64	0.841	1.438	0.202	3.36E+07	8.88E+08	2.65E+08
148	broad_river	united states	3.30E+08	1	3	3	16.24	0.776	6.827	0.000	3.62E+07	9.43E+08	3.04E+08
149	sepalo_sounds	united states	1.51E+08	1	3	3	20.03	0.899	1.148	0.751	1.70E+07	5.38E+08	9.02E+07
150	simons_sounds	united states	2.20E+08	1	3	3	18.16	0.937	1.042	0.924	2.49E+07	7.09E+08	1.61E+08
151	cape_canaveral	united states	1.11E+09	2	3	3	10.34	0.880	1.222	0.626	1.51E+08	2.67E+09	1.19E+09
152	cape_cable	united states	3.57E+08	1	3	2	7.41	0.882	1.219	0.619	1.03E+08	9.63E+08	2.55E+08
153	everglades_1	united states	1.51E+08	1	3	2	9.72	0.847	1.429	0.126	3.99E+07	4.92E+08	6.30E+07
154	charlotte_harbour	united states	1.02E+09	4	2	2	8.26	0.903	1.143	0.743	2.88E+08	2.98E+09	5.82E+08
155	tampa_bay	united states	1.20E+09	1	2	2	5.00	0.905	1.141	0.742	1.51E+08	2.12E+09	1.68E+09
156	apalchicola_bay	united states	8.66E+08	4	2	2	8.69	0.930	1.062	0.881	2.41E+08	2.62E+09	4.48E+08

157	panama_city	united states	7.28E+08	1	2	2	5.88	0.849	1.424	0.079	1.75E+08	1.57E+09	8.01E+08
158	pensacola_bay	united states	1.36E+09	2	2	2	6.02	0.851	1.421	0.071	3.40E+08	3.01E+09	1.44E+09
159	mobile_bay	united states	1.26E+09	2	2	2	6.16	0.851	1.420	0.066	3.27E+08	2.87E+09	1.28E+09
160	galveston	united states	1.63E+09	1	2	2	4.40	0.853	1.417	0.047	1.63E+08	2.49E+09	2.64E+09
161	mantagorda_bay	united states	1.28E+09	2	2	2	6.14	0.855	1.415	0.006	3.29E+08	2.89E+09	1.31E+09
162	san_antonio_bay	united states	6.46E+08	2	2	2	7.66	0.860	1.412	0.000	1.86E+08	1.79E+09	4.32E+08
163	aransas_bay	united states	8.11E+08	2	2	2	7.12	0.855	1.416	0.000	2.32E+08	2.11E+09	6.27E+08
164	corpus_christi_bay	united states	8.66E+08	1	2	2	5.56	0.913	1.134	0.724	1.83E+08	1.75E+09	1.04E+09
165	laguna_de_terminos	mexico	2.69E+09	2	3	2	4.79	0.931	1.080	0.827	2.68E+08	4.52E+09	4.01E+09
166	holbox_lagoons	mexico	3.98E+08	1	3	1	1.62	0.857	1.415	0.000	2.00E+08	1.04E+09	1.85E+08
167	cozumel	mexico	1.54E+09	2	2	1	1.28	0.860	1.413	0.000	4.72E+08	3.00E+09	1.62E+09
168	ascension_bay	mexico	5.08E+08	1	2	2	6.61	0.867	1.410	0.000	1.41E+08	1.24E+09	4.53E+08
169	chetumal	belize	3.16E+09	3	2	2	5.21	0.943	1.055	0.873	5.21E+08	5.92E+09	4.20E+09
170	caratasca_lagune	honduras	8.66E+08	1	2	1	1.22	0.918	1.130	0.709	2.29E+08	1.57E+09	1.02E+09
171	rio_grande_delta	nicaragua	5.36E+08	1	2	2	6.50	0.918	1.130	0.709	1.46E+08	1.29E+09	4.93E+08
172	el_buff	nicaragua	1.92E+08	2	2	2	11.13	0.900	1.202	0.545	4.66E+07	6.79E+08	6.27E+07
173	san_san_lagune	panama	1.94E+09	4	2	3	14.56	0.865	1.409	0.000	1.92E+08	4.83E+09	2.22E+09
174	isla_salamanca	colombia	5.36E+08	2	3	1	1.87	0.920	1.128	0.704	3.17E+08	1.53E+09	1.36E+08
175	restinga_laguna	venezuela	7.56E+08	1	2	2	5.81	0.803	6.302	0.000	1.78E+08	1.61E+09	8.49E+08
176	rio_mearim_estuary	brasil	4.25E+09	1	2	4	12.40	0.966	1.029	0.915	6.84E+07	2.27E+09	1.16E+10
177	central_bahia	brasil	1.59E+09	2	2	3	12.58	0.870	1.401	0.000	1.14E+08	3.20E+09	2.36E+09
178	guaratiba_bay	brasil	2.51E+09	2	3	2	4.92	0.925	1.124	0.688	2.72E+08	4.37E+09	3.62E+09
179	paranagua_bay	brasil	1.21E+09	1	3	2	4.98	0.875	1.394	0.000	1.48E+08	2.14E+09	1.71E+09
180	tubarao_lagoon	brasil	7.14E+08	2	3	2	7.41	0.927	1.121	0.680	2.05E+08	1.93E+09	5.10E+08
181	peixe	brasil	1.37E+10	1	3	2	1.66	0.877	1.391	0.000	1.37E+09	6.23E+09	3.38E+10
182	rio_negro	argentina	3.60E+10	1	4	2	1.05	0.928	1.120	0.678	3.60E+09	1.08E+10	9.28E+10
183	baya_blanco	argentina	2.54E+09	1	3	4	3.61	0.811	5.866	0.000	2.54E+08	3.04E+09	4.77E+09
184	rio_colorado	argentina	1.72E+09	1	3	4	17.97	0.929	1.120	0.676	2.18E+07	1.83E+09	4.21E+09
185	rio_deseado	argentina	1.65E+08	1	4	4	33.33	0.913	1.188	0.478	1.04E+07	6.15E+08	1.53E+08
186	isla_puna	ecuador	3.81E+09	2	2	2	4.11	0.945	1.058	0.827	3.81E+08	5.34E+09	6.50E+09
187	rio_chone	ecuador	1.51E+08	1	2	4	33.94	0.882	1.380	0.000	9.59E+06	5.74E+08	1.40E+08
188	rio_santiago	ecuador	3.85E+08	1	2	4	27.52	0.883	1.379	0.000	2.10E+07	1.02E+09	5.62E+08

189	panama_bay	panama	7.97E+08	1	2	4	14.86	0.916	1.184	0.457	4.64E+07	1.56E+09	1.28E+09
190	rio_san_pablo	panama	6.87E+08	2	2	4	22.47	0.935	1.113	0.653	5.08E+07	1.93E+09	8.05E+08
191	armuelles	costa rica	1.13E+09	1	2	3	11.34	0.922	1.176	0.419	4.68E+07	1.89E+09	1.95E+09
192	piedras	costa rica	2.39E+09	1	2	3	8.40	0.962	1.041	0.839	7.45E+07	2.49E+09	5.23E+09
193	fonseca_gulf	honduras	2.73E+09	1	2	3	7.93	0.954	1.101	0.608	8.86E+07	2.59E+09	6.17E+09
194	mar_muerto	mexico	2.47E+08	1	3	3	17.59	0.975	1.035	0.819	2.79E+07	7.72E+08	1.93E+08
195	lugana_superior	mexico	2.20E+08	1	3	3	18.16	0.974	1.042	0.771	2.49E+07	7.09E+08	1.61E+08
196	tiburon	mexico	1.03E+09	2	2	3	14.30	0.912	1.299	0.000	9.97E+07	2.51E+09	1.22E+09
197	baja_california	mexico	2.75E+08	2	2	4	28.02	0.979	1.018	0.875	2.20E+07	1.05E+09	2.00E+08
198	magdalena_bay	mexico	2.31E+09	4	2	3	10.23	0.931	1.293	0.000	3.08E+08	5.45E+09	2.53E+09
199	sebastian_vizcaino_bay	mexico	1.09E+09	1	2	3	11.47	0.979	1.031	0.796	4.92E+07	1.86E+09	1.85E+09
200	san_diego	united states	3.57E+08	1	3	3	15.88	0.862	3.713	0.000	3.87E+07	9.95E+08	3.44E+08
201	santa_monica	united states	3.57E+08	1	3	3	15.88	0.942	1.235	0.000	3.87E+07	9.95E+08	3.44E+08
202	san_fransisco	united states	2.69E+09	1	3	3	7.98	0.950	1.212	0.000	8.68E+07	2.58E+09	6.05E+09
203	colombia_river	united states	6.87E+08	1	4	3	13.15	0.964	1.154	0.000	5.63E+07	1.50E+09	9.25E+08
204	willapa_bay	united states	7.01E+08	1	4	3	13.07	0.982	1.122	0.000	5.66E+07	1.52E+09	9.53E+08

