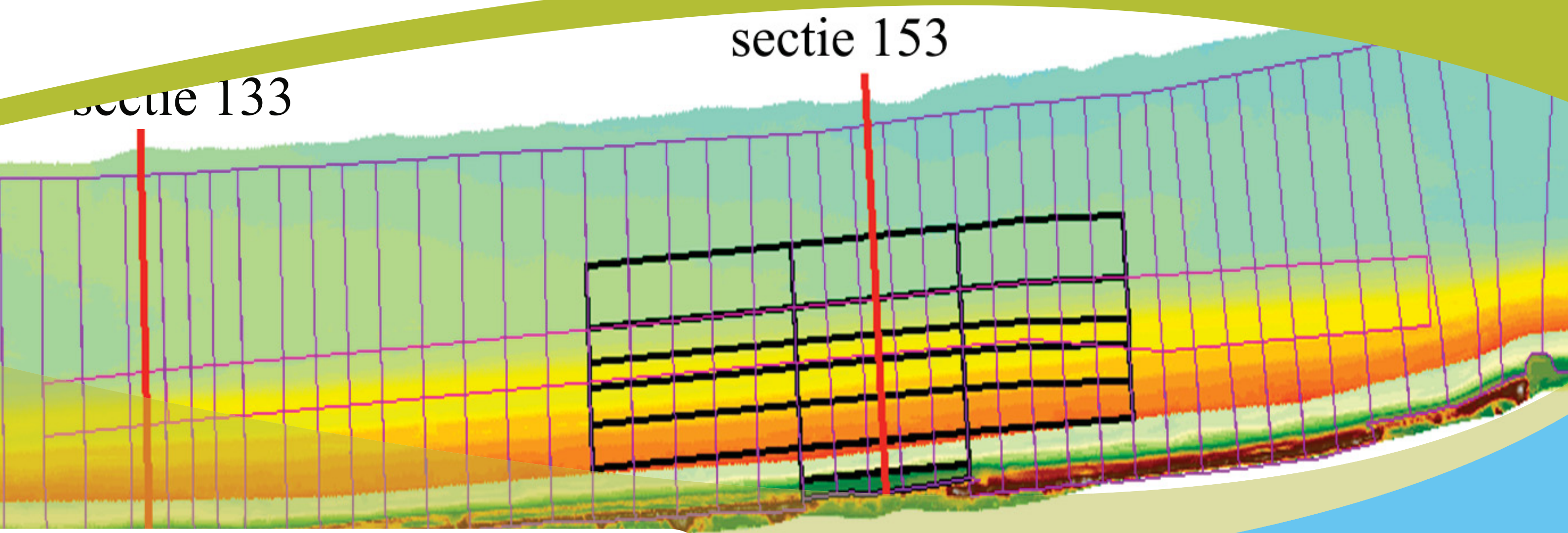
Mobility and Public Works department

Evaluation of a shoreface nourishment in De Haan

ANALYSIS OF 20 YEARS OF DATA



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Vlaamse overheid

Evaluation of a shoreface nourishment in De Haan

Analysis of 20 years of data

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1.0	22/08/2012	Concept version	Rik Houthuys
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Abstract

In the framework of the implementation of the Master Plan for Coastal Safety and Vlaamse Baaien project, an assessment of the added value of shoreface nourishment as coastal protection measure and as alternative to classic procedures for beach nourishment maintenance will be performed. This project, entitled “Shoreface nourishments as coastal protection measure”, is carried out at Flanders Hydraulics Research with as central activity the monitoring of a pilot shoreface nourishment that will take place in 2013 in Mariakerke.

The only antecedent of a shoreface nourishment in Belgium is the nourishment performed in De Haan in 1990. This document brings together results from the monitoring carried out in the 90’s as well as new results obtained from later surveys in the study area. The results is a more than twenty years analysis of the morphological evolution of the coast at the Haan. The interpretation of the results is not straight forward due to the various nourishments performed since then in neighboring areas. However, it is possible to conclude that after a local cross-and long-shore redistribution of the sand nourished in the shoreface, this sand has not been transported and therefore has remain in the system acting as sand supply for the beach.

A general reduction of the background erosion has also been detected during this analysis but the fact that during the study period no severe storms occurred makes it difficult to draw a definitive conclusion in this regard.

Taking into account the difficulties encountered to draw conclusions on the evolution of the beach and shoreface in De Haan during this study and the goals of the new project it is recommended that during the monitoring of the pilot shoreface nourishment to be started in 2013 no other nourishments on the beach and/or neighboring shoreface and beaches are executed.

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1 Introduction

To evaluate the coastal morphological impact of shoreface nourishments, the present report reassesses existing data documenting the morphological evolution of the shoreface nourishment carried out in the 1990s in and near De Haan (about 9km east of Oostende). The report also updates the further morphological evolution of the area to 2011, by spatially refining some of the results reported in “Morfologische trend van de Vlaamse kust tot 2011” (Houthuys, 2012).

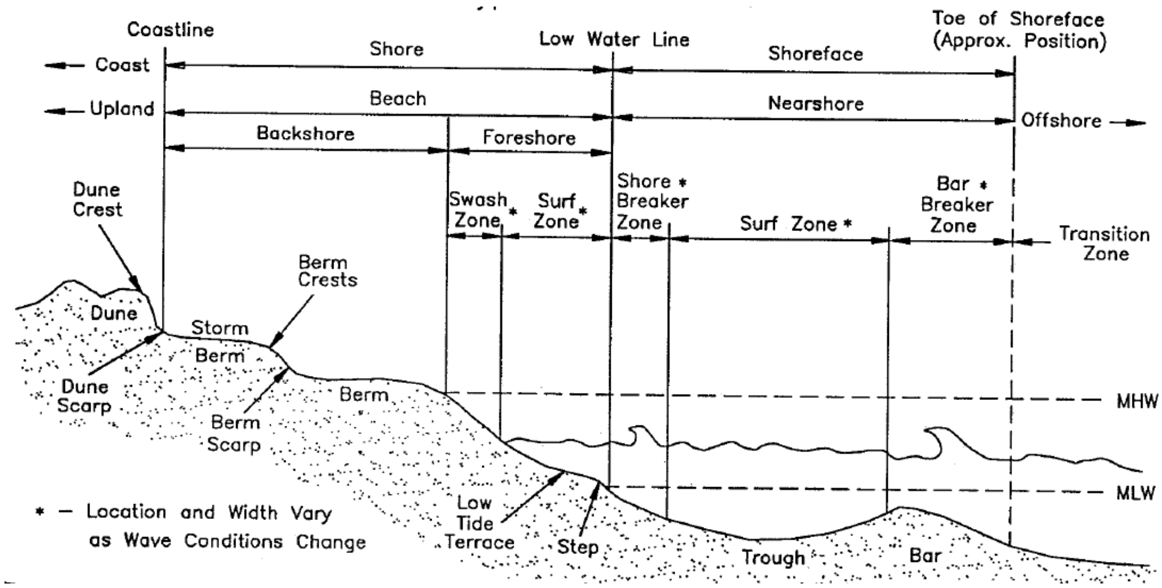


Figure 3.1 Definition of morphological description terms used in this report.

In and around De Haan, 3 or 4 breaker bars are present in the coastal profile. The one where shoreface nourishments have taken place in the 1990s is the most seaward bar or outer bar. It was at the time of nourishment in some documents also indicated by the term “feeder berm”. In the coastal monitoring surveys, the national Belgian height datum “TAW” (Tweede Algemene Waterpassing or Second General Height Levelling) is used. Its zero is approximately MLLW. By convention, in the coastal morphological monitoring surveys, the upper limit of the foreshore is placed at +4.39m TAW, the lower limit at +1.39m TAW which is also the upper limit of the nearshore, and the nearshore lower limit is at –4.11m TAW. When referring to the nearshore as the underwater continuation of the sloping beach, in this report the term “shoreface” is preferred.

The Belgian coast is subdivided into areal sectors, called sections, that each contain some 200 to 300m of coastal length, and are bounded at the land side by the seawall or the crest or landward foot of the outer dunes. The boundaries between sections are perpendicular to the general coast direction and are chosen to coincide with the crest of groins if present (in De Haan there are no groins). The sections are numbered from West to East. Their boundaries do not change in time and are defined by coordinates in the Belgian planimetric reference system Lambert 1972. The area of interest of this report is between the seaside resorts of Bredene (about 2 km east of Oostende) and Wenduine (about 13 km east of Oostende), from section 131 to 172 (see Figure 3). The central focus area is the beach and shoreface of De Haan in front of the seawall which had a length of about 1000m and is covered by sections 151 to 155.

2 Description of the 1990s nourishment scheme at De Haan

The beaches in and near De Haan suffered erosion during decades. Around 1980, in 18 sections west of De Haan a system of Longard tubes was installed (Eurosense, report MIWE 92.001). This measure was accompanied with sand nourishments. The tubes were installed in sections 133 to 142 in the spring of 1978. Around and between the sand-filled geotextile tubes, a sand fill of 558,230m³ was carried out. In a second phase, a similar system of tubes was laid in sections 142 to 150 in the second half of 1980 and 686,370m³ of sand were filled around the tubes. In spite of this work, erosion went on, especially on the foreshore.

During several storms at the end of the 1980s, but especially during the 28 February 1990 storm, all beaches in and near De Haan lost several thousands of cubic metres and high erosion cliffs were cut in the dune front. It was estimated that by spring 1990, depending on the site, between 30 and 45% of the sand nourished west of De Haan in 1978-1980 had been eroded (Eurosense reports). The beach in De Haan-Centrum was kept at a safe enough level (the criterion being that a wide enough backshore should be present in front of the seawall to allow tourist use of the beach at all times) by yearly beach scrapings and small-scale sand fills, mostly carried out in May, before the start of the tourist season. The amounts involved are reported in the beach morphological monitoring reports and are summarized in Houthuys (2012). Over the 10 year period preceding the 1992 beach nourishment, a total of ca. 380,000m³ of sand had been used for the yearly fills, of which about 55% was trucked in from sea borrowed stocks and the remaining 45% was scraped up from near the low-water mark. The top year was 1990, when 55,800m³ had to be trucked in and another 26,800m³ was bulldozed up to restore the backshore after the severe February 1990 storm.

Samples were taken on 31 May 1990 (Haecon, 1990, p. 99). The median grain size at that time was between 200 and 230 µm, with a mean of about 220 µm, on the beach at De Haan, while the shoreface was a bit finer and less well sorted (mean grain size about 180 µm). The adjacent seabed yielded samples between 160 and 200 µm with variable amounts of mud.

It appeared that during the February 1990 storm, wave force had been focused on the beaches of De Haan (Haecon, 1990). A novel idea to protect the coast was introduced. The beaches would be repaired by beach and dune foot nourishments (called beach nourishment in this report), but at the same location and slightly preceding the beach nourishment, a shoreface nourishment (below the low-water mark) was to be performed to create a “feeder berm”. This is a sand fill on the submerged outer breaker bank, of which it was hoped that it would act as a source to feed the foreshore by fair-weather beach building processes. The work first focused on the seaside resort of De Haan (phase 1) and was in subsequent years extended west- and eastward of De Haan (phase 2).

2.1 Phase 1 : centre of De Haan

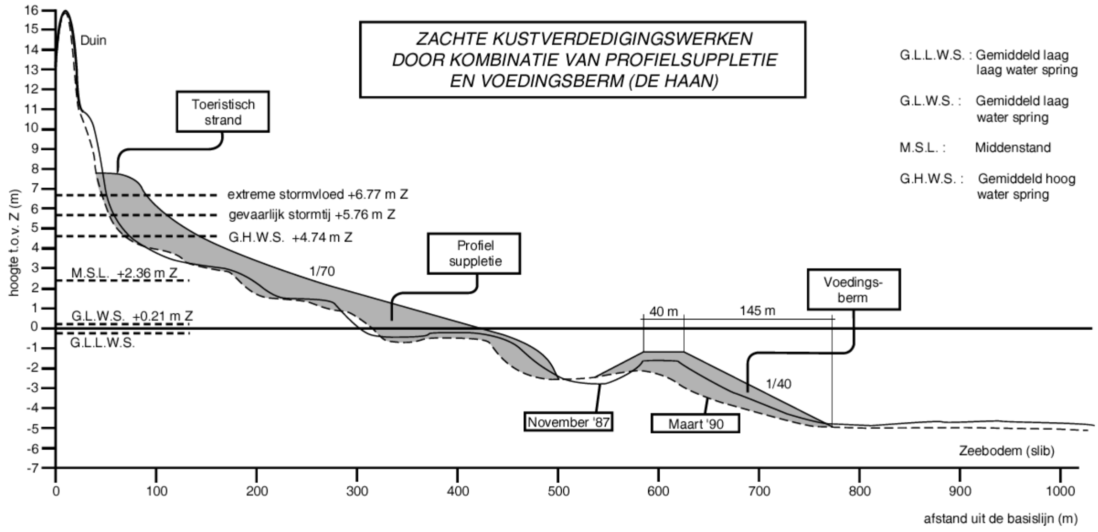


Figure 4.1 Design profile of the 1991-1992 feeder berm ("voedingsberm") and 1992 beach profile nourishment ("profielsuppletie") in De Haan. Full horizontal line is 0m Z = -0.11m TAW.

The feeder berm was constructed at the seaward side of the outer bar (De Wolf et al., 1997). Its construction involved the supply of ca. 220 m³/m of fine sand (D50 ≥ 180 µm). The slopes connecting the bar crest had a design value of 1:40. The bar crest design width was 40m. The profile nourishment raised the beach under a slope of 1/70 by applying ca. 375 m³/m of medium-sized sand (D50 ca. 300 µm).

The crest of the feeder berm was designed at 1m below low water level (Z – 1m = TAW – 1.11m).

The feeder berm was made by dumping sand, borrowed from deepening works in the Oostende harbour access channel, at high tide. The feeder berm was built in the year preceding the beach nourishment (see Table 1). The sand for the beach nourishment was borrowed in the offshore navigation channel "aanloop Scheur". Grain sizes of the dredged sand varied between 190 and 300 µm on board of the dredger. After pumping it on the beach, in-situ samples were taken which had D_{50} grain sizes of 275 to 325 µm. The reason for the coarser grain size is that when pumping a sand-water mixture on the beach, the fine sand fractions wash out (Eurosense, BERM 95.001 and 002).

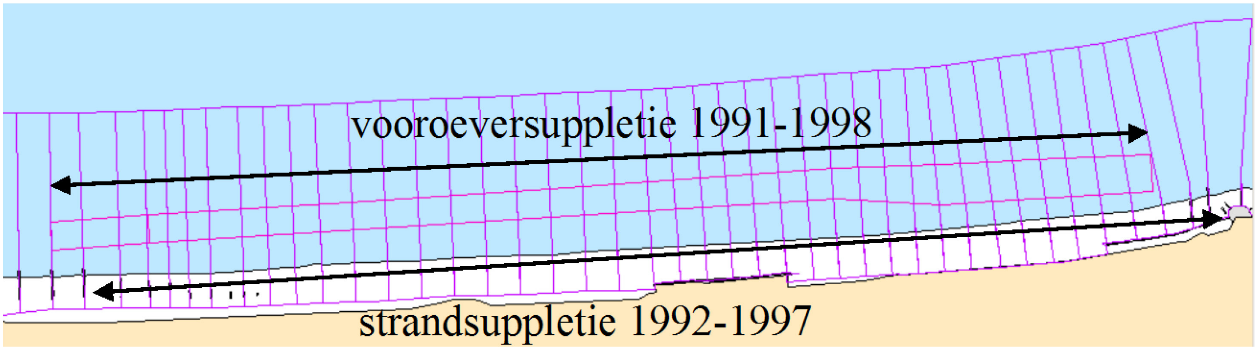


Figure 4.2 Plan view of the 1990s coastal defence works at and near De Haan. Fine purple line outlines sections. First full section on the left is n° 130, last full section on the right is n° 172. The resort of Bredene is just outside the left margin of the map. De Haan seawall is in the middle above the text "1992-1997". In the far right is the seawall square "rotonde" of Wenduine, that marks a break in the coastline direction. Fine red line is outline of the feeder berm. "Vooroeversuppletie" = shoreface nourishment, "strandsuppletie" = beach nourishment.

2.2 Phase 2: from Bredene to Wenduine

As the first tests proved successful, it was decided to apply the same lay-out for the nearly 9 km coast from section 131 near Bredene to section 172 in Wenduine. The site protected in phase 1 is in the middle of the coastal tract involved in phase 2 and some sections at the outskirts of phase 1 received a second nourishment in phase 2. This phase involved large amounts of sand to be spread on the beach and to be dumped on the shoreface. The work was therefore carried out in phases spread over 1993-1998. Also here, the feeder berm was locally constructed before the corresponding part of the beach nourishment. Some information on grain sizes involved in the beach nourishments of phase 2a can be found in Eurosense (1995) :

- the most urgent part of the second phase of the beach nourishment was carried out in November-December 1994 over a beach length of 670m near the beach entrance “Vosseslag” (sections 140-142). The sand was borrowed offshore on the Kwinte Bank and in the navigation channels near “A1-boei Scheur”. Samples taken on board the dredgers had D_{50} ranging from 350 – 400µm. The cumulative volume onboard was 203,440m³. The mean D_{50} on the beach after nourishment was 376µm;
- the next part from section 134 to 149 was nourished in April – June 1995. The sand was borrowed on the Kwinte Bank (samples with D_{50} of 380 to 500µm) and in the navigation channels near “A1-boei” (D_{50} of 300µm). The cumulative volume onboard was 894,611m³. The mean D_{50} on the beach after nourishment was 388µm with values ranging from 350 to 400µm;
- a next stage at the west side in sections 132 to 134 was carried out between 2 and 10 October 1995. The volume onboard was 118,851m³. No data on grain size have been reported;
- a final stage around section 144 involved an onboard volume of 223,062m³. Also here, no grain sizes have been reported.

No grain sizes have been reported for the shoreface nourishments carried out around the same time in these sections.

Also for the beach nourishment east of De Haan (phase 2b), sand of maintenance dredging works was used to realise the sand fill. Of this particular phase, and of the accompanying shoreface nourishments, no grain sizes have been reported (Eurosense, 1997, report MIWE 97.002).

In 1998-2000, replenishments of the feeder berm were carried out locally between Bredene and De Haan.

The timing and amounts involved in the 1990s nourishment scheme at and near De Haan are summarized in Table 1.

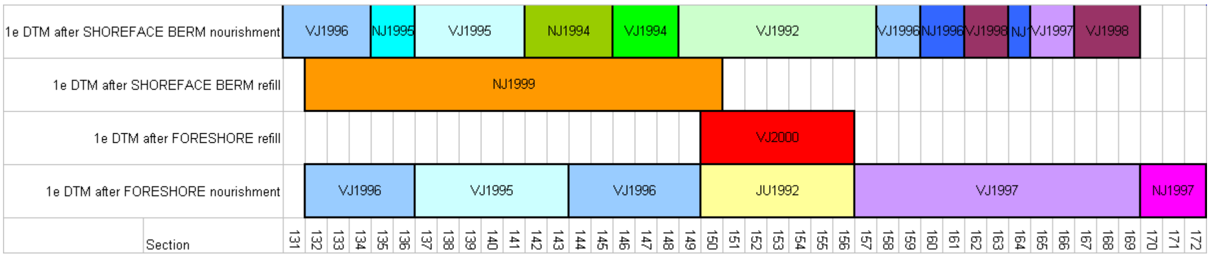
Table 1 – Timing and amounts involved in the 1990s nourishment scheme at and near De Haan (Houthuys, 2012).

Timing	*Nourishment type*	*Location*	*Length (m)*	*Volume onboard (m³)*	*Volume increment between 2 surveys (m³)*	*Efficiency ship vs. in situ volume based on measurements at other fill projects*	*part assumed above LW*	*part assumed below LW*
Feb-Jul 1991 & Dec91-Mar92	underwater berm phase 1	sections 148-157	2170	661787	556100	0.78		1
Apr-May 1992	beach phase 1	sections 149-158	2200	794365	583200	0.85	0.8	0.2
Nov93-Sep94 & Oct-Dec95	underwater berm phase 2a	sections 131-148	4043	649128	477600	0.78		1
Nov94-Nov95	beach phase 2a	sections 132-149	3250	1439964	1049200	0.85	0.9	0.1

Jan96-Feb98	underwater berm phase 2b	sections 158-169	2400	471493	205700	0.78		1
Mar-Oct96	beach phase 2b	sections 157-172	3200	1002385	696400	0.85	0.9	0.1
Feb98-Aug99	supplementary dumps at underwater berm	sections 132-150	4318	94989	?	0.78		1
May-Jun 2000	supplementary beach fill	sections 150-156	1200	260493	?	0.85	0.8	0.2

Several monitoring surveys were carried out at the time. Due to the stepwise realisation of the project, the first survey after local completion differs significantly from section to section. Table 2 summarizes this.

Table 2 – Overview of timing and location of the several components in the 1990s De Haan coastal restoration scheme.
“VJ” = “voorjaar” = spring survey; “NJ” = “najaar” = fall survey.



No exact timing of the supplementary shoreface nourishments in sections 132-150 in 1998-1999 is known, but according to the volume time series in Houthuys (2012), it can be assumed they took mostly place between VJ1999 and NJ1999.

3 Summary of the morphological monitoring reports in the 1990s

Within months after the completion of a particular section of feeder berm, its crest was lowered by 0.5 to 1 m (De Wolf et al., 1997). The sand was transported both in alongshore (prolonging the extremities of the artificial berm) and cross-shore directions (feeding a nearshore linear area situated 150 m landward).

Likewise, the intertidal part of the beach nourishment area was soon re-modelled into a beach bar morphology. This process involved a net loss of sand to (i) the dune foot area where eolian sand was trapped, (ii) neighbouring parts of the beach, especially in the downdrift direction, east of De Haan, and (iii) the adjacent part of the nearshore. From the morphological follow-up, there was no indication of a net loss towards the offshore.

The Eurosense monitoring reports “Kustmorfologie. Gecombineerde resultaten (Koppeling)” in the period 1992-1997 contain more details. A collection of relevant extracts of these reports is grouped in Annex 1. The extracts are from various parts in the section of each report that deals with the coast between Bredene and Wenduine. The conclusions of morphological changes related to the shoreface nourishments are as follows :

- the shoreface nourishment was carried out over several years, first in De Haan-Centrum, later west and finally east of De Haan. Each time, a similar local response followed : flattening of the bar’s crest by about 0.5m in the first weeks to months after the sand dumping works and accretion in a coast-parallel strip, landward of the nourished bar (location and time of appearance of the accretion strip suggests the nourished berm is the source of the accretion);
- a second coast parallel shoreface accretion strip, situated more landward, appeared each time a beach nourishment was carried out, facing the beach fill;
- a few years after the shoreface nourishment, the crest was 1 to 1.5m deeper than the design level;
- though the major morphological response was in the transverse direction, each time also some accretion both west and east of the constructed berm was noted. This was interpreted as a feature due to longitudinal transport. The measurable effect (height differences in excess of 0.25m) was most often limited to one section (about 200m) neighbouring the freshly dumped sites, though in 1996, accretion of up to 0.5m occurred till almost 1km west of the western tip of the shoreface nourishment. This demonstrates an important role of the longshore transport, even westward. In this way, earlier constructed parts of the underwater bank may have profited from new dump activities;
- the coast around De Haan with its typical ridge-and-runnel morphology showed foreshore accretion and shoreface erosion after quiet months and foreshore erosion along with shoreface accretion after stormy months. This phenomenon was present throughout the series of spring and fall echosounding surveys, before and during the shoreface nourishment scheme. The shoreface nourishment may have enhanced the landward transport, but not in demonstrable quantities;
- no influence of the shoreface nourishments was remarked on the nearby sea bottom. After a few years, the seaward base of the nourished bank started to erode.

4 Data preparation

4.1 Available DTMs

The present study makes use of the data and results of the project “Morfologische trend van de Vlaamse kust tot 2011” (Houthuys, 2012), shortly referred to as “Kusttrends”. From that study, 10x10m DTM grids were available for all nearshore echosounding surveys from VJ1997 onwards (VJ = “voorjaar” = spring; NJ = “najaar” = fall). The study provides also time graphs of beach (actually, the part of the section above the low water plane) and nearshore-and-seabed (the part of the section below the low water plane) volumes. For contiguous coastal tracts, corrected time graphs are available, in the sense that the volumes of sand added or subtracted from the area have been removed or added to the observed volumes. The coastal tracts n° 29 to 35 cover the 1990s nourishment area.

4.2 Purpose created DTMs

In view of the detailed developments during the De Haan coastal defence scheme, more data were needed to cover the 1990s.

To achieve this, use was made of digitised depth contours available at WL. The available data sets cover all NJ surveys from 1987 to 1999 in the area from section 146 (about 1 km west of De Haan-Centrum) to section 176 (east end of Wenduine resort). The datasets are in dwg format and contain polylines of all whole metre contour lines from –6 to +1m Z, and in addition the +1.5, +3 and +4.5m Z lines. The source of the data is very likely the 1/10,000 paper map of the “Kustmorfologie. Gecombineerde resultaten” reports. The lines were digitised in the UTM zone 31 system (ED50).

For our purposes, they had to be projected in Lambert 72 and converted to TAW. For the projection conversion, use was made of CoordConvert.exe made available by the National Geographic Institute. This tool requires previous conversion of polylines to points. The 2D coherence of the dataset is then lost.

In order to verify the data quality, scans were made (at Coastal Division) of the corresponding 1/5,000 echosounding maps, available on paper. These scans were georeferenced using two tick marks left and right of the data area. The error of the scan and the georeferencing is estimated to be smaller than 4m (in XY). On a 1:40 slope this may give rise to a modelled morphology that is maximally 0.1m too shallow or too deep. This value is comparable to the error of height referencing the echosoundings.

The digitised contour lines proved to be between 0 and 15m removed from the contour lines on the scanned maps. Most often, the digitised contour lines were systematically offset to the seaward side, making the DTM shallower than the real morphology. No immediate explanation was found for this often systematic shift. Had heights in TAW inadvertently been digitised instead of heights in Z, entire number contour lines in TAW would be shifted a bit landwards instead of seawards. The local slope at the seaward flank of the most important breaker bank is 1:40. This would, when making a DTM based on the digitised contour lines, give (locally) rise to a morphology that is up to 1m x (15/40) = 0.375m too shallow. Such deviations are evaluated to be too large for the detailed morphological effects we want to monitor. It is concluded that the 1/10,000 maps of the combined surveys were either ill scanned or give a representation of the seabed morphology that is too shallow.

It was also realized that the echosounding map is already an upper wrap of the bed morphology as minimum depths were at the time of survey routinely selected within 10 to 15m windows along track during the map making.

It was decided that good-quality data were essential for the present (and future) studies. Therefore, digitisation was done over again. This rather time-consuming step allowed to create intermediate contours where necessary. Also, 3D-polylines were inserted at troughs and crests, so that these important features would not be omitted in the DTM. Creating new digital contour lines based on mentally visualizing the bed morphology from the depth figures furthermore offers the advantage of allowing to correct for zigzagging contour lines related to the effect of navigation direction. Moreover, some compensation can be made for the ‘minimum depth’ sampling method during echosounding, by drawing contours at the transition to the next shallower figure.

Digitising like this requires to constantly interpret the morphology, which is quite an effort – but the result is attractive (Figure 4).

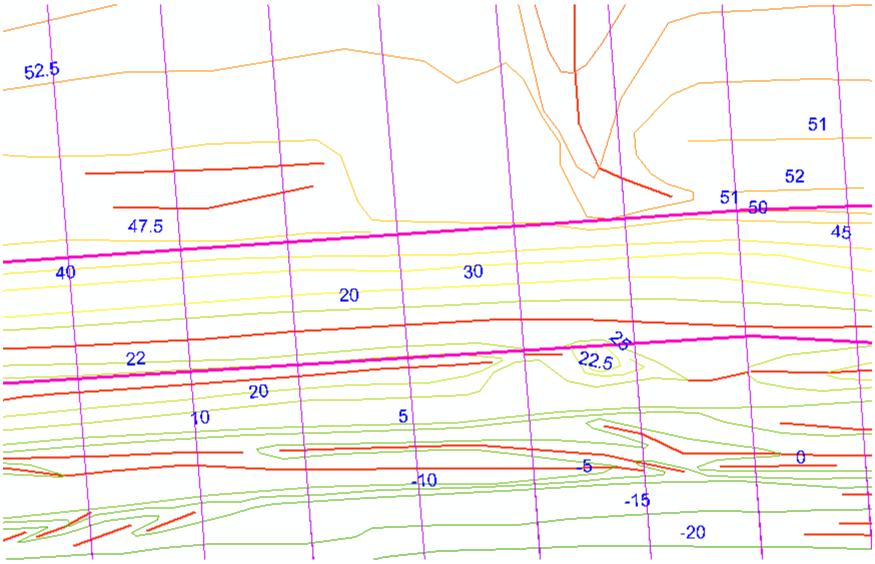


Figure 6.1 Example of a set of contour lines and break lines digitised on a scanned paper print of the VJ1993 survey (fine purple lines are section boundaries). Elevations are here recorded as depths in dm below Z. They are later converted to TAW. Colour coding the contour lines allows to check the coherence of the digitisation work.

After new digitisation, a TIN was produced on the basis of digitised lines input as hard break lines. The TIN was then converted into a 10x10m grid.

In this way, a DTM for sections 146 to 176 was created for the surveys NJ1990, VJ1993, NJ1994 and NJ1995.

4.3 Cross-shore profiles

It was realized that major efforts would be required to cover the complete time and space resolution of the study area. Therefore, it was decided to make two representative cross-shore profiles (Figure 5), at numerous surveys in time, to look at the dynamics at these locations first.

A profile in section 133, near the beach access “Hippodroom”, was chosen as this is near the western extremity of the nourishment works. It had been reported in the 1990s monitoring reports that cross interferences between the several phases of the nourishment works occur. The 1990s reports suggested the western sections of the nourished area might be the first to suffer renewed erosion. The location in section 133 may be little affected by additional nourishments. A profile was then defined by its start point at X = 53006.559 and Y = 217164.906 and its end point at X = 52004.004 and Y = 218774.781 (all coordinates in Lambert 72).

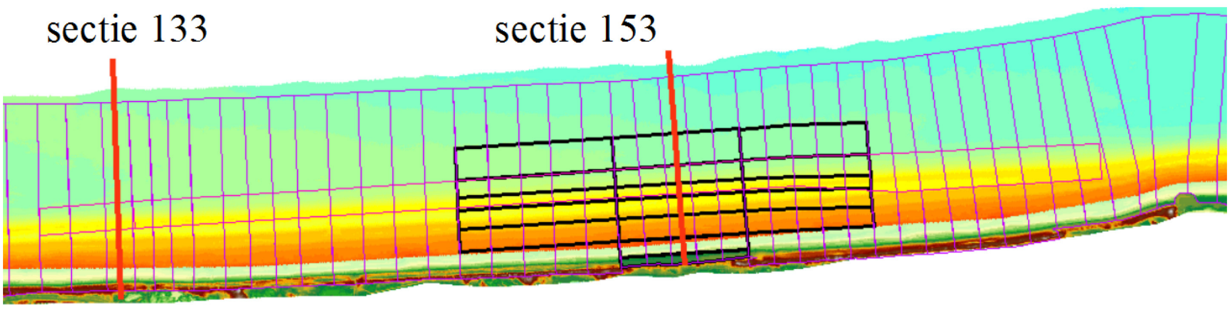


Figure 6.2 Location of the two cross-shore profiles (red) and the boxes (black) used to study the evolution of the nourishments at De Haan. Background is the 2011 DTM.

The second profile was chosen in the middle of De Haan-Centrum, in section 153. This profile would cover all interactions between the different steps of the nourishment scheme. It is defined by its start point at X = 56716.679 and Y = 219618.147 and its end point at X = 55757.053 and Y = 221020.997.

The profiles were simply measured on the scanned 1/5000 echosounding maps of NJ1987, NJ1988, NJ1989, NJ1991, VJ1995, and VJ1996. Automatic profiles were generated for all the available DTMs till 2011.

4.4 Further data from mean profiles

For some echosounding surveys, the maps could not be retrieved. In these cases, use was made of profiles reported in a study “Versteiling vooroever” (in Dutch, “Shoreface steepening”) (Eurosense, 1998). These profiles are average profiles over 4 to 6 sections (about 1km coastal length) where the depth values are projected parallel to the coast onto a predefined profile line. The principle of profile construction is shown in Figure 6.

All elevation points in a certain outlined box are first rotated so that the coast direction is horizontal. Next, a TIN of the data points makes a cover of the elevation surface and a rectangular grid is interpolated on the TIN (red points in Figure 6). Afterwards, per horizontal grid line the average value of the points inside the box boundary is computed. These average values are finally plotted according to their vertical distance in the grid to produce the box’s average profile. The landward limit of the bounding box is indicated in the average profile, as well as the landward limit of the points that represent the full width of the box. The values on the average profile determine thus also the volume inside the box at the distance indicated on the horizontal axis. That volume can be calculated by multiplying the elevation by the box’s width at that point. The boundaries of the average profiles in “Versteiling vooroever” were parallel, so the box width was constant. When the morphology does not vary too much in a coast-parallel direction, the average profile also represents a typical profile for the box.

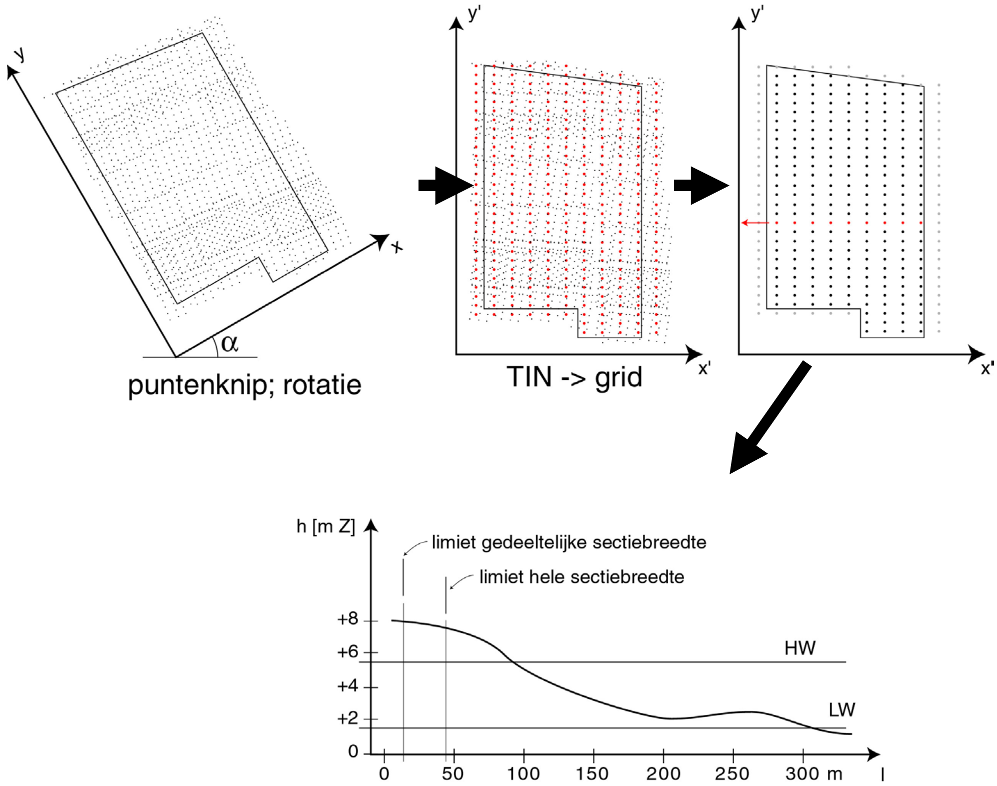


Figure 5.3 Principle of creating an “average profile” of a bounded area.

The “Versteiling vooroever” profiles were computed for every survey available till VJ1998 and so provide an interesting time series of profiles.

An example (zoomed in at the part of the section below +2m Z) is shown in Figure 7.

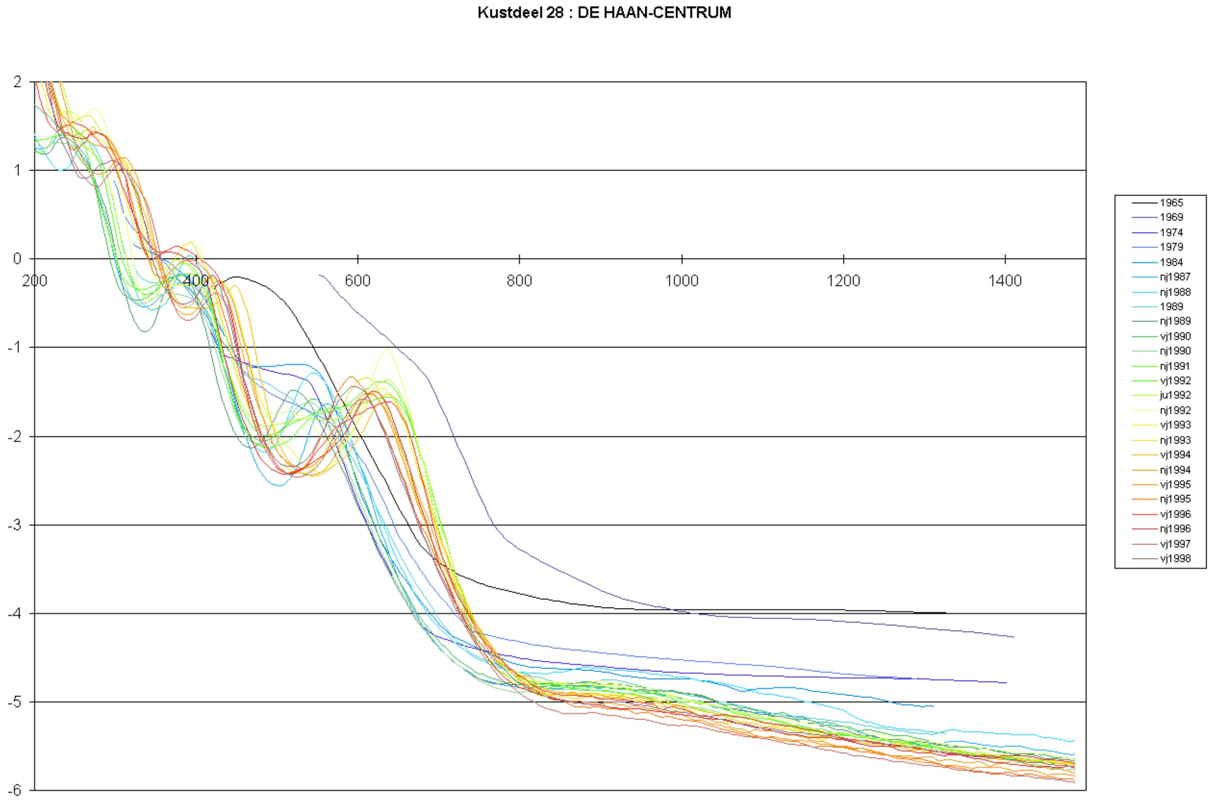


Figure 5.4 Example of a series of average profiles available in Excel format for the surveys indicated, here for coastal tract n° 28.

Use was made of coastal tracts (“kustdeel”) n° 25 and 28. The elevation data were in Z and were converted to TAW by subtracting 0.11m. In order to make the average profile match the actual profiles of sections 133 and 153, the position of the two most seaward bar crests and the intervening trough in 8 surveys, where both a measured profile and an average profile for the coastal tract was available, was compared (Figure 8).

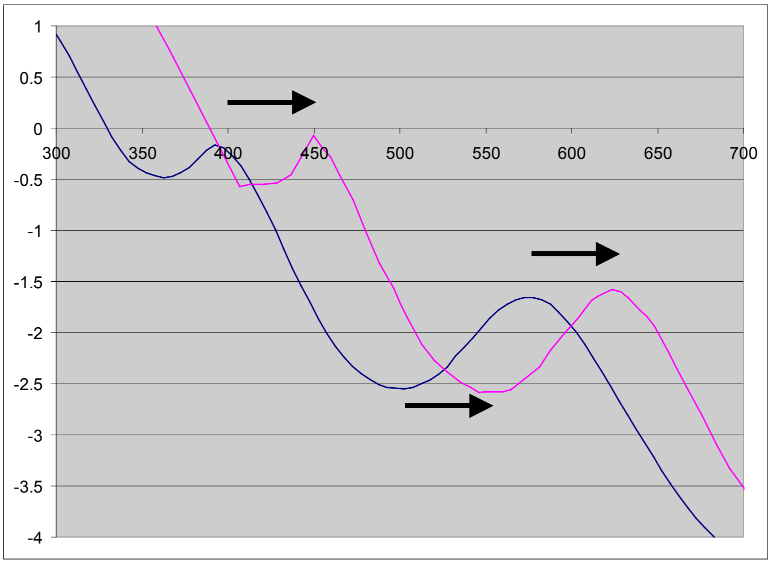


Figure 5.5 Illustration of an average profile (blue) and an actual profile (magenta) for matching surveys. Three distances (position shifts between troughs and crests) were determined, see arrows.

It appeared that the average profile of tract n° 25 had to be shifted seaward by 52m in order to match with our profile of section 133, while that of tract n° 28 had to be shifted seaward by 2.27m in order to match with our profile of section 153.

In this way, profiles were retrieved for the surveys VJ1990, VJ1992, VJ1993, VJ1994, and NJ1996, and as more surveys had been done in De Haan, there also for JU1992 (June) and NJ1992.

Also, all available average profile parts of the subaerial part of the beach were added in the profile of section 153, so that also the evolution of the backshore part of the beach could be studied for the years where no beach DTM was available (period before 2000).

5 Analysis method

5.1 Time series of elevation maps, contour lines and elevation difference maps

Of all the available and project made DTMs, a series of elevation maps, contour line maps and height difference maps is represented in a powerpoint file “DeHaanContourLines_DifH.ppt”. These maps are focused on De Haan-Centrum. They are carefully aligned so that flipping through the slides creates the effect of moving images. The maps provide a first impression of the morphodynamics, but finer viewing methods were needed to detect more details.

5.2 Time series of cross-shore profiles

The time series of the two cross-shore profiles consists of 28 steps for section 133 and 31 steps for section 153. They are arranged in a powerpoint show (file name “ProfileSection133Hippodroom.ppt” and “ProfileSection153DeHaan.ppt”) where the successive profiles have been carefully aligned so that quick running through the slides creates the effect of a moving profile.

First, the series is given without comments. Next comes the same series, but now with arrows and comments. The thick red arrows indicate shift of certain bars or troughs. These shifts are morphological changes, and are a good first indication of time-integrated sediment transport directions.

The data behind the profiles are in the Excel file “ProfilesDeHaan.xls”. The graphs with the comments are added in Annex 2 and 3.

5.3 Time series of distance and elevation of the outer bar

A time series for both profiles (section 133 and 153) was made of the position (profile X) and crest elevation (profile Z) of the outer bar. The plots are given in Figure 11.

5.4 Time series of volumes in narrow coast parallel boxes

The morphodynamics of the central area near De Haan was further investigated by establishing a time series of volumes inside boxes defined in differently behaving parts of the profile. By doing so, the wealth of spatially covering DTMs could be exploited. The cross profile of section 153 contains a few successive parts that have a distinct behaviour. By outlining these parts, the “below LW” graphs of the “Kusttrends” (Houthuys, 2012), tract n° 32, could be supplemented by the greater detail of five partial zones that together cover the entire shoreface.

The five partitions were defined as follows :

1. from X = 225m to 400m (X is distance in the profile): from about TAW +2m to about 0m, so upper part of the shoreface around the low-water mark;
2. from X = 400m to 550m: adjoining part of the upper shoreface, area between low low water and landward foot of nourished berm;
3. from X = 550m to 650m: landward flank and crest area of the underwater berm, afterwards crest area of most seaward bar;
4. from X = 650m to 800m: seaward flank of the underwater berm, afterwards seaward flank and foot area of most seaward bar;
5. from X = 800m to 1050m: part of the sea floor (channel floor of “Grote Rede”) adjoining the underwater berm and area where some influence on the morphology can be discerned.

Later analysis required two more parts to be defined on the supratidal and intertidal beach (labelled –1 and 0), see below. The parts are shown in Figure 9.

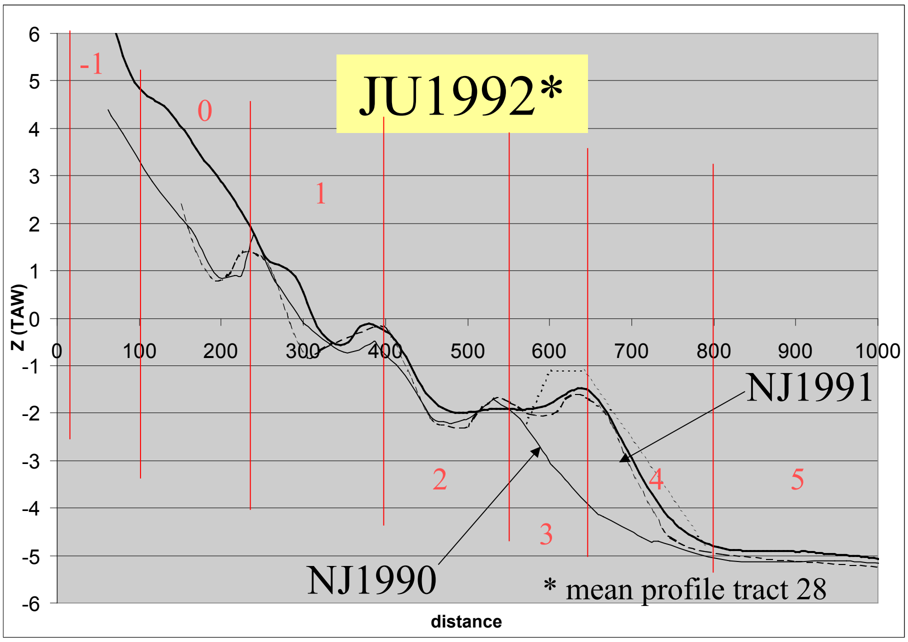


Figure 7.1 Vertical lines (red) separating partial areas of the profile with a distinct behaviour.

In order to use the complete areal coverage available in the DTMs listed above, boxes were defined with longshore edges at these X distances, parallel to the design boundaries of the shoreface nourishment, and with lengths equal to the coastal tracts used in the Kusttrend project. The DTMs constructed in this project also cover the neighbouring coastal tracts “De Haan-West” en “Vlissegem”; therefore, additional boxes labelled with two digits were defined in these tracts too (see fig. 10).

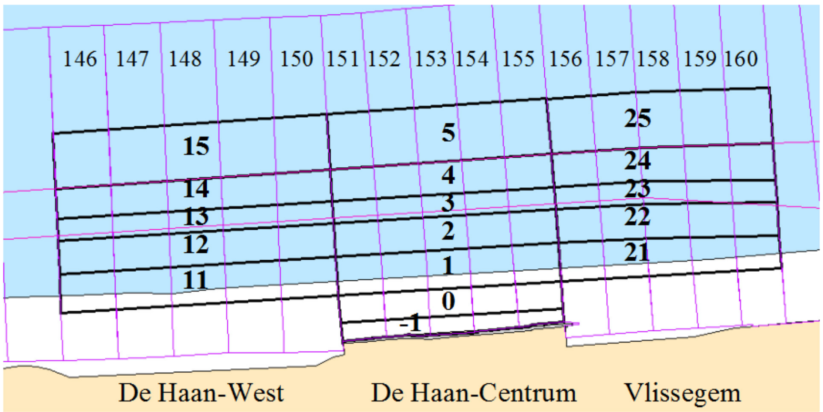


Figure 8.2 Box outlines (bold numbers) for the volume evolution graphs.

In each box, for each DTM the volume with reference to the TAW = 0 plane was calculated. The NJ1990 survey was used as a reference. Of each volume, the NJ1990 volume was subtracted so that actually, the evolution with respect to the NJ1990 situation is determined.

In order to provide comparable volume figures, the volume difference figures were further divided by the area of each box. The resulting figure can also be interpreted as the mean elevation difference with respect to NJ1990 inside each box.

In De Haan-Centrum, the mean elevation figures time series can further be completed using all available profiles. Indeed, the profile of section 153 is situated in the middle of boxes 1 – 5 and the surveys show most morphological features are fairly coast-parallel in De Haan-Centrum. This allowed to add 13 data points in the time series. This explains why only boxes 1-5 show pre-NJ1990 data points.

The added points are marked in the graphs of Annex 5 by a full circle for the data based on the profile in section 153 and by a hollow circle for the data based on the average profile of coastal tract n° 28.

Furthermore in box 1, a special point was inserted at the 2000 beach refill. This was possible because in VJ2000, the echosoundings were before the nourishment works, and the laserscanning survey was just after. In box 1 (around the low-water mark), both surveys overlap.

In boxes 3 and 4, a special point was inserted to represent the (possibly hypothetical) situation on the 1st of June 1991, after completion of the shoreface berm (information of MIWE 92.101, see Annex 1).

These added special points are marked in the graphs by a square symbol.

For the group of sections 151 to 155 (De Haan-Centrum), data was available to extend the box series onto the foreshore and backshore. A box "0" was added between X = 100m (in many surveys, about the position of the high-water mark) and X = 225m, and another box "-1" between X = 15m (the foot of the seawall) and X = 100m (see fig. 9 and 10).

In all graphs, a vertical line mark at 10 June 1992 indicates the end of the first phase of the nourishment scheme. In the graphs for the boxes around the low-water mark, a second line marks the completion of the 2000 replenishment works.

The graphs are added in Annex 5 and in the powerpoint file "DeHaanContourLines_DifH.ppt". The data behind the graphs are in the Excel file "VolumesPerBoxAndSurvey.xls".

Trends of height change in the boxes were calculated using linear regression between selected start and end dates. The trends express the mean height change per year inside the box. When multiplied by the box area, the trend can be converted in the mean volume change per year.

5.5 Interpretation of data

The changes noted at each site and survey were compared with the information of the nourishment scheme.

Also grain sizes have been assembled and their evolution was taken into account for the conclusions of this study.

7 Grain size information

In 2001 (VITO, 2002), surface and shallow depth (upper metre) samples were taken on the beach in each coastal tract and at three locations with respect to the waterline: near the low-water mark, in the middle of the intertidal beach, and near the high-water mark. Near the low-water mark, D_{50} ranged from 180 to 220µm throughout the coastal strip from Bredene to Blankenberge. Elsewhere, e.g. west of Oostende and west of Nieuwpoort, grain sizes at the low-water mark were mostly finer, between 160 and 180µm. In the middle part of the beach and near the high-water mark, grain sizes varied between 220 and 280 µm, with local coarser places near Vosseslag (320 – 360 µm). In Vosseslag, the coarsest material had been used during the 1990s beach nourishment scheme. Elsewhere, west of Oostende, the beach sand is usually between 180 and 200µm, at least in the sites where no beach nourishments, scrapings or yearly sand fills take place.

In 2004 (VITO, 2007), surface samples were taken on the beach with the following results:

- section 138: ca. 300µm around the high water mark and 270µm in the new dunes near the high water mark;
- section 152: ca. 250µm near the low water mark and around 300µm near the high water mark;
- sections 170-172: 240 to 280 µm; locally in a beach trough 224µm.

In 2006, 25 intertidal and 26 subtidal samples were taken near Wenduine-Rotonde (Van Ginderdeuren et al., 2007). The beach samples had a D_{50} of 269 +/- 6µm while the mean grain size of the subtidal samples was 127 +/- 18µm. The latter contained up to 40% of mud. The subtidal samples were taken in a 1 km wide area. The samples of the shoreface were between 125 and 250µm according to fig. 4.1 in Van Ginderdeuren et al. (2007). These latter samples may be seen as an indication of the grain size present in the shoreface area west of Wenduine, i.e. in the nourishment area between De Haan and Wenduine.

From these results, as from the profile series, it is clear that (part of) the sand supplied in the 1990s on the beach is still in place. The relatively coarser sand near the low-water mark, in comparison with the sand west of Oostende at the same profile position, proves the low-water area and the upper part of the shoreface were fed by and still bear the signature of the beach nourishment sand, rather than from the shoreface nourishment.

9 Results

9.1 Cross-profile time series

The profile time series is best studied in the powerpoint files added to the report. The successive profiles are also added in the annexes. The time steps labelled with an asterisk have been derived from average profiles per coastal tract ("kustdeel"). For section 153, the "above low water" part of the profile for surveys where no beach DTM is available, was retrieved from the average profiles of coastal tract n° 28. The survey dates have been labelled with "^" if the beach part of the profile has thus been added. A second section in the powerpoint show contains annotations and red arrows indicating the morphological changes through time. The main observations follow from comparing successive profiles. The direction of sand transport is inferred from the movements of the morphological features. Though they give no absolute certainty on the transport direction, movements are often so consistent that their indicator role for the sediment transport, especially for the half-year time steps, may be considered as very reliable.

9.1.1 Profile series in section 133

These profiles are shown in Annex 2. The time series consists of 28 profiles. For the surveys where both types of profile were available, the average profile of coastal tract n° 25 ("Hippodroom") could not always be fitted exactly on the corresponding profile of section 133. This means that this part of the coast contains some morphological features that vary along the coast. The average profile then smoothes out such features. These are the main observations:

- NJ1987 to NJ1989: shoreface retreat (erosion) and minor seabed lowering
- NJ1989 to NJ1990: shoreface bars descend (shift seawards) and the seabed rises: probably the effect of the severe early 1990 beach and dune erosion
- NJ1990 to NJ1994: breaker banks on shoreface shift seaward in periods with storms and landward in periods without severe storms. The NJ1991 accretion of the most seaward breaker bank may be influenced by the shoreface nourishments carried out in the preceding months in De Haan-Centrum. There is no substantial change in shoreface volume, except some growth at the seaward flank of the most seaward breaker bank
- VJ1995: the profile is raised by 0.25 to 0.5m in response to both the beach nourishment and the shoreface nourishment in sections east of section 133. The vertical growth is largest at the longshore continuation of the nourishment sites, but the intermediate part of the shoreface also shows a small growth. The accretion does not fill completely the design profile, which has been explained at the time by the fact that in the weeks between dump activities and the survey, some redistribution of the nourished sand had taken place. The profile shows vertical accretion of the neighbouring seabed, by about 0.3m, especially at the foot of the nourishment. This indicates losses to the seabed (channel "Grote Rede")
- NJ1995: the shoreface nourishment goes on. The berm sits in the same position, but the seaward flank and the seabed undergo lowering. The upper part of the shoreface receives sand from the beach nourishment then going on
- VJ1996: the shoreface nourishment was finished shortly after NJ1995. The profile shows important accretion, locally over 1.5m, but not at the site of the dumpings. This profile, compared with NJ1995, may well represent the important redistribution that occurs after the nourishment works. The upper part of the shoreface receives sand from the beach nourishment
- VJ1996 tot VJ1998: intermediate bars first descend, then ascend. The outer bar gradually moves landward
- VJ1998 and VJ1999: a small short-lived seaward shift of the berm may be due to replenishments carried out around that time. The beach remains stable with minor shifts of the intermediate bars
- VJ1999 – VJ2011: the seaward flank of the underwater berm recedes landward. After 15 years, the seaward foot of the berm is again at the NJ1990 position, i.e. 0.5m deeper and 30m more landward than after the shoreface nourishments. The berm crest climbs landward and upward. The intermediate shoreface breaker banks go back and forth, but the profile is still c. 30m more seaward than after the nourishments.

Conclusion : the profiles confirm the morphological responses noted during the construction of the shoreface nourishment in the contemporary reports. A new element is the short-lived seabed accretion during shoreface nourishments going on in the sections east of the profile. Furthermore, the relatively mild erosion after NJ1996 is remarkable. This development is hard to attribute to the shoreface nourishment alone. Apart from a shift of sand form the nourished bar crest to the landward trough, no clear indication of a “feeding” function for the beach was noted.

9.1.2 Profile series of section 153

These profiles are shown in Annex 3. The time series consists of 31 profiles. For the surveys where both types of profile were available, the average profile of coastal tract n° 28 (“De Haan-Centrum”) fitted well, sometimes almost exactly, on the corresponding profile of section 153. This means that this part of the coast contains morphological features that have no or little variations in the longitudinal direction. The main observations are described here :

- NJ1987 to NJ1990 : predominantly shoreface erosion. The intermediate bars go back and forth. The beach remains more or less stable (due to yearly minor beach fills and sand scrapings)
- NJ1991: this first survey after the local shoreface nourishment shows the design profile is not achieved. The “feeder berm” is deeper and narrower than the design profile. This fact was in the contemporary reports attributed to a first redistribution of the dumped sand having occurred between the dump activities and the survey. Two breaker banks landward of the dump site show accretion. This has to be related to sand supply from the dump site. Two small breaker bars around the low-water mark shift landwards. This also might be taken as a “feeding” effect. The size of movement and volume increase is very modest. The seaward berm foot also shows a slight accretion by about 0.1m
- VJ1992: further accretion of the intermediate shoreface area (seaward shift of breaker banks by c. 20m) and further accretion of the seabed near the foot of the berm by another 0.1m. Both types of accretion must be due to redistribution of sand from the crest area of the feeder berm. Nourishments have been going on till March 1992 at the western and eastern tip of the berm, a few hundreds of metres away from section 153. The breaker bars near the low-water mark show a minor seaward shift, which indicates rather some beach erosion than “feeding” from the shoreface nourishment
- June1992: the foreshore nourishment has been carried out. The crest of the underwater berm shows further lowering and feeding of the intermediate shoreface area. The seabed still accretes, by less than 0.1m
- NJ1992: erosion of nourished beach. The shoreface breaker banks, including the nourished berm, shift seaward. The seabed still accretes, by less than 0.1m
- NJ1992 to NJ1999: the accretion at the berm foot on the seabed quickly disappears and does not return. The shoreface breaker banks migrate up and down. The evolution trend appears to be erosion, but at least three times, intermediate accretion is seen, especially at the most seaward bank, and each time related to underwater replenishments west and east of De Haan: VJ1994, VJ1996, VJ1998. This last survey shows also the upper shoreface breaker banks shifting seaward, in response to the 1997 beach nourishment east of De Haan
- VJ2000: beach recharge; beach and shoreface profile shifts seaward. The shoreface breaker banks shift about 20m seaward and grow 0.1 – 0.2m vertically
- VJ2003 – VJ2011: gradual erosion. The overall shoreface gradient decreases and the seabed lowers slightly (a “pit” on the seabed in VJ2004 is probably due to works)

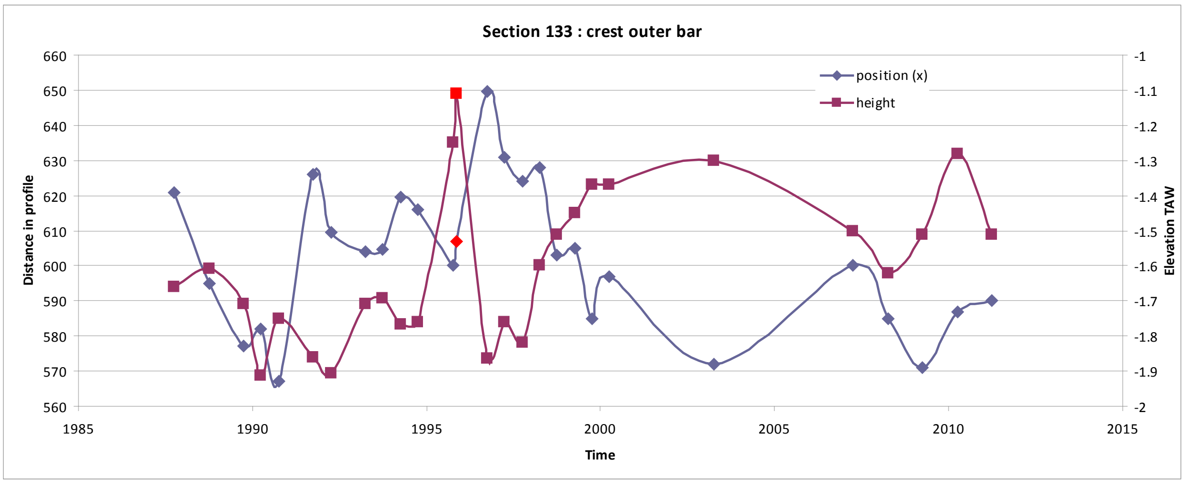
Conclusion : the profiles confirm the morphological responses observed during the construction of the shoreface nourishment in the contemporary reports. A new element is the short-lived seabed accretion during shoreface nourishments going on in nearby sections. Furthermore, the relatively mild erosion after VJ2000 is remarkable. This development is hard to attribute to the shoreface nourishment alone, especially because it is long in time since the shoreface nourishment. Apart from a shift of sand form the nourished bar crest to the landward trough shortly after the shoreface nourishment, no clear indication of a “feeding” function to the beach was noted.

9.2 Movement of the nourished bar through time

Figure 11 depicts the evolution through time of the distance in the profile and the elevation of the crest of the most seaward bar (where the shoreface nourishment took place). Red marks relate to the design profile.

The blue line is the distance of outer bar crest in the profile (left scale).

The purple line is the elevation of the outer bar crest (right scale).



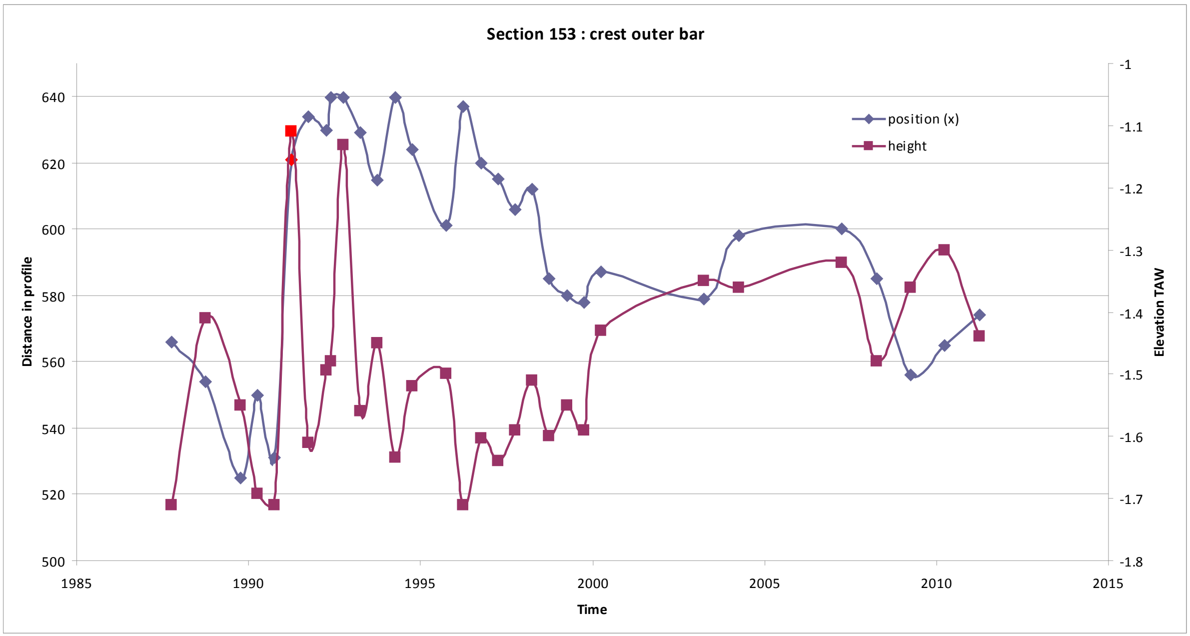


Figure 11. Evolution in time of the outer bar crest in section 133 (top) and 153 (bottom).

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9.2.1 Section 133

The bar crest recedes 50m landward between NJ1987 and NJ1990 and lowers by 0.3m. The 60m seaward shift between NJ1990 and NJ1991 is remarkable, but the crest remains low. Within months after the shoreface nourishments in 1995-1996, the crest of the bar lowers by 0.75m. In the next 7 years, the crest rises gradually by 0.55m while the crest position recedes gradually landwards by 75m. Finally, between VJ2003 and VJ2011, no important changes occur any more. The final crest position and height resemble the very first survey.

9.2.2 Section 153

The bar crest recedes 40m landward between NJ1987 and NJ1989 and lowers by 0.3m between NJ1988 and NJ1990. The 1991 shoreface nourishments push the bar 90m out and raise it by 0.6m. Within months after the shoreface nourishments the crest of the bar lowers by 0.55m. In the next 7 years, the crest goes up and down while the crest position goes back and forth in a 40m band width. The final evolution, between VJ2000 and VJ2011, is a gradual landward retreat with some oscillations in a 40m wide band and a gradual height increase of a few decimetres. The final crest position is equal to that in the very first survey while the crest is a bit higher now.

9.3 Detailed trends at De Haan-Centrum

As De Haan-Centrum was the first site to receive a shoreface nourishment, most data are available for this stretch of the coast.

In De Wolf et al. (1997) (their fig. 4, repeated in this report as Figure 12), a pre-nourishment erosion rate of -24 m³/m/yr was observed in De Haan-Centrum, while after the nourishment and a first phase of intense erosion, the trend was –8 m³/m/yr between 1995 and 1998.

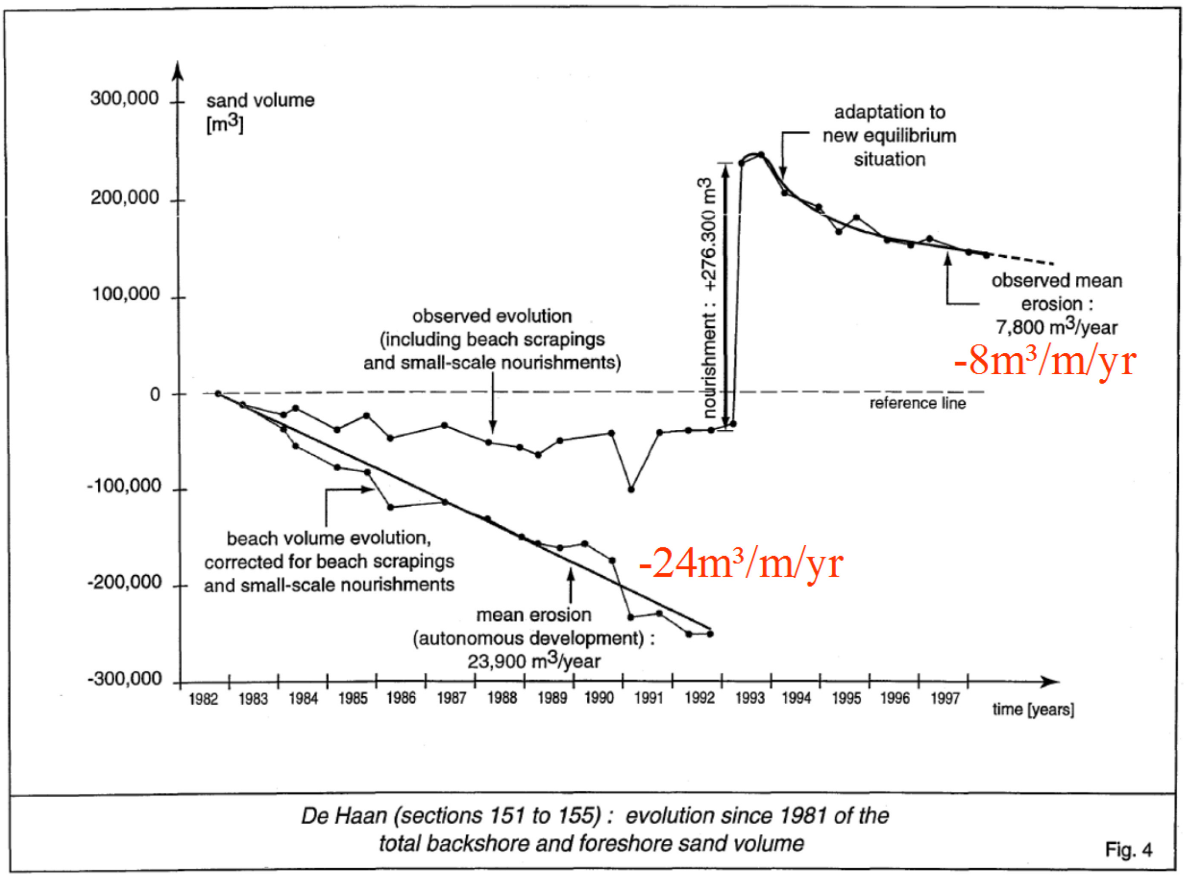


Figure 12. Observed and corrected beach volumes for sections 151 to 155
(total coastal length : 1006m). Trends in m³/m/yr added in red (De Wolf et al., 1997).

The “Kusttrend” project (Houthuys, 2012) showed and discussed the evolution in time of volumes of the part above and below the low-water mark per group of sections (coastal tract). The main findings based on corrected evolution series (i.e. the volumes added by nourishments were subtracted at the time of the replenishment works) for De Haan-Centrum were (see graphs in Annex 4) :

- the successive nourishment phases obscure a simple morphological trend;
- a deepening of the tidal channel “Grote Rede” around 1987-1990 may have been an explaining factor for the strong shoreface and beach erosion during the severe 1990 storms;
- when correcting for the nourishments, both the part above and below LW showed important erosion : –33 m³/m/yr (1981-NJ1991) and –57 m³/m/yr (1987-NJ1990), respectively (Figure 13);
- a first trend change occurred after 1992. The erosion figures decreased to –19 (JU1992-NJ1999) and –25 m³/m/yr (VJ1992-VJ2000), respectively;
- a second trend change occurred around 2000. The erosion figures decreased to –8 m³/m/yr and –4 m³/m/yr (2000-2011), respectively.

The pre-nourishment erosion appears to be more intense than mentioned in De Wolf et al. (1997). The reason is that correction of beach volumes involved now also correction for sand bulldozed in from around the low-water mark. Half of the volumes bulldozed in are considered to be an import for the “above LW” part and an export for the “below LW” part.

On the other hand, the after-1992 evolution is more erosive. The trend was now calculated on more surveys till NJ1999.

To explain the milder erosion trends after 2000, reference was made to the generally milder wave climate at the Belgian shore compared to before 2000.

It was realized, however, that the global figures masked local differences.

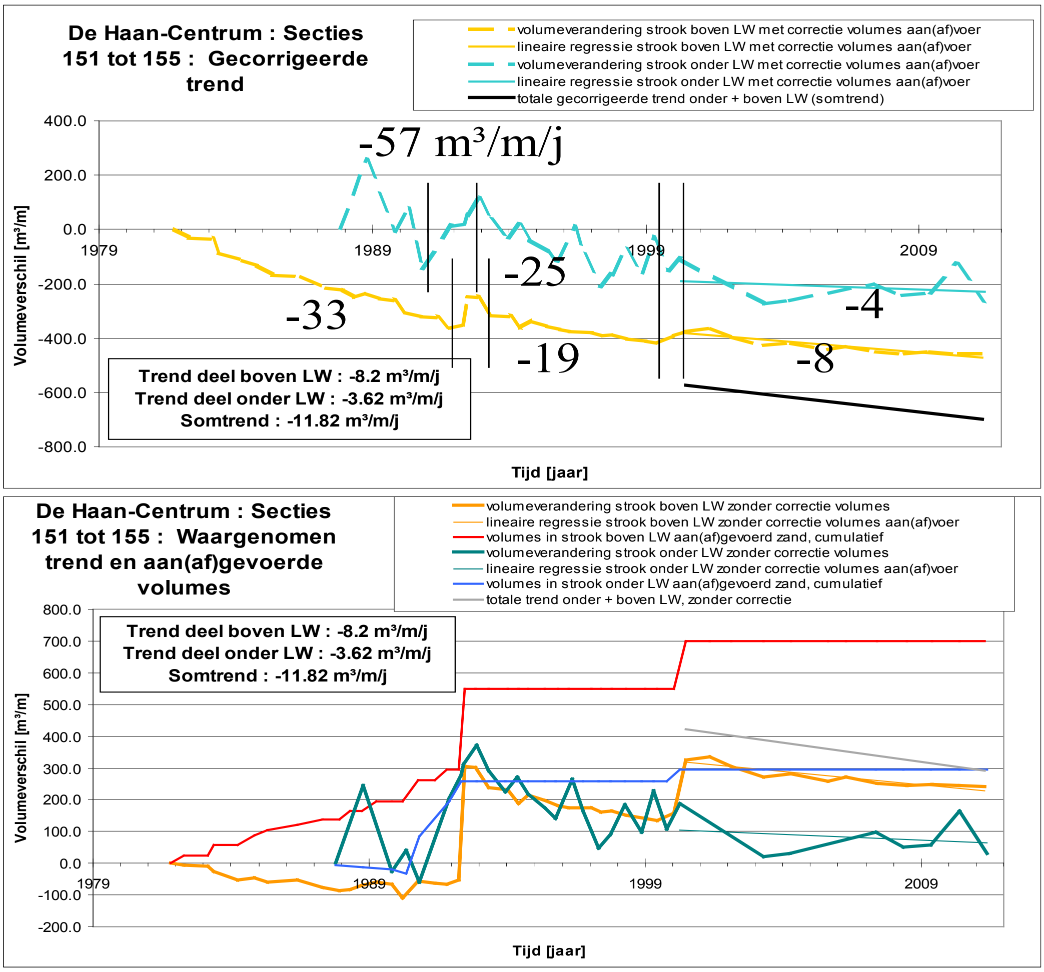
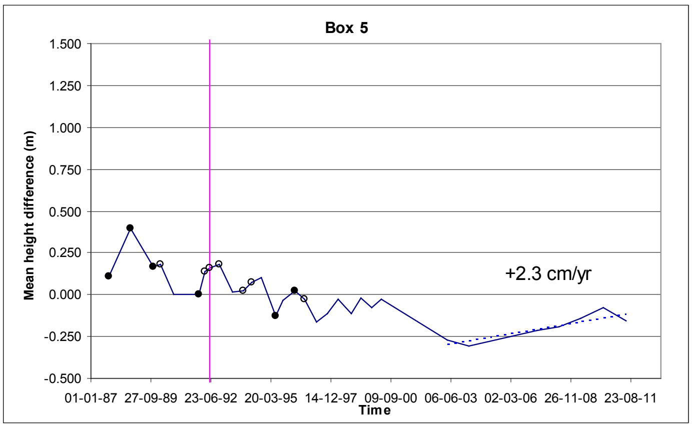
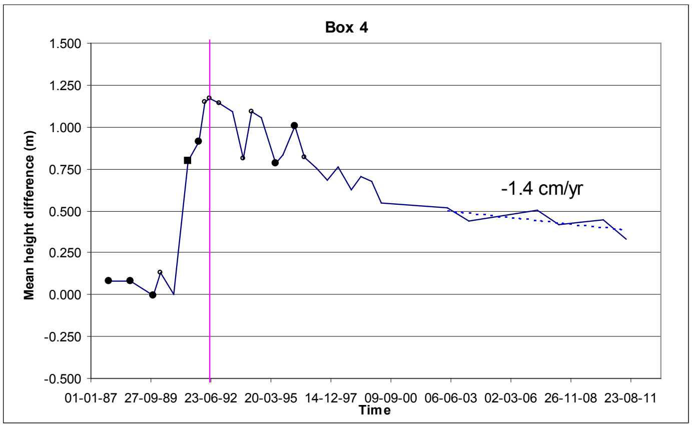


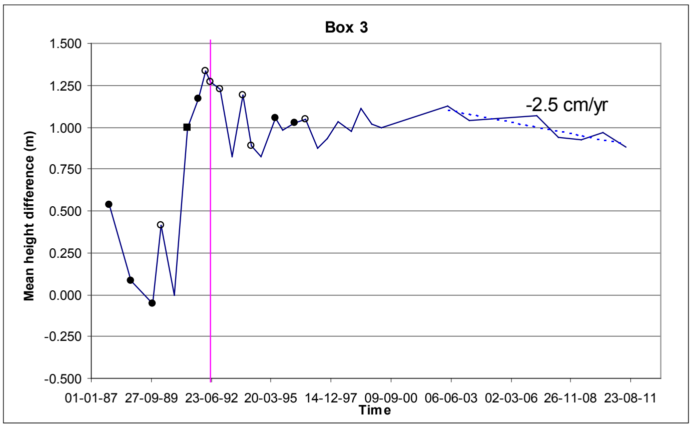
Figure 13. Observed and corrected beach volumes in m³/m/yr for sections 151 to 155 (total coastal length : 1006m) for the beach (above LW, “boven LW”, in orange) and nearshore plus seabed (below LW, “onder LW”, in light blue). Corrected trends are shown in the upper figure and are added in bold for

certain trend periods. Observed volumes (orange and light blue) and cumulative nourished or borrowed volumes in the lower figure (blue for below LW, red for above LW) (Houthuys, 2012).

These results are now refined so as to obtain more detail in seven partial areas of the profile. The data and graphs per box are added in Annex 5. Figure 14 shows the graphs covering sections 151-155, but an overview in geographic order followed by all the graphs of the boxes in full detail is given in the annex.







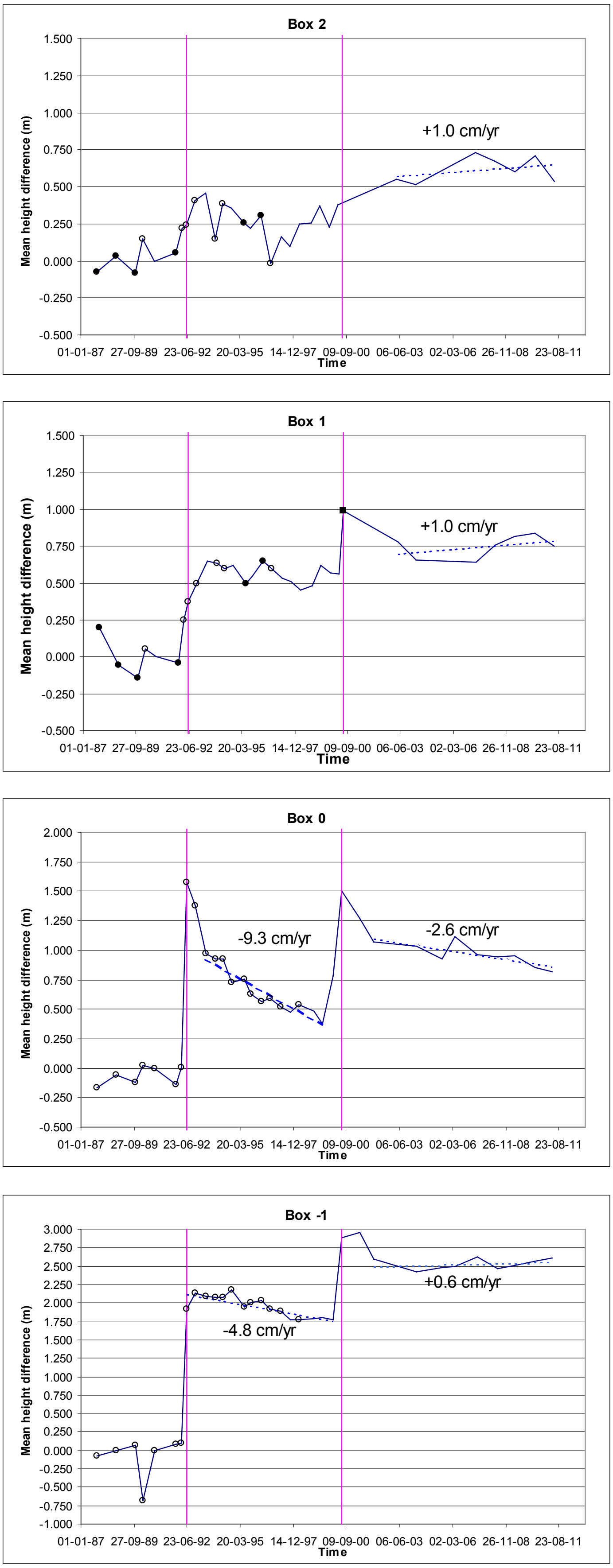


Figure 14. Graphs of mean height evolution (volume divided by box area) per rectangular box in De Haan (location, see Figure 10). Magenta lines indicate first survey after nourishment.

Evolution before 1990 (boxes -1 to 5)

Box 1 lowered by 34cm while box 2 remained stable. This may indicate beach erosion and (temporary) storage of the eroded sand on the shoreface. Boxes –1 and 0 remained stable, but this must be ascribed to relatively important beach scrapings and sand fills. Boxes 3 and 5 lowered by 59 and 40cm, respectively, indicating important erosion at the shoreface foot.

Evolution around the construction of the underwater berm

The construction of the underwater berm raised the mean elevation in box 3 and 4 by 1.5m. The full elevation rise is not encountered in the graphs. Contemporary information suggests a situation near the design profile must have been realised all along the underwater berm, though at different times according to the works' progress. Contemporary sources agree that the achieved profile was short-lived, especially at the berm crest (box 3). The shoreface nourishment was finished at the location of the profile in section 153 at the NJ1991 survey; however, dumping still went on till March 1992 especially in boxes 13, 14, 23 and 24, thus at the tips of the planned berm.

Evolution between the berm construction and the beach nourishment (NJ1991 – 16 March 1992)

If any direct influence of the underwater berm can be seen, it would show in this short interval as most of the shoreface nourishments, at least in De Haan-Centrum, were finished by 31 May 1991 and no beach nourishment was started.

Box –1 rises 1.5cm and box 0 rises 13.5cm. Boxes 1 and 2 accrete by 29 and 16cm, respectively, boxes 3 and 4 loose 20 and 32cm, respectively, while box 5 accretes by 14cm.

The evolution around and shortly after the shoreface berm construction must be interpreted taking sand fill works into account. In terms of volumes, Table 3 shows the record for the period VJ1990 to VJ1992: observed volume changes per box, and sand quantities known to have been nourished or rearranged due to beach scrapings.

Table 3 – Volume differences per box in De Haan-Centrum in the three survey intervals preceding VJ1992. The total corrected volume change is the sum over the 7 boxes minus the sum of volumes added plus the volumes removed. The maximum possible error is based on maximum measurement errors of 5cm on the beach and 10cm on the shoreface.

Evolution in De Haan sections 151-151 between VJ1990 and April 1992			Observed volume difference (m³)		
Zone	Corresponds to	Data source	**VJ1990-NJ1990**	**NJ1990-NJ1991**	**NJ1991-VJ1992**
Box -1	backshore	this report	58 700	6 500	1 300
Box 0	foreshore	this report	-2 800	-17 900	18 700
Box 1	upper shoreface	this report	-8 800	-7 200	51 600
Box 2	trough betw. beach and outer bar	this report	-22 600	8 300	24 400
Box 3	outer bar crest	this report	-41 500	117 600	16 800
Box 4	outer bar seaward slope	this report	-20 100	138 100	35 000
Box 5	seafloor near outer bar	this report	-45 800	1 000	34 000
Sand supplied for underwater nourishment		Kusttrends tract 32		239 300	
Sand removed by beach scraping		Kusttrends tract 32	-13 200	-10 500	
Sand supplied by beach scraping and minor fills		Kusttrends tract 32	69 000	33 900	
Sand supplied for underwater berm E and W of De Haan-(		Kusttrends tract 32		276 900	
Total corrected change in the entire profile (box -1 to 5)			**-138 700**	**-16 300**	**181 800**
Maximum possible error over the entire profiel (box -1 to 5) +/-			94 300	94 300	94 300

The net change between VJ1990 and NJ1990 is erosion, mainly situated on the shoreface such as mentioned before.

Between NJ1990 and VJ1990 there is no net change when taking volumes of nourishments and internal rearrangements into account. The sand brought in or out almost exactly matches the volume changes of the boxes where the operations took place (figures in similarly coloured cells).

The overall volume change between NJ1991 and VJ1992 is +181,800 m³. It is remarkable that boxes 3 and 4 win 16,800 and 35,000 m³, respectively. The cross profile series of section 153 shows that between the two surveys, the morphology rearranges itself. But the crest area of the nourished berm also rises by about 0.1m. Furthermore, also the foot area at the berm's seaward side rises. Both phenomena are the signature of sand import by longitudinal transport from adjacent areas where shoreface nourishments are still going on. Indeed, the dumping operations near De Haan-Centrum lasted till March 1992. Part of the 276,900 m³ nourished at the berm site east and west of De Haan was only nourished after the NJ1991 survey. It is concluded that this nourished contributed substantially to the gain in boxes 3 and 4. Box 2 may have been fed by the nourishment berm, but equally well from the ongoing nourishments near De Haan. The profile series of section 153 shows (see red arrows) however that most of the volume increase in box 2 and probably all of the increase in box 1 probably had its origin on the beach, as the local bars shift seawards. Boxes –1 and 0 finally show an increase in volume, but the amounts are insignificant and it is unlikely that they would receive sand from the nourished underwater berm while the intermediate box 1 would not have been receiving sand from that source.

It must be concluded that the morphological benefits of the shoreface nourishment berm in the first half year after its completion were limited to the immediate environment of the berm, i.e. the trough between the berm and the low-water line and the seaward berm foot and channel floor area.

Evolution related to the 1992 beach nourishment (VJ1992 – June 1992)

Box –1 accretes vertically by 1.82m, box 0 by 1.57m (both due to the beach nourishment), box 1 by 12cm, box 2 by 3cm, box 3 lowers by 7 cm, boxes 4 and 5 both accrete by 2cm. The growth of box 1 is certainly due to the beach nourishment; the profile evolution of section 153 shows a slight seaward shift of the breaker bank here. The evolution in boxes 2 to 5 can be seen as the further spreading of the sand of the shoreface nourishment.

Evolution between the beach nourishment and the completion of the successive phases of the nourishment scheme (June 1992 – NJ1999)

Boxes 2 to 5 clearly show oscillations on a general descending trend. The erosive trend is of the order of 1 to 3 cm/yr, which is very modest. Positive oscillations in the order of 20 to 25 cm are consistently related to further nourishment works, either west or east of De Haan (hundreds of metres outside of the boxes). This fact once again demonstrates that sand freshly dumped at a given berm location is also redistributed in a longshore direction.

Boxes 1 and 2 show an initial important increase of 20 to 30 cm after the completion of the beach nourishment. The shift direction of the breaker bars is clearly from beach to shoreface (see profile section 153). Afterwards, box 1 remains at the same elevation with oscillations in the order of 10cm.

The beach responds to the nourishment by an initially strong erosion of the foreshore, box 0 (-0.6m). This effect is limited to the first year after the nourishment and the erosion was probably to the benefit of the neighbouring boxes –1, 1 and 2. From NJ1992 to 1999, box –1 (the backshore) lowers following a linear trend of 5 cm/yr (or 4 m³/m/yr) and box 0 (the foreshore) erodes following a linear trend of 9 cm/yr (or 11 m³/m/yr). When taking the part of box 1 into account that is above the plane of +1.39m TAW, the total erosion trend of 19 m³/m/yr of "Kusttrends", mentioned above in Figure 13, is found back. The evolution shows no influence of beach nourishments carried out then in the neighbourhood of De Haan. No influence is seen from the presence of the feeder berm. However, the corrected erosion figure before 1991 was –33 m³/m/yr. In the period after 1992, especially in 1993, 1995 and 1996, some storms caused significant erosion elsewhere at the Belgian coast, but not in or near De Haan. The lower erosion rate and the fact that no significant storm cliffs have been formed after 1992 may be seen as an effect of the presence of the shoreface nourishment berm. The effect is not straightforward, in the sense that other reasons may equally well have reduced the erosion rate. The wave incidence of the later storms may have been different. But also the grain size had been coarsened by the beach nourishment from about 220 µm before to around 300 µm after the nourishment, which has an important effect on sediment transport.

The 2000 beach replenishment

The 2000 beach replenishment raises box –1 by 1.12m, box 0 by 0.72m and 1 by 0.43m. The time spacing of the surveys does not allow to single out an influence on the other boxes.

Since 2000

The evolution after 2000 is described by the trend between VJ2003 and VJ2011 (the reason for not involving VJ2000 is that the De Haan beach replenishment occurred after the VJ2000 echosounding survey and is not captured in the scarce echosounding surveys around that time). The upper shoreface shows a small gradual growth (+1 to +2cm/yr in boxes 1, 2, 11, 12, 21 and 22). The middle shoreface (position of the underwater berm) gradually erodes in De Haan-West and Centrum (-1 to –2.5cm/yr) but remains stable in Vlissegem. The shoreface foot shows accretion (+1.6 to +2.3 cm/yr). The intertidal beach in De Haan undergoes slight erosion (-2.6cm/yr) but the backshore shows even a minor growth (+0.6cm/yr). The evolution is in all cases a very mild one. The erosion at the berm location may be interpreted as a further feeding function to the area. It may equally well represent the natural evolution of a slowly receding lower shoreface.

Table 4 – Mean elevation trends after 2000.

Mean elevation evolution trend VJ2003 - VJ2011 [cm/yr] (bold if $r^2 > 0.707$)		
box 15 1.6	box 5 **2.3**	box 25 1.6
box 14 -1.0	box 4 -1.4	box 24 -0.5
box 13 -1.6	box 3 **-2.5**	box 23 0.4
box 12 1.8	box 2 1.0	box 22 1.9
box 11 1.3	box 1 1.0	box 21 2.2
	box 0* -2.6	
	box -1* 0.6	

*VJ2001 to VJ2011, no data for VJ2003

In VJ2011, 20 years after the creation of the underwater berm in De Haan-Centrum, there is still 23% of the nourishment volume left in box 4 and 58% in box 3.

The elevation in and around De Haan with respect to NJ1990 in most parts of the shoreface is still 0.5m or more higher. The shoreface foot area, however, has locally become deeper than in 1990 (Table 5).

Table 5 – Mean elevation difference VJ2011 minus NJ1990 in the boxes (m).

Mean elevation in VJ2011 with respect to mean elevation in NJ1990 (m)		
box 15 **0.02**	box 5 **-0.16**	box 25 **-0.11**
box 14 **0.27**	box 4 **0.33**	box 24 **0.44**
box 13 **0.70**	box 3 **0.88**	box 23 **0.77**
box 12 **0.45**	box 2 **0.54**	box 22 **0.53**
box 11 **0.61**	box 1 **0.75**	box 21 **0.74**
	box 0 **0.82**	
	box -1 **2.61**	

Thanks to the greatly reduced erosion rates since 2000, the beach and shoreface profile is still much safer (higher) than in NJ1990, after the strong storm erosion.

In conclusion, the evolution between March and June 1992 shows that the underwater berm may to a very limited extent have contributed immediately to feed the upper shoreface. This sand may well have been available to have fed the foreshore afterwards, but the beach nourishments carried out then in the neighbourhood of De Haan-Centrum obscure any such trend. Most probably, based on the profile series in section 153, no beach accretion can be attributed to sand nourished on the outer shoreface bar. The evolution in neighbouring sections, as well as in De Haan-Centrum, shows that an immediate loss (in the first weeks to months after each local shoreface nourishment step) to the shoreface foot and in a longshore direction to the middle shoreface west and east of the nourishment sites, also occurs. When looking at the evolution well after the soft nourishment scheme in and around De Haan (i.e. after 2000), very mild erosion rates are striking. The upper shoreface even continued to grow. The question remains whether this evolution would have occurred also in the absence of the shoreface nourishment. Indeed, very severe northwester storms such as the ones of the beginning of the 1990s, did not recur. Yet, a few storm erosion events around 1993-1995-1996 did cause serious foreshore and dunefront erosion elsewhere, also in the then still unprotected sections west of De Haan, but not in or near De Haan. Since 1996, the local wave climate was milder.

When generalizing the longer-term observed profile evolution at De Haan, it can be concluded that the 1991-1997 coastal defence scheme in and near De Haan “turned back the clock”, meaning that the complete beach to shoreface profile was shifted seawards (Figure 15). After 2000, the shoreface part recedes landwards, probably at rates comparable to the (not documented) pre-1987 evolution.

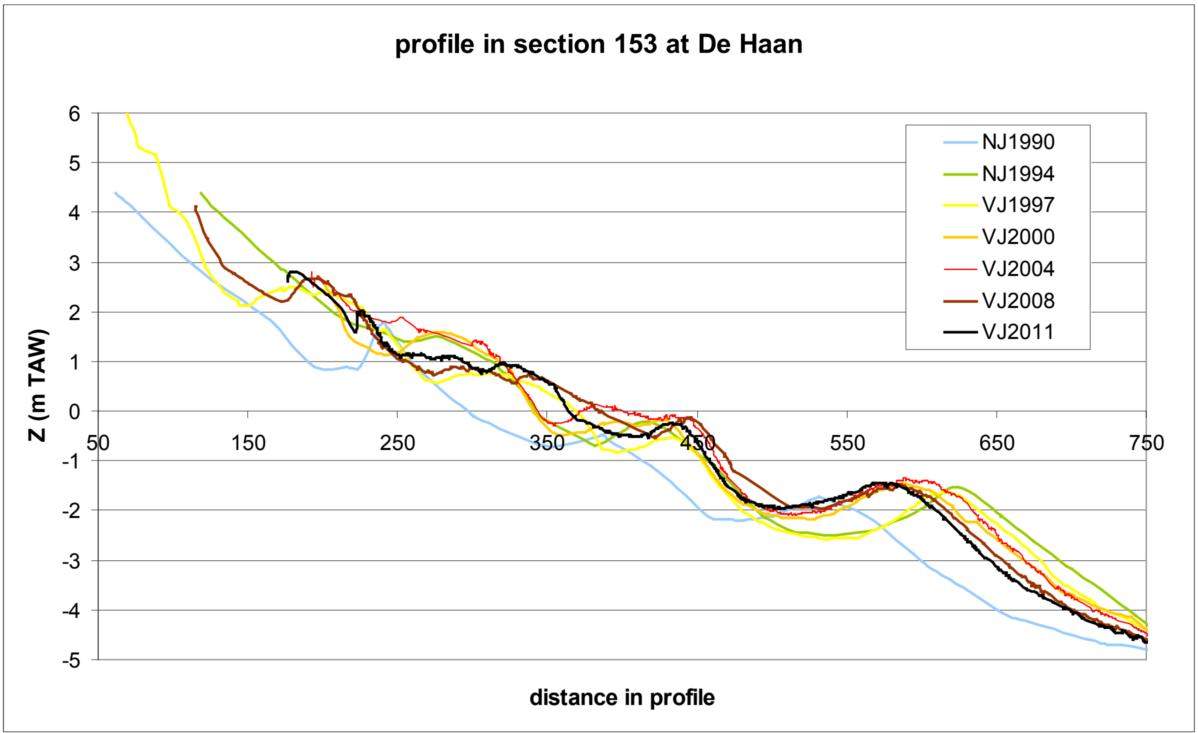


Figure 15. Selection of profiles at 3-4 yr time intervals at De Haan.

11 General conclusion

The morphological evolution of the 1991 shoreface nourishment at De Haan was studied using nearshore echosounding surveys and contemporary reports, volume figures and average profiles reporting on the morphology. The morphodynamics were detailed using profile time series in two sections, and volume time series in morphology-related boxes centred on the core area of the 1990s nourishment scheme in De Haan-Centrum. The time series were extended till the recent survey of VJ2011.

Straightforward morphological trends at any one location are difficult to interpret as repeated additional replenishments in neighbouring sites, both on the beach and on the shoreface, certainly did influence the post-1992 evolution at De Haan-Centrum and thus obscure simple morphological responses to the shoreface nourishment. The coastal protection scheme had a length of over 8km, so that the evolution at the central resort of De Haan may differ from what would happen when the shoreface nourishment would have had a shorter length.

This study confirms the earlier conclusions about the underwater nourishment berm: in the first months after building the berm, sand is immediately removed from the top of the berm to the shoreface trough between the berm and the low-water mark, which indicates wave transport, but sand is also redistributed in a longshore direction west and east of the nourishment site. After the first morphological adaptations, most of the nourished sand remains in the nearshore area and is thus – theoretically – available for building up the shore by the natural processes.

This study allowed to detect some more detailed morphological changes.

It was demonstrated that the shoreface nourishments also give rise a short-lived seabed accretion, at the shoreface foot near the nourishment site, while shoreface nourishments are going on.

Over the short time between the construction of the underwater berm and the beach nourishment in De Haan-Centrum, the shoreface part between the underwater berm and the intertidal beach accreted, over its complete coast-normal width of about 300m. It was demonstrated that the nourishment berm contributed to the immediately adjoining parts, seaward and mostly landward of it. But the area received also sand from the ongoing shoreface nourishment east and west of De Haan. No unequivocal influence on the beach of the presence of the freshly made berm could be detected.

After the first nourishment leg (1992), beach erosion rates were almost down to half the corrected rates before 1992. The erosion reduction could not be explained by the presence of the underwater berm.

The evolution well after the soft nourishment scheme in and around De Haan (i.e. after 2000), is characterised by even milder erosion rates. The beach erosion was now only one quarter of its corrected rate before 1992. The upper shoreface even continued to grow. As this “mild” evolution is far separated in time from the 1990s nourishments, a milder wave climate and the coarser grain sizes present in the area are more likely factors to explain this trend.

After 2000, the lower shoreface profile is retreating again. The net overall effect of the shoreface nourishments may then well have been a time delay of 15 to 20 years in the natural erosion trend at De Haan.

As the evolution over 10-15 years after the beach and outer breaker bar nourishments is redistribution of sand in the profile so that the area of the upper shoreface between the beach and the outer bar is a net beneficiary of the operation, it may be considered to nourish the complete profile, from the outer breaker bar all the way up to the backshore. A sharp-crested bar will anyway soon be smoothened in line with the general profile form of the shoreface.

A pure test of a shoreface nourishment would require no simultaneous beach nourishment. Only in that setting, a pure morphological development would ensue. Reports from The Netherlands indicate the influence of such a nourishment would be limited to two years.

However, the total profile shift observed in Figure 15, suggests a new nourishment scheme should be carried out over the complete profile, from the beach all the way down to the outer shoreface bar.

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Report ref. MIWE 92.101 (koppeling voorjaar 1992)

Het profiel van de aan te leggen voedingsberm heeft de volgende kenmerken : kruin op Z = -1 m (± 0,5 m), kruinbreedte 40 m (± 5 m). In het pachtjaar 1990-1991 werd sediment gebaggerd in de toegangsgeul tot de haven van Oostende, ter hoogte van de Stroombank, en daarvan werden, t.b.v. de aanleg van de voedingsberm, 127.840 m^3 gestort[1] in het gedeelte ter hoogte van De Haan-Centrum (sections 152-155), in het kader van de uitvoering van fase 1. In het erop volgende pachtjaar 1991-1992, dat op 1 april 1992 afliep, werd 533.946 m^3 gestort nabij De Haan, voor de verdere aanleg van de onderwater-voedingsberm op de vooroever. Rekent men opnieuw met een verhouding zand/totale beuninhoud van 77 %, dan vindt men een gestort zandvolume van 509.575 m^3 voor de twee jaren samen. Op het tijdstip van de voorjaarskoppeling 1992 was dus ruim een half miljoen m^3 zand aangebracht op de vooroever.

Bij de huidige koppeling zien we het effect van de aanleg van de onderwater-voedingsberm, die, t.o.v. de koppeling najaar 1991, nu ca. 500 m westwaarts en ca. 350 m oostwaarts verlengd werd. De totaal gerealiseerde lengte bedraagt aldus, bij de koppeling voorjaar 1992, ca. 1.900 m, van in sektie 149 in het kustdeel "De Haan-West" tot sektie 157 in het kustdeel "Vlissegem". In de tussenliggende sekties 152 t/m 155 nam het vooroevervolume eveneens toe, met 32.700 m^3

De aangroei van de vooroever ten westen en ten oosten van het kustdeel "De Haan-Centrum", als gevolg van de aanleg van de onderwater-voedingsberm, is het meest opvallende element in de kaart. Uit de opmetingen tot de huidige koppeling is niet af te leiden of het storten van voedingszand op de vooroever van het kustdeel "De Haan-Centrum" aanleiding gegeven heeft tot een aangroei van het strand of de vooroever nabij de voedingsberm. Er doen zich tot op heden geen morfologische fenomenen voor die op een dergelijke geïnduceerde aangroei zouden wijzen.

Report ref. MIWE 92.102 (koppeling najaar 1992)

De aanleg van de **onderwater-voedingsberm** situeerde zich voornamelijk in 1991 en het begin van 1992. Mogelijk verloor de vooroever, tussen de koppeling van najaar 1990 en voorjaar 1992, reeds een niet nader te achterhalen zandvolume ten gevolge van erosie. De lagere kruinhoogte in het reeds langere tijd aangelegde centrale gedeelte van de voedingsberm wees eveneens op erosie. De oorspronkelijke kruinhoogte was ontworpen op Z - 1 m (±0,5 m). Deze hoogte is nu nergens meer bereikt. Zij wordt nog het meest benaderd nabij het westelijk en het oostelijk uiteinde van de voedingsberm, dat het meest recent werd aangelegd.

Buiten de twee genoemde zones met een belangrijke hoogtetoename, die aan de kustbeveiligingswerken voor De Haan zijn toe te schrijven, zijn er t.o.v. najaar 1987 nog twee andere zones waarin de hoogte is toegenomen, met een bedrag van 0,25 m tot bijna 1 m. Beide zones liggen tussen de onderwater-voedingsberm en de strandsuppletie in, en zijn langgerekt met lange as parallel met de kust zoals strandruggen.

De eerste van deze zones ligt op de laagwaterlijn, op 270 m van de zeedijk van De Haan. De aangroeizone strekt zich uit van sektie 150 t/m 157, dit is tegenover de strandsuppletie. Op de verschilkaart met de koppeling van juni 1992 (MIWE 92.102/D2) is te zien dat deze rug zich grotendeels gevormd heeft in de periode tussen juni en oktober-november 1992. De ligging tegenover het gedeelte van het opgespoten strand dat in dezelfde periode afslag kende suggereert dat de aangroei hier ten koste van de afslag op het droogvallend strand is gebeurd. De volume-afname beliep hier, in dezelfde periode, 31.500 m^3 Blijkbaar ging dit proces gepaard met kilvorming.

[1]volumes in beun

De tweede zone ligt op een afstand van 350 tot 500 m van de zeedijk, dus midden op de vooroever, ter hoogte van sekties 149 t/m 156. De aangroei hier dateert voor een gedeelte van voor de koppeling van juni 1992, maar de aangroei ging verder in de periode juni 1992 - najaar 1992 (differentiële hoogtekaart MIWE 92.102/D2). De ligging van deze aangroeizone, alsook de in de tijd vroegere aanvang van de aangroei, laten er weinig twijfel over bestaan dat deze zone gevoed werd door afslag van de onderwater-voedingsberm. De hoogte-evolutie van de voedingsberm tussen juni en najaar 1992 laat een geringe afname in hoogte zien aan de flanken van de berm en dit voornamelijk in de oostelijke sekties 155, 156 en 157.

De evolutie van de morfologie in de eerste maanden na de strandsuppletie in De Haan is duidelijk een uitspreiden van de aangebrachte zandmassa. Hetzelfde geldt voor de onderwaterberm, waarbij er een resulterend transport was naar de vooroever landwaarts van de berm. De kilvorming wijst er in beide gevallen op dat dit proces van uitspreiding voornamelijk door de golfwerking wordt uitgevoerd.

Report ref. MIWE 93.101(koppeling voorjaar 1993)

In de eerste zone is er nog verdere aangroei opgetreden tussen najaar 1992 en voorjaar 1993.

In de tweede zone ging de aangroei verder in de periode juni 1992 - voorjaar 1993. De ligging van deze aangroeizone, alsook de in de tijd vroegere aanvang van de aangroei, laten er weinig twijfel over bestaan dat deze zone gevoed werd door afslag van de onderwater-voedingsberm.

Tussen najaar 1992 en voorjaar 1993 was er verdere afslag aan de berm. De kruin is een weinig in hoogte afgenomen en de landwaartse flank kende verder erosie.

Report ref. MIWE 93.102 (koppeling najaar 1993)

Storm 14 november 1993: duinklifvorming tussen Hippodroom en De Haan. De hogere vooroever kende tussen voorjaar en najaar 1993 aangroei, en dit vooral tegenover zones die duinafslag geleden hebben. Hetzelfde geldt voor de vooroever in De Haan-Centrum. Omheen de afslag van het opgespoten strand wordt aangroei vastgesteld op de hogere vooroever. Iets dieper, op gemiddeld 200 m zeewaarts van de laagwaterlijn, bevindt zich een langwerpige afslagzone in het middengedeelte van de vooroever, over de kuststrook van Bredene tot Wenduine. Deze afslagzone stemt overeen met de landwaartse flank van de onderwaterkil voor het strand.

Zeewaarts van deze langwerpige afslagzone ligt de vooroeverberm in De Haan, ter hoogte van sekties 149 tot 158. Hier werd afslag genoteerd aan de zeewaartse flank en een lichte aangroei op de landwaartse flank.

In sekties 147 en 148 (kustdeel "De Haan-West") nam het volume van de vooroever met 34.500 m^3 toe. Het grootste gedeelte van deze toename moet toegeschreven worden aan de werken ter verlenging van de vooroeverberm in de richting van Bredene. Op een gemiddelde afstand van 650 m van de landwaartse begrenzing van de strandsekties nam de hoogte tot iets meer dan een meter toe sinds de koppeling voorjaar 1993.

De aangroei van de hogere vooroever in De Haan kan ook gedeeltelijk gevoed zijn door de afslag aan de vooroeverberm. Wellicht is deze bijdrage echter niet al te groot, aangezien de vooroeverberm voornamelijk aan de zeewaartse zijde blijkt af te slaan.

Report ref. MIWE 94.101 (koppeling voorjaar 1994)

De aanleg van de verlenging van de **onderwater-voedingsberm** in westelijke richting startte kort na de hevige storm van 14 november 1993. Bij de lodingen voor de koppeling najaar 1993 (uitgevoerd op 23 tot 27 november 1993) waren de werken reeds begonnen in sekties 147 en 148. Thans (eind april 1994) is de vooroeverberm aangelegd tot in sektie 142, ter hoogte van de afrit Vosseslag. Voor de aanleg van de vooroeverberm werd in het baggerpachtjaar 1993-1994 (dat liep tot 31 maart 1994) ca. 375.000 m^3 gestort (volume in beun).

Kort voor de lodingen van najaar 1993 werd de kust getroffen door de hevige storm van 14 november 1993. Hierbij trad vooral afslag op aan de duinvoet in alle sekties met duinen en aangelegde droogstrandberm.

Bij de storm van 26-28 januari 1994 trad er nogmaals duinafslag op. De erosie was in sommige kustdelen vergelijkbaar met de afslag bij de storm van 14 november 1993.

Tussen najaar 1993 en voorjaar 1994 nam het vooroevervolume van Bredene tot Wenduine toe met 471.500 m^3. Het is de belangrijkste aangroei sinds de vooroeverlodingen begonnen.

De aangroei is ruimtelijk als volgt gespreid :

- er is aangroei tot meer dan 1 m van sektie 142 tot 147 tussen de Vosseslag en het Zeepreventorium in een kustparallelle strook op 400 tot 500 m afstand van de laagwaterlijn. Deze zone is de eind 1993 - begin 1994 aangelegde westwaartse verlenging van de onderwater-voedingsberm;
- overigens kennen alle kustdelen aangroei op de vooroever in twee tot drie kustparallelle, smalle zones. Deze zones zijn doorgaans 50 tot 75 m breed. Landwaarts ervan wordt een van vorm vrijwel identieke afslagstrook gevonden;
- in de kustdelen "De Haan-West", "De Haan-Centrum" en "Vlissegem" zijn de aangroei- en afslagzones op de vooroever in dezelfde volgorde als elders aanwezig, maar de aangroeizones zijn breder, tot 100 m en meer.

De ruimtelijke spreiding geeft duidelijke aanwijzingen over de verklaring van de aangroei op de vooroever.

De aangroei in sekties 142 tot 147 op 400 tot 500 m van de laagwaterlijn is toe te schrijven aan de verlenging van de onderwater-voedingsberm.

De twee tot drie parallelle aangroeistroken in alle kustdelen wijzen op de zeewaartse verplaatsing van brekerbanken op de vooroever. Deze evolutie is typisch in de winter, wanneer de stormfrekwentie hoger is. De aangroeizones worden gevoed door de aangrenzende, landwaarts gelegen afslagstroken. De hoogste aangroeizone wordt gevoed door de stormafslag van het strand.

De bredere aangroeizones in de kustdelen "De Haan-West", "De Haan-Centrum" en "Vlissegem" wijzen op de grotere voeding door :

- de zandmassa gevormd door de net aangelegde vooroeverberm in sekties 142 tot 147;`
- afslag van de oudere vooroeverberm in sekties 148 tot 157;
- afslag van het in 1992 opgespoten strand in sekties 149 tot 158.

De aangroei van de vooroever tussen najaar 1993 en voorjaar 1994 heeft dus twee bronnen: in sekties 142 tot 147 is het aangevoerd zand ter aanleg van de vooroeverberm; elders is het zand afgeslagen van duinvoet, strand, hogere vooroever en de oudere vooroeverberm ter hoogte van De Haan-Centrum. Hieruit kan men afleiden dat veel van het in de winter 1993-1994 afgeslagen zand nog aanwezig is in het systeem, voornamelijk op de lagere vooroever. Tussen de koppeling van voorjaar 1993 en voorjaar 1994 verloren strand en duinaanzet van de kustdelen "Hippodroom" over De Haan tot "Wenduine-Oost" een volume van 305.900 m^3. De vooroever groeide aan met 461.900 m^3. Het positief saldo is toe te schrijven aan de aanleg van de vooroeverberm tussen de Vosseslag en het Zeepreventorium.

Theoretisch blijft het zand op de vooroever beschikbaar voor de natuurlijke heropbouw van het strand tijdens de zomer. Strandopbouw gebeurt immers voornamelijk bij mooi weer, wanneer het cross-shore sedimenttransport een netto landwaartse komponent heeft.

De evolutie tussen de koppelingen najaar 1993 en voorjaar 1994 is een typische winterevolutie, met lokaal intensere zandverschuivingen als gevolg van de in 1991-1992 en 1994 aangevoerde zandmassa's ter aanleg van de onderwater-voedingsberm en de suppletie in De Haan. Uit de opvolging van de strandmorfologie is gebleken dat de omgeving van De Haan relatief gespaard is gebleven van duin- en strandafslag bij de stormen van de winter 1993-1994. De koppeling toont aan dat de verplaatsingen van zand op de vooroever intenser zijn geweest dan elders, ten oosten en ten westen van De Haan.

De ter hoogte van De Haan-Centrum aangelegde voedingsberm op de vooroever vertoont afslag. De afslag aan de zeewaartse zijde, eerder vastgesteld bij de koppeling najaar 1993, is verdwenen. T.o.v. de vorige koppeling heeft er aan de zeewaartse zijde immers aangroei plaatsgevonden, waardoor de afslag gekompenseerd is. Meer dan waarschijnlijk is er een voeding opgetreden van de nieuw aangelegde berm ten westen van de in 1991-1992 aangelegde vooroeverberm.

De afslagzone aan de landwaartse zijde van de vooroeverberm is uitgebreid t.o.v. de situatie in het najaar van 1993. De hoogte is hier meer dan een halve meter afgenomen.

Men zou in eerste instantie kunnen stellen dat het aangevoerde volume dus nog aanwezig is op de vooroever van het kustdeel. In werkelijkheid heeft er erosie plaatsgevonden, gevolgd door aanvoer van zand vanaf het strand en de nieuwe vooroeverberm ten westen van De Haan.

Report ref. MIWE 94.102 (koppeling najaar 1994)

De aanleg van de verlenging van de **onderwater-voedingsberm** in westelijke richting startte kort na de hevige storm van 14 november 1993. De berm werd geleidelijk westwaarts verlengd. Voor de aanleg van de vooroeverberm werd in het baggerpachtjaar 1993-1994 (dat liep tot 31 maart 1994) ca. 375.000 m^3 gestort (volume in beun). Er werd doorgewerkt tot 9 september 1994, waarbij een totale lengte van 2.850 m werd gerealiseerd van sektie 148 tot sektie 137 (krib 12, op 350 m ten oosten van de toegang "Hippodroom"). Het aangevoerde volume zand bedraagt 525.400 m^3 (baggerpachtjaren 1993-1994 en 1994-1995). In 1995 zal de berm nog westwaarts worden verlengd. Deze fase behoudt dezelfde ontwerpkarakteristieken als voor de voedingsberm in De Haan-Centrum.

Tussen najaar 1993 en voorjaar 1994 nam het vooroevervolume in sekties 142 t/m 147 met 186.100 m^3 toe. En tussen voorjaar 1994 en najaar 1994 steeg het vooroevervolume in sekties 137 tot 143 met 42.700 m^3. De gezamenlijke toename is dus 263.300 m^3 en het grootste gedeelte van deze toename is dus aan de aanleg van de vooroeverberm toe te schrijven. De gemeten toename is slechts de helft van de aangebrachte hoeveelheid. Uit voorgaande rapporten blijkt dat de morfologie van de aangelegde berm snel kan worden gewijzigd. Zo was bij de lodingen voor de koppeling voorjaar 1994 een afgevlakte morfologie opgemerkt voor het gedeelte aangelegd in het begin van 1994, hetgeen kan wijzen op initële erosie. Ook voor de lodingen bij de koppeling najaar 1994 kan men aannemen dat de berm erosie gekend heeft tussen aanleg en meting. In de periode tussen voor- en najaar 1994 kende de vooroever langs omzeggens de hele Vlaamse kust erosie als gevolg van het zomeraangroei-effekt van het strand. Men kan aannemen dat dit proces ook aan de Vosseslag gespeeld heeft.

Zoals vaak in de zomer kent de vooroever onder het rustige golfklimaat erosie en groeit het laagstrand aan. De brekerbanken op de vooroever zijn t.o.v. de voorjaarssituatie landwaarts opgeschoven. In het geheel verminderde het vooroevervolume van Bredene tot Wenduine met 210.000 m^3 (de zone tussen de toegangen Hippodroom en Vosseslag, waar aangroei was als gevolg van de aanleg van de vooroeverberm, niet meegerekend). Op laag- en middenstrand werd over dezelfde periode een aangroei van ca. 150.000 m^3 gemeten.

De markante hoogtetoename in sekties 137 tot en met 143 (met 42.700 m^3) is zoals hierboven reeds gezegd toe te schrijven aan de tussen voor- en najaar 1994 uitgevoerde zandstortingen ter aanleg van de vooroeverberm. De as van het gebied met hoogtetoename ligt 550 m zeewaarts van de landgrens van de strandsekties. In hoogte is de toename nergens groter dan een meter. Het is echter zeer aannemelijk te stellen dat na storting van het zand reeds verlaging en landwaartse verplaatsing van de berm opgetreden is. Hierdoor is deze berm meteen gaan funktioneren. Mogelijk is zelfs de vrij grote zomeraangroei op de stranden van de kustdelen "Vosseslag" en "De Haan-West" geïnduceerd door de aanleg van de berm.

Report ref. MIWE 95.101 (koppeling voorjaar 1995)

Er werden op de vooroever geen verdere zandstortingen uitgevoerd tussen de koppelingen najaar 1994 en voorjaar 1995. Pas eind 1995 werd de berm nog westwaarts verlengd, in de sekties ter hoogte van de strandtoegang "Hippodroom".

In de maanden november en december 1994 werd een strandsuppletie uitgevoerd in de urgentste zone (ten westen van de toegang Vosseslag), gevolgd door een strandsuppletie in april, mei en juni 1995, in de sekties 137 tot 144 (vanaf 1.200 m ten westen van Vosseslag tot 500 m ten oosten).

Tussen de koppeling van najaar 1994 en voorjaar 1995 situeert zich een zeer regenachtige periode, met een opeenvolging van stormen vanaf december tot in maart. Qua impakt op de strandmorfologie was de storm van 1-2 januari 1995 de belangrijkste.

De meest opvallende verandering is het gevolg van de strandsuppletie in sekties 137 tot en met 144, met een belangrijke vertikale aangroei van het strand. Een aanpalende zone op de vooroever is eveneens, doch in mindere mate, in hoogte toegenomen. Er is blijkbaar een gedeelte van het opgespoten zand op de hogere vooroever terecht gekomen. Neemt men aan dat de andere wijzigingen op de vooroever in deze zone elkaar kompenseren (hetgeen men kan afleiden uit de differentiële hoogtekaart), dan kan men de toename in vooroevervolume tussen de vorige en de huidige koppeling, met 126.200 m^3, toeschrijven aan zandtoevoer tijdens de strandsuppletie.

Tussen de koppelingen najaar 1994 en voorjaar 1995 werd geen zand aangevoerd voor de verlenging van de voedingsberm. Het bij de koppeling voorjaar 1995 recentst aangelegde gedeelte (sekties 137 tot en met 143) vertoont, t.o.v. de vorige koppeling, een afslag aan de kruin van de voedingsberm. De afslagzone valt samen met de kruinzone van de berm en heeft over een lengte van 900 m een kruinverlaging met meer dan een halve meter. Daarentegen zijn zowel de zeewaartse als de landwaartse flank aangegroeid, en ook is er wat aangroei aan het westelijk uiteinde van de voedingsberm. Het is duidelijk dat de voedingsberm in de winter volgend op zijn aanleg afgevlakt is en dat het zand afkomstig van de kruinzone omheen de berm is neergezet. Het aangevoerde zand is dus wel nog in de aanlegzone van de berm aanwezig en blijft beschikbaar voor een eventuele hervoeding van het strand.

Hetzelfde proces heeft, minder intens, gewerkt op de zone in sekties 145 tot en met 148. De kruin is hier meestal met 25 cm verlaagd en omheen de kruin van de voedingsberm zijn zones met een aangroei gesitueerd. Dit gedeelte van de berm is eerder aangelegd (eind 1993 - begin 1994), en hier is reeds vóór de koppeling najaar 1994 verlaging aan de kruin vastgesteld. Het hermodelleren van de voedingsberm naar een lager profiel is dus nog doorgegaan tussen de koppelingen najaar 1994 en voorjaar 1995.

Aan de Vosseslag blijkt er tegelijk met de strandsuppletie een langwerpige aangroeizone te zijn ontstaan op de hogere vooroever, ongeveer ter hoogte van de hoogtelijn van 0 m. Deze aangroei was nog niet aanwezig bij de koppeling najaar 1994. De gemiddelde hoogte is hier gestegen tussen 0,5 tot 1,0 m. Een vergelijkbare aangroeizone heeft zich in De Haan-Centrum gevormd in het eerste jaar na de profielsuppletie aldaar. Men kan voor beide, ca. 50 m brede aangroeizones stellen dat ze gevoed werden door zand afkomstig van initiële afslag uit de zone van de strandsuppletie. De vorm van de aangroeizone, vergelijkbaar met een gewone brandingsrug, wijst er in beide gevallen op dat dit proces gebeurt door golfwerking en dwarstransport. Het strand verkrijgt hierbij zijn oorspronkelijke morfologie met killen en ruggen.

Tevens is er ter hoogte van de kustdelen "Hippodroom", "Vosseslag" en "De Haan-West" een tweede aangroeizone op de vooroever, eveneens ca. 50 m breed, waarvan de as evenwijdig verloopt met de kustlijn en gelegen is op 250 m van de laagwaterlijn en 100 m landwaarts van de kruin van de voedingsberm. De hoogte is hier tussen 0,25 en 0,50 m gestegen. Een gelijkaardige aangroeizone is eveneens in De Haan-Centrum te vinden. In beide gevallen gaat het om een zone die aangegroeid is ten koste van de voedingsberm. Het ontstaan van deze aangroeizone is gebonden aan de eerste maanden na de aanleg van de voedingsberm, en volgt de gefaseerde aanleg van oost naar west. Naderhand blijkt de zone zich te handhaven, maar niet verder aan te groeien. Hierdoor is het zand, aangevoerd bij de aanleg van de voedingsberm herverdeeld over de vooroever, maar het blijft in de omgeving van de aanlegzone aanwezig. De voedingsberm zelf is overal, volgend op de gefaseerde aanleg, met ruim een halve meter verlaagd.

Report ref. MIWE 95.102 (koppeling najaar 1995)

In het najaar van 1995 werd de bank nog verder verlengd tot voorbij de afrit Hippodroom. De zandstortingen in het kader van de aanleg van de voedingsberm op de vooroeverberm werden verdergezet tot 20 december 1995. Hierdoor is de totale aanleg nog niet gerealiseerd bij de onderhavige koppeling (loding ter hoogte van de Hippodroom op 21 november 1995). De verhoging van de vooroever als gevolg van de verdere aanleg van de voedingsberm situeert zich in sekties 133 tot en met 136, ter hoogte van de toegang "Hippodroom". De zone met waargenomen hoogtetoename is hier meer landwaarts gelegen dan wat wordt aangegeven door de grenzen van de aanlegzone. Vandaar dat de volumetoename zich gedeeltelijk voordeed buiten het aanleggebied van de voedingsberm. Bovendien vertoont het hoogste gedeelte van de vooroever hier een volumetoename die verbonden is met de strandsuppletie, eveneens uitgevoerd tussen voor- en najaar 1995 (nl. in oktober 1995). Het globale cijfer van 73.900 m^3, de volumetoename van de vooroever in sekties 133 tot en met 136 tussen de koppelingen voorjaar 1995 en najaar 1995, omvat dus een gedeelte zand, afkomstig van de strandsuppletie, en een gedeelte zand, gestort bij de aanleg van voedingsberm, maar zowel binnen als buiten de aanlegzone.

Voor de koppeling najaar 1995 vond de strandsuppletie plaats in sekties 132 tot en met 137 en 144 tot en met 149, met een belangrijke vertikale aangroei van het strand. Een aanpalende zone op de vooroever is eveneens, doch in mindere mate, in hoogte toegenomen. Er is blijkbaar een gedeelte van het opgespoten zand op de hogere vooroever terecht gekomen. Dit is vooral het geval ter hoogte van de toegang "Hippodroom"; in de zone tussen de Vosseslag en het Zeepreventorium (sekties 144 tot en met 149) is de vooroever tussen voor- en najaar 1995 veel minder gegroeid.

Tussen de koppelingen voorjaar 1995 en najaar 1995 werd verder gewerkt aan de verlenging van de voedingsberm ter hoogte van de Hippodroom. De differentiële hoogtekaart vertoont een hoogtetoename tot meer dan een meter op de vooroever van sekties 133 tot en met 136. De waargenomen hoogtetoename situeert zich gedeeltelijk binnen en gedeeltelijk buiten (landwaarts van) de aanlegzone.

Voor zover bekend wordt bij de aanleg van de voedingsberm steeds gewerkt volgens hetzelfde dwarsprofiel. De meer landwaartse ligging van de zone met hoogtetoename tussen de koppelingen voorjaar 1995 en najaar 1995 is ofwel te wijten aan een meer landwaartse aanleg, ofwel aan een inmiddels opgetreden landwaarts transport, ofwel aan een kombinatie van beide. In het gebied met hoogtetoename ligt de kruin van de voedingsberm op -1 m, hetgeen overeenkomt met de aanleghoogte en dus wijst op een meer landwaartse uitvoering. Langsheen het kilometerslange, eerder aangelegde gedeelte van de voedingsberm komt op de hogere vooroever een langgerekte aangroeizone voor, waarvan het ontstaan en de evolutie duidelijk verbonden was aan de aanleg en de verdere ontwikkeling van de voedingsberm (zie vorige rapporten Koppeling). Hieruit kan men afleiden dat er wel degelijk een landwaarts zandtransport optreedt bij en na het aanleggen van de voedingsberm.

Het overige gedeelte van de voedingsberm vertoont een lichte afslag, en dit voornamelijk aan de zeewaartse helling en de kruin.

Report ref. MIWE 96.101 (koppeling voorjaar 1996)

De strandsuppletie reikt tot sectie 132 en was beëindigd op 1 november 1995. De voedingsberm op de vooroever reikt tot sectie 131 en was klaar op 20 december 1995.

Op de vooroever was men begonnen met de oostwaartse verlenging van de voedingsberm, aansluitend bij de in 1991-1992 aangelegde berm voor De Haan-Centrum. Op het ogenblik van de vooroeverlodingen voor de huidige koppeling waren er voornamelijk zandstortingen gebeurd in secties 158 en 159 van het kustdeel "Vlissegem". Door de onmiddellijk volgende uitspreiding van het zand kenden ook secties 157 en 160 enige aangroei.

Enkele maanden voor de huidige koppeling voorjaar 1996 is de aanleg van de berm beëindigd in secties 131, 132 en 133. De breedte (loodrecht op de kust) van de zone ondieper dan -2 m is 150 m op de grens van secties 131 en 132. De kruin ligt op -1,7 m. Merkwaardig is de aanwezigheid van een ondiepe brekerbank als het westelijke vervolg in de lengte-as van de aangelegde berm ter hoogte van het kustdeel Bredene-Oost, tot sectie 127. Hier zijn geen stortingen gebeurd. De brekerbank heeft zijn kruin thans tot een halve meter ondieper dan bij de koppeling najaar 1995. Het ondiepste punt van de bank in sectie 129 is -1,5 m.

De verklaring is een aangroei van de bestaande bank, met voeding van materiaal afkomstig van de aanlegzone in secties 131-133. Er zijn tussen de aanleg en de vooroeverloding een viertal maanden verstreken. De ontwikkeling wijst op een belangrijk langstransport, ditmaal gericht van oost naar west. Het langstransport kan tijdelijk deze richting aannemen wanneer oosten- en noordenwind domineren, hetgeen het geval was tussen de koppeling najaar 1995 en voorjaar 1996.

Van sectie 134 tot 155 ligt de kruin van de voedingsberm thans op -1,7 à -1,8 m. In profiel gezien ligt de kruin nog steeds op de plaats van aanleg, maar dan enkele decimeters dieper dan bij de aanleg.

In secties 158 en 159 is de voedingsberm, gemeten aan de dieptelijn van -2 m, 140 m breed. Hier dateert de aanleg van net voor de vooroeverlodingen. De kruin ligt dan ook droger dan -1 m, slechts op -0,4 m in sectie 159.

De aangroei van de brekerbank ter hoogte van het kustdeel "Bredene-Oost" laat er geen twijfel over bestaan dat de verlaging van de berm in het kustdeel "Hippodroom" aanleiding heeft gegeven tot een lateraal zandtransport volgens de as van de voedingsberm, in de eerste maanden na de aanleg. Er is geen aantoonbare invloed op de morfologie van de aanpalende zeebodem. Deze is effen en blijft dit ook tijdens de aanleg van de berm. De hermodellering onmiddellijk na de aanleg van de voedingsberm is voornamelijk een verticale wijziging van het profiel gecombineerd met een afvoer via lateraal transport; de plaats van de kruin in het profiel wijzigt niet.

Landwaarts van de aanlegzone van de voedingsberm, maar nog op de vooroever, zijn twee zones met aangroei te herkennen. Het gaat om twee kustparallelle stroken met tot een meter verticale aangroei. De ligging van de aangroeistroken en de fasering van de kustverdedigingswerken laten er weinig twijfel over bestaan dat de aangroei het resultaat is van de herspreiding van het zowel bij de strandsuppletie omheen de toegang Hippodroom als bij de onderwatersuppletie aan de voedingsberm aangevoerde zand. Het ligt het meest voor de hand om te veronderstellen dat de meest zeewaartse aangroeizone gevoed werd door de voedingsberm en de meest landwaartse door de erosie afkomstig van het gesuppleerde strand.

Report ref. MIWE 96.102 (koppeling najaar 1996)

In 1996 werd het minst urgente gedeelte van de kustverdedigingswerken aangevat en grotendeels uitgevoerd, nl. fase 2b (van sectie 158 in het kustdeel "Vlissegem" tot sectie 172 in Wenduine, ten westen van de rotonde). De huidige koppeling stemt overeen met de nameting met betrekking tot de strand-suppletie in deze zone. De opspuitingen waren immers beëindigd op 18 oktober 1996. Op de vooroever is in 1996 begonnen met de oostwaartse verlenging van de voedingsberm, aansluitend bij de in 1991-1992 aangelegde berm voor De Haan-Centrum. De aanleg gebeurt gespreid in de tijd. Hierdoor is er geen echte voor- en nameting beschikbaar. Bij de koppeling voorjaar 1996 was de aanleg gevorderd tot in secties 158 en 159. Bij de huidige koppeling najaar 1996 is de berm verlengd tot in sectie 160 en 161 en werden er ook stortingen verricht in sectie 164.

De morfologische evolutie van de brekerbank nu eens ten westen, dan weer ten oosten van de net aangelegde gedeelten, laat er geen twijfel over bestaan dat de verlaging van de berm in de net voltooide gedeelten aanleiding heeft gegeven tot een lateraal zandtransport volgens de as van de voedingsberm, in de eerste maanden na de aanleg.

Tussen de koppeling van voorjaar en najaar 1996 deden zich twee stormen van betekenis voor, nl. op 29 augustus en op 29 oktober 1996. Wat de zone met kustverdedigingswerken van Bredene tot Wenduine betreft, hier werd nauwelijks enige morfologische schade opgemerkt.

De verticale aangroei bedraagt tot meer dan een meter in secties 160 en 161, en minder dan een meter in secties 164 en 165.

Deze kaart toont ook aan dat, van sectie 158 tot 168, twee stroken die parallel liggen met de laagwaterlijn, aangroei gekend hebben. De ene strook ligt op het laagste deel van het laagstrand, de andere op de hogere vooroever. Tussen de laatstgenoemde aangroeistrook en de zone waarin de voedingsberm wordt aangelegd, ligt een strook met erosie.

Bij de profielsuppletie in de zone Vlissegem - Nieuwmunster - Wenduine West (secties 157 tot 172) werd enkel de hoogste zone van het laagstrand en het gebied aan de duinvoet opgehoogd. Het grootste deel van de suppletie was afgewerkt voor de zomer van 1996, een klein stuk ter hoogte van de zeedijk in Wenduine-West werd voltooid in oktober 1996. De bij de koppeling najaar 1996 weergevonden aangroeistroken rond de laagwaterlijn zijn dus tijdens en kort na de beëindiging van de werken ontstaan. Zij kenden wellicht aangroei tijdens de opspuitingswerken, wanneer een deel van de opgespoten specie terugvloeit naar zee. Ook bevatten zij allicht zand afgeslagen bij de eerste erosie aan de profielsuppletie, b.v. bij de stormen van 29 augustus en/of 29 oktober 1996. De morfologische schikking van de aangroeizones in twee stroken parallel met de laagwaterlijn wijst op de werking van golven bij de afzetting.

Tussen Hippodroom en Vlissegem vertoont de voedingsberm erosie. De zeewaartse helling van de berm is hier en daar tot 25 cm verlaagd. In de voor de vorige koppeling aangelegde gedeelten (sectie 131 tot 134 en sectie 157 tot 159) bedraagt de verticale erosie sinds de vorige koppeling meer dan een halve meter.

Bij de huidige koppeling najaar 1996 is er geen sprake van laterale aangroei, ten gevolge van het langstransport, in secties palend aan de recentste aanlegzones.

Report ref. MIWE 97.101 (koppeling voorjaar 1997)

Bij de huidige koppeling voorjaar 1997 zijn er op de vooroeverberm stortingen verricht in een kleine zone op de grens van secties 165 en 166. Vanaf het onderwatersuppletiegebied in sectie 165 en 166 strekt zich een enkele tientallen meters brede aangroeistrook uit op de vooroever van secties 167, 168 en 169. In deze secties samen vermeerderde het vooroevervolume sinds de koppeling najaar 1996 met 12.800 m^3. De vorm van de aangroeistrook en zijn verbinding met het onderwatersuppletiegebied laten er geen twijfel over bestaan dat het meeste van deze aangroei ontstaan is door afvoer tijdens of kort na de stortingen voor de verlenging van de onderwatervoedingsberm in secties 165 en 166.

In de kustdelen "Hippodroom", "Vosseslag", "De Haan-West", "De Haan-Centrum" en "Vlissegem" heeft de voedingsberm sinds de vorige koppeling enige decimeters afslag gekend aan de zeewaartse flank. De kruin van de berm is niet verlaagd. Een gedeelte van het zand is op de landwaarste flank van de berm terecht gekomen (zie differentiële hoogtekaart). De afslagzones in het voedingsbermgebied zijn uitgestrekter dan de aangroeizones.

In het recentst aangelegde gedeelte op de grens van de kustdelen "Vlissegem" en "Nieuwmunster" is de afslag aan de zeewaartse flank en de aangroei op de landwaarste flank intenser dan bij de vroeger aangelegde gedeelten van de voedingsberm.

Op de hogere vooroever zijn eveneens langwerpige aangroei- en afslagstroken zichtbaar, die getuigen van de verschuivingen van brekerbanken tussen de vorige en de huidige koppeling. Deze hebben geen grote netto volumeveranderingen tot gevolg.

Report ref. MIWE 97.102 (koppeling najaar 1997)

Er zijn geen verdere stortingen gebeurd tussen de koppeling voorjaar 1997 en najaar 1997. Er worden voor de winter 1997-1998 nog stortingen voorzien in secties 162 en 165 tot 169. De aanlegwerken werden pas beëindigd op 14 februari 1998.

Het grootste gedeelte van de strandsuppletie werd uitgevoerd tussen 25 maart en juni 1997 (de aanvoer van zand behelsde 847.825 m^3). De laatste honderden meters tot de rotonde van Wenduine werden in september-oktober 1997 uitgevoerd. De totale aanvoer bedroeg dan (inclusief het reeds in het voorjaar uitgevoerde gedeelte) 1.002.385 m^3.

De differentiële gekoppelde hoogtekaart sinds de vorige koppeling geeft aan dat de voedingsberm in het kustdeel "Hippodroom" lichte erosie gekend heeft. In de kustdelen "De Haan-West", "De Haan-Centrum" en "Vlissegem" is er eerder lichte aangroei te melden.

De hogere vooroever vertoont eveneens eerder lichte aangroei. Dit is vooral duidelijk in de kustdelen "Hippodroom" en "De Haan-Centrum". De aangroei bevindt zich in de nabijheid van afslagzones op het strand. Deze aangroei hoort bij de morfologische aanpassing van het strand na de profielsuppletie van 1995 en 1996.

De aangroeizones op de vooroever sinds 1992 zijn duidelijk kleiner dan de erosiezones. De stockage van zand op de hogere vooroever is een tussenstadium in een uiteindelijke afvoer. De invloed van de voedingsberm in De Haan-Centrum kan tot op heden gezien worden in een lager erosieritme van het strand dan wat men mag verwachten na een strandsuppletie alleen. Het is niet aan te tonen dat er aanvoer van zand van de voedingsberm naar het strand is opgetreden.

Ruimtelijk gezien wordt zand verplaatst van erosieve zones naar sedimentaire gebieden in de omgeving van de suppletiezones. In het geheel genomen overweegt in het gehele gebied van fase 2a echter de erosie op de aangroei. Het wordt dus duidelijk dat een netto afvoer van sediment uit de zone van de kustverdedigingswerken optreedt.

T.o.v. de evolutie tussen Bredene en De Haan en in De Haan-Centrum zijn er voor de zone van fase 2b twee verschillen :

- de afslagintensiteiten van het strand zijn kleiner;
- de vooroever groeide zelfs lichtjes aan.

Dat laatste wijst op een mogelijk laterale aanvoer vanuit het westen.

Ofschoon de aanleg van de kustverdediging over verschillende jaren gespreid gebeurde, maken alle fasen van de combinatie voedingsberm-strandsuppletie na afwerking eenzelfde initiële morfologische evolutie mee. In de eerste maanden tot het eerste jaar na de aanleg verlaagt de kruin van de voedingsberm met een meter, verflauwen de flanken, kent de zeewaartse glooiing van de profielsuppletie afslag, wordt de morfologie van brekerbanken heringesteld, en kennen strand en vooroever rond de laagwaterlijn een beduidende aangroei. De herinstelling van de brekerbankenmorfologie wijst op het belang van het dwarstransport in deze kustzone.

Bij de aanleg van de voedingsberm werd bij de opvolging van de morfologie echter tevens duidelijk de invloed van het langstransport gemerkt, zowel in oostelijke als westelijke richting, maar na verloop van enkele jaren overwegend in oostelijke richting. Zo kende het kustdeel "Vlissegem" heel wat aangroei in de eerste jaren na de uitvoering van fase 1 (De Haan-Centrum) en kende vervolgens vooral de vooroever en de voedingsberm in De Haan-Centrum aangroei toen de aanleg van de voedingsberm in de zone Hippodroom - Zeepreventorium in uitvoering was. In het voorjaar van 1996 was het de beurt aan de vooroever van het kustdeel "Bredene-Oost" (aanvoer vanaf de berm aan de Hippodroom) en van het kustdeel "De Haan-Centrum" (aanvoer vanaf de bermverlenging in het kustdeel "Vlissegem") (in de winter voor de koppeling voorjaar 1996 overheerste tijdelijk het westwaarts langstransport).

De werking van het langstransport blijkt ook uit de huidige vorm van de voedingsberm, die vanaf de kustdelen "Hippodroom" en "Vosseslag" geleidelijk in profiel verbreedt in de richting van het kustdeel "Vlissegem", waar de berm nu zelfs breder is dan bij de aanleg. Deze profielverandering gebeurde geleidelijk sinds de koppeling voorjaar 1996 en wordt geïnterpreteerd als een aanpassing van de bermvorm onder de werking van het langstransport.

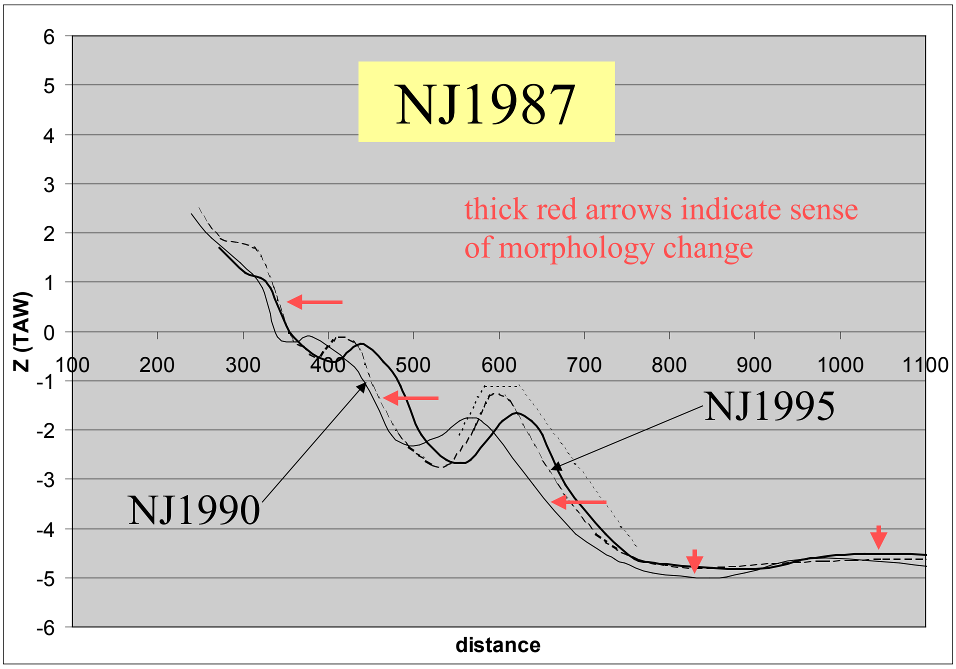
Merkwaardig genoeg is er tot bij de huidige koppeling geen invloed te merken van een vooroeveraangroei ten oosten van Wenduine. Vooral ter hoogte van de rotonde, maar overigens in de beide kustdelen "Wenduine-West" en "Wenduine-Oost", kent de vooroevervoet vrij ernstige erosie.

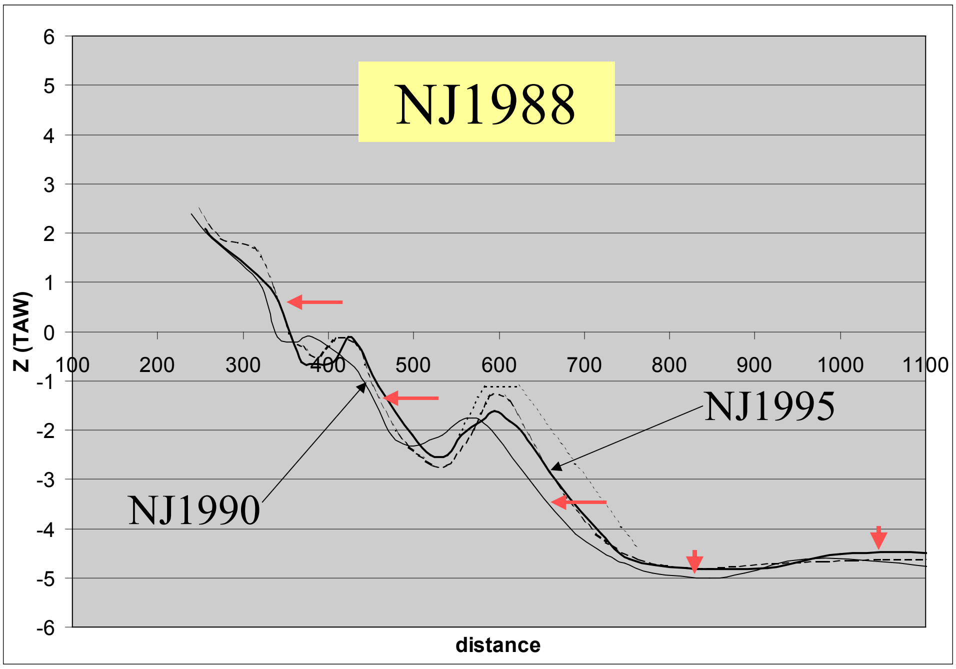
Hoewel de initiële morfologische veranderingen gepaard gingen met vrij grote hoeveelheden sedimenttransport, bleef het transport aanvankelijk beperkt tot korte afstanden, zodat het weggenomen sediment in de buurt van de aanlegzone bleef en over het geheel van de zone van de kustverdedigingswerken het vooroever- en laagstrandvolume constant bleef.

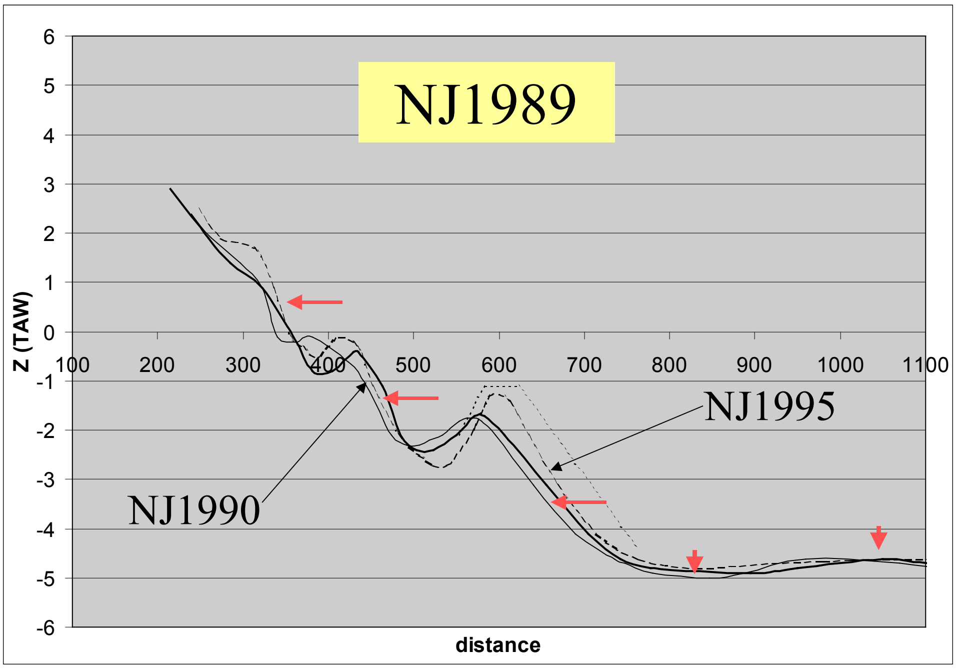
Het laatste jaar beginnen netto verliezen op te treden uit het gebied van de kustverdedigingswerken.

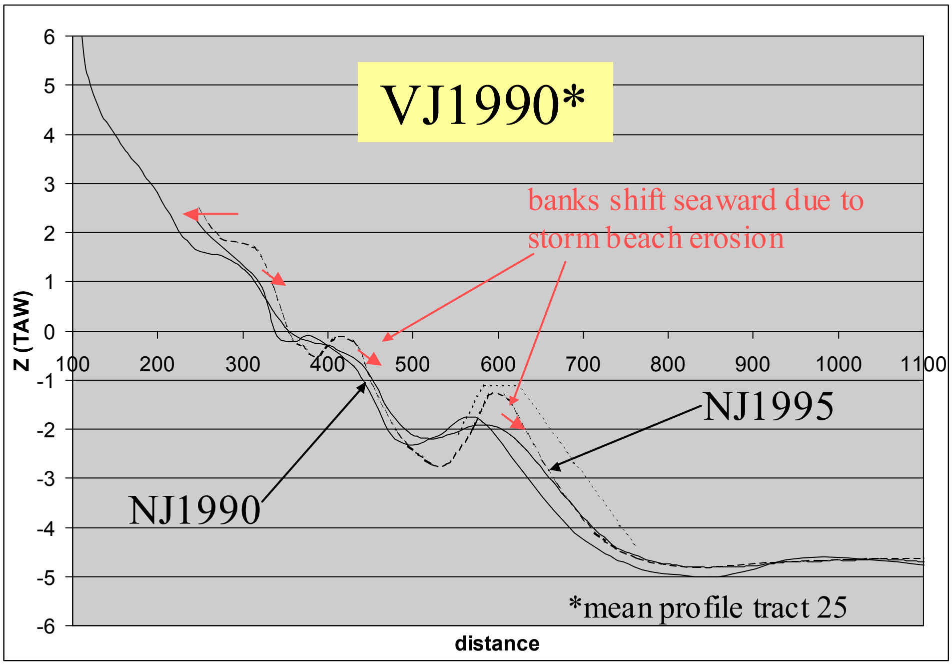
Annex 2. Profile series for section 133

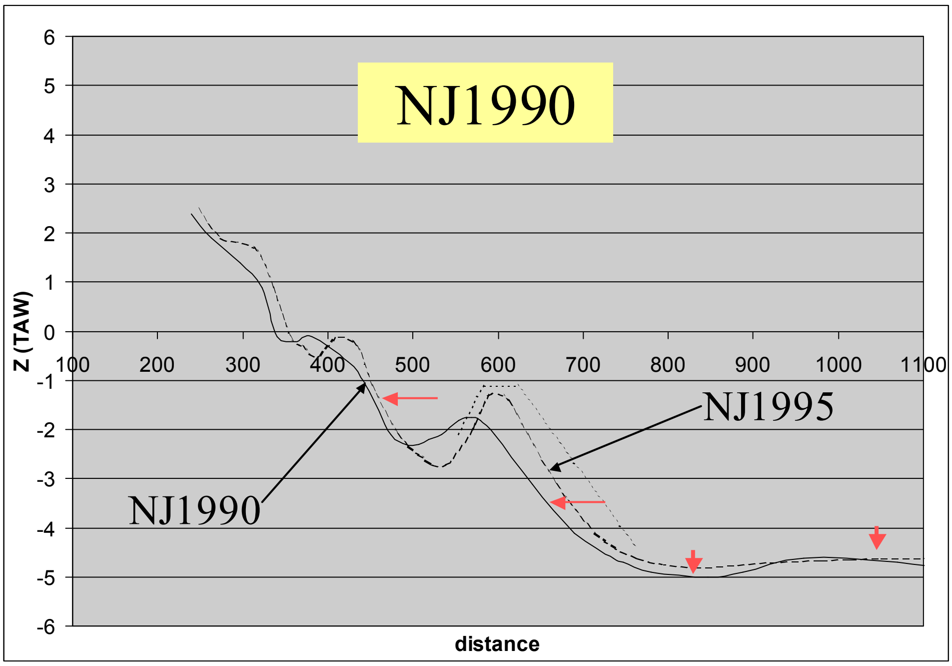
Each figure shows the NJ1990 and NJ1995, as well as the design profile of the feeder berm, in fine lines, for reference. Comments are in red.

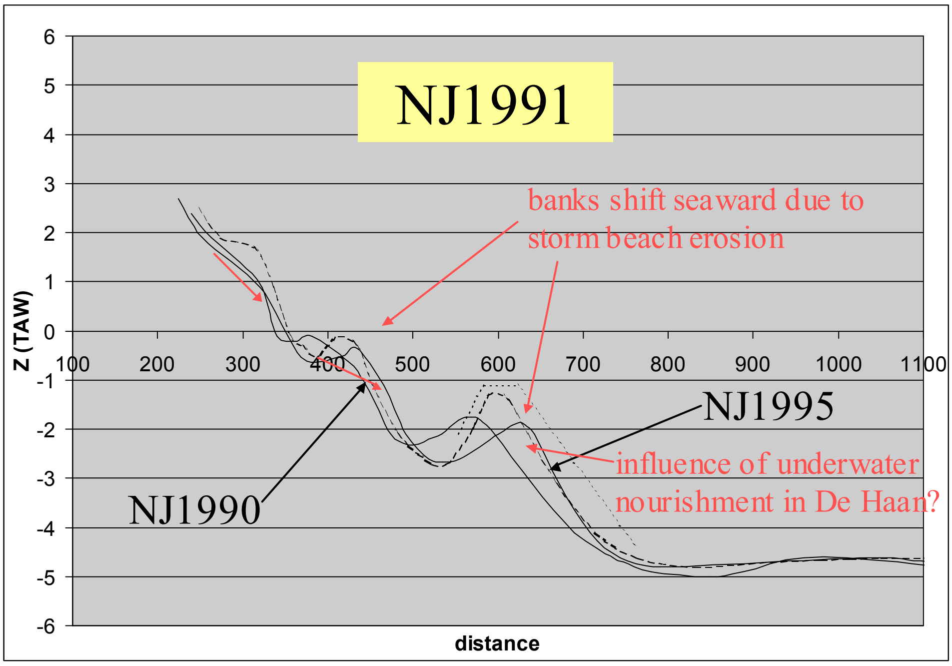


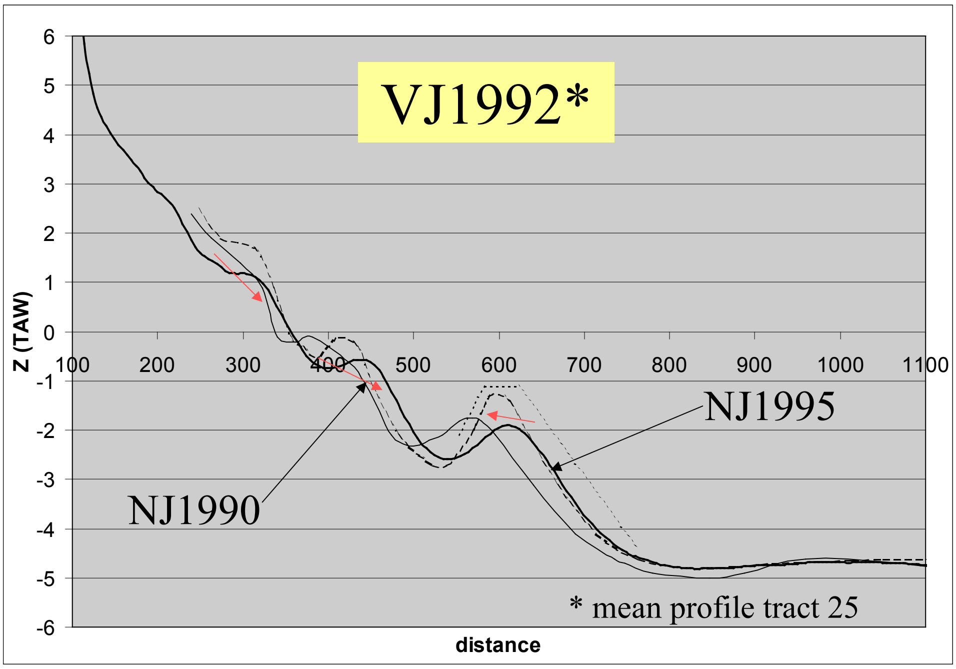


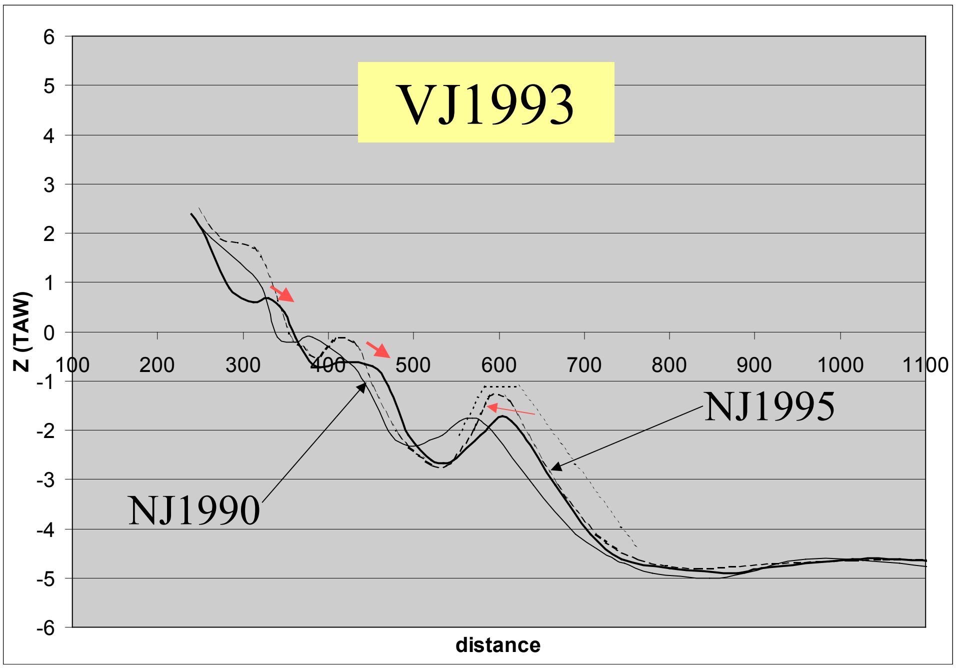

NJ1989
NJ1995
NJ1990
Z (TAW)
distance

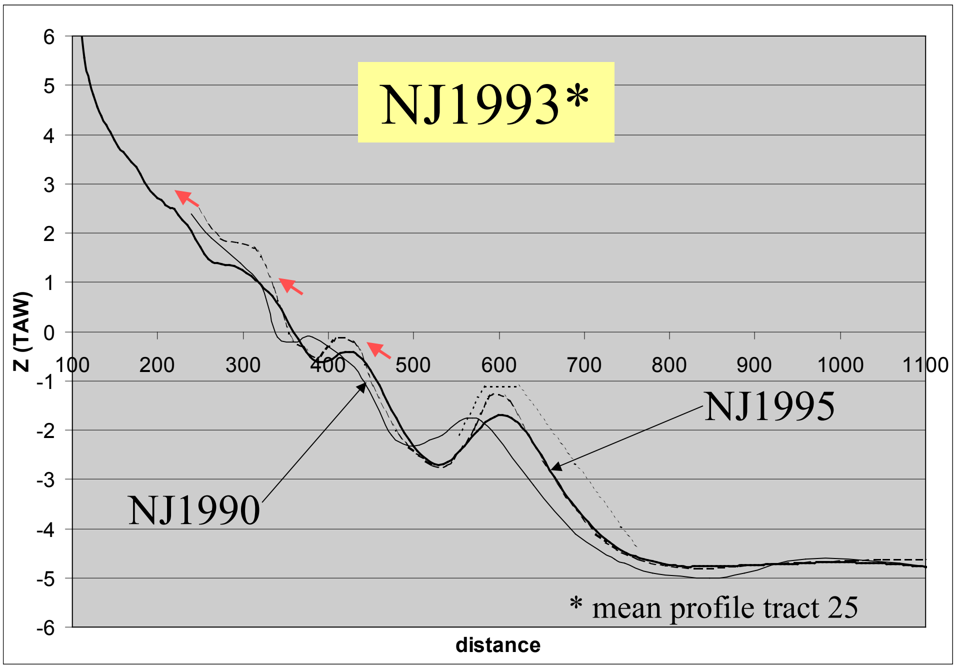

VJ1990*
banks shift seaward due to storm beach erosion
NJ1995
NJ1990
*mean profile tract 25
Z (TAW)
distance

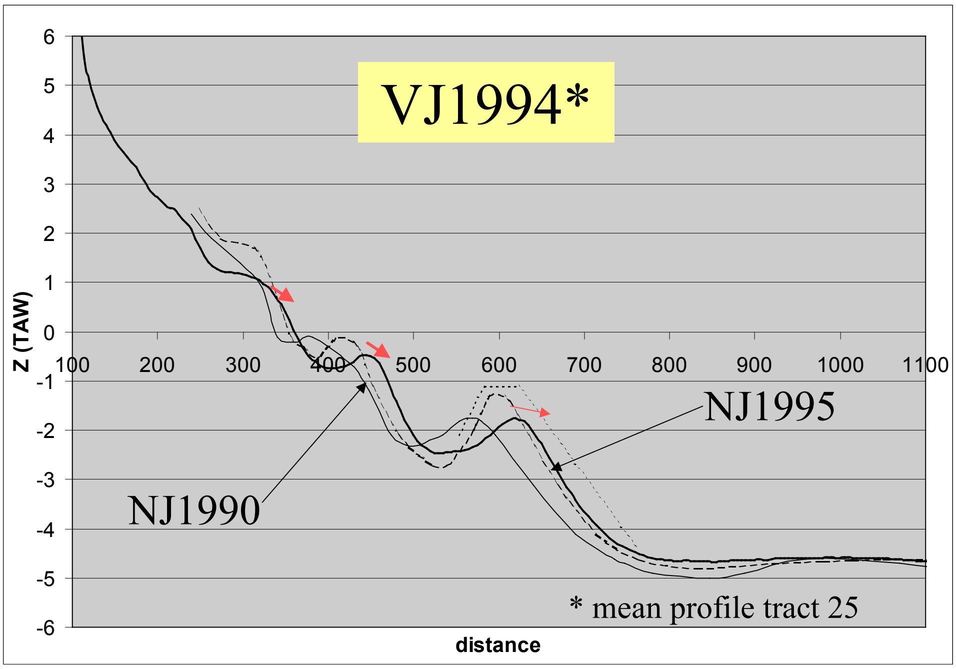

NJ1990
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
Z (TAW)
100
200
300
400
500
600
700
800
900
1000
1100
distance
NJ1995
NJ1990

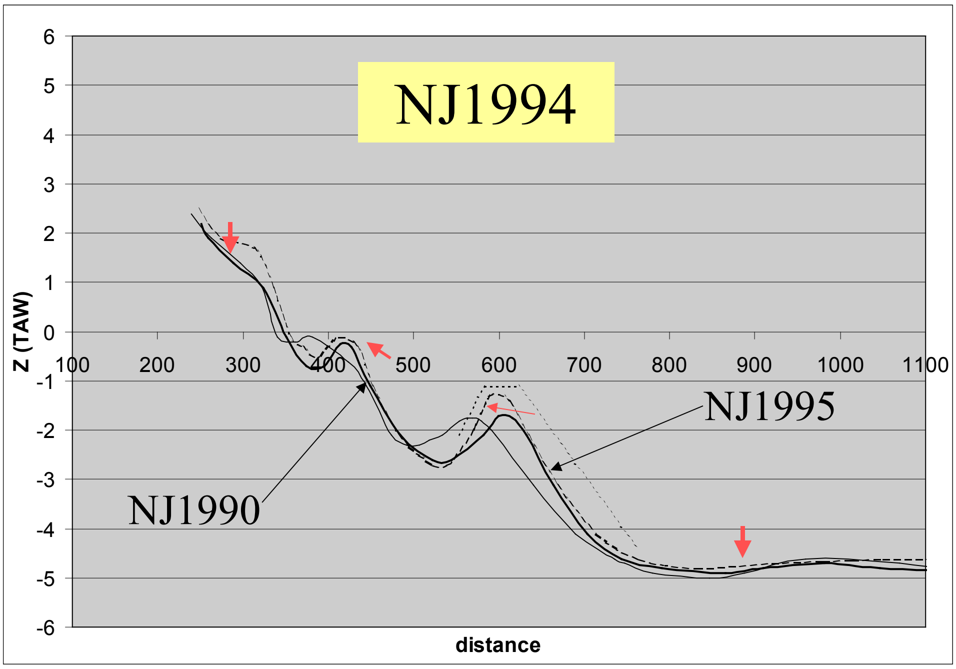

NJ1991
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
Z (TAW)
100
200
300
400
500
600
700
800
900
1000
1100
distance
banks shift seaward due to
storm beach erosion
NJ1995
influence of underwater
nourishment in De Haan?
NJ1990

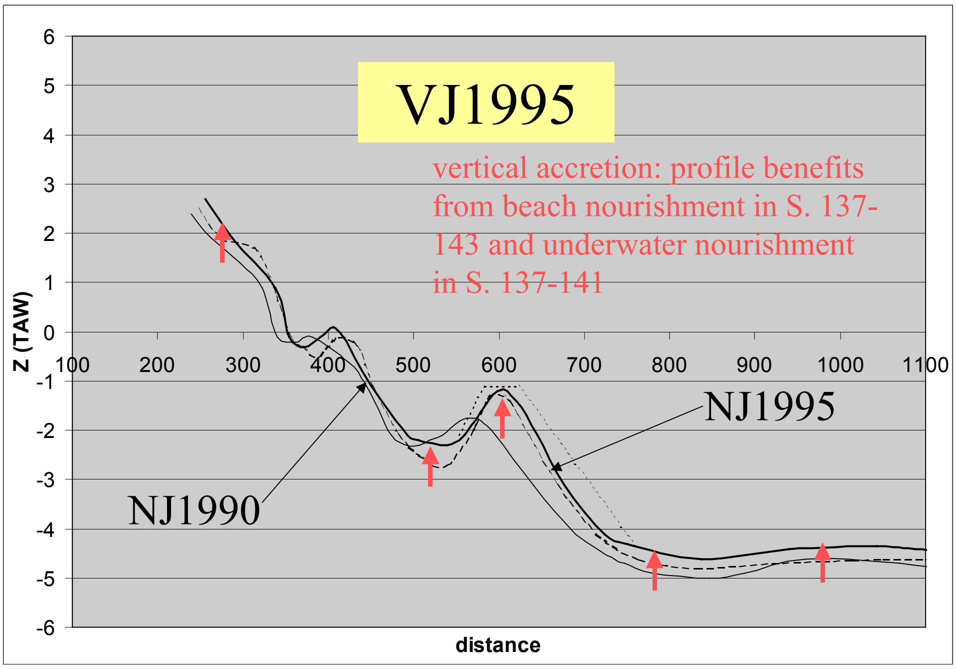

VJ1992*
Z (TAW)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100
NJ1995
NJ1990
* mean profile tract 25
distance

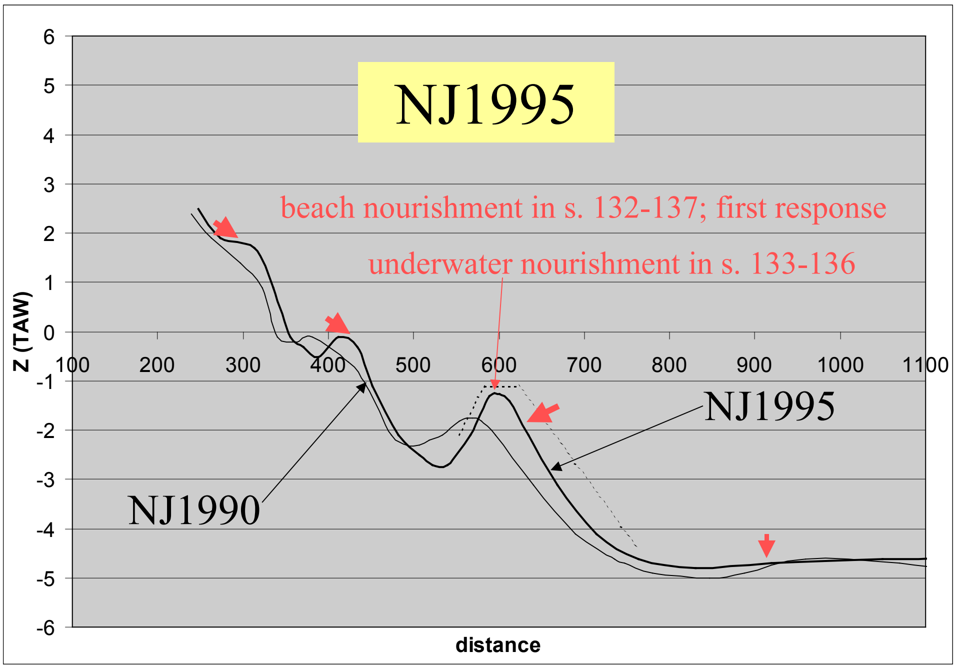

VJ1993
Z (TAW)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100
NJ1995
NJ1990
distance

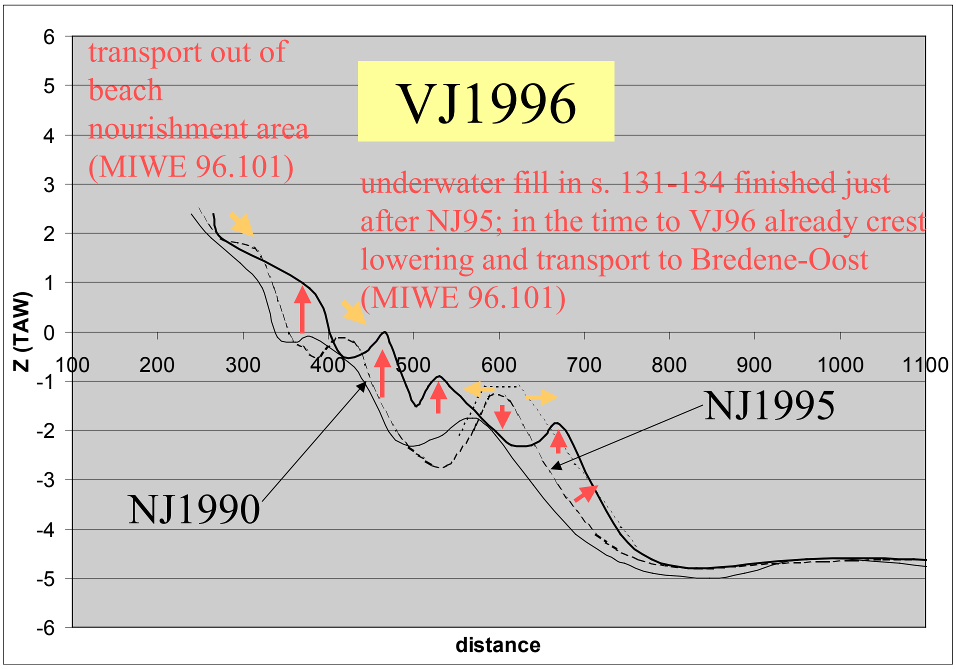

NJ1993*
NJ1995
NJ1990
* mean profile tract 25
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

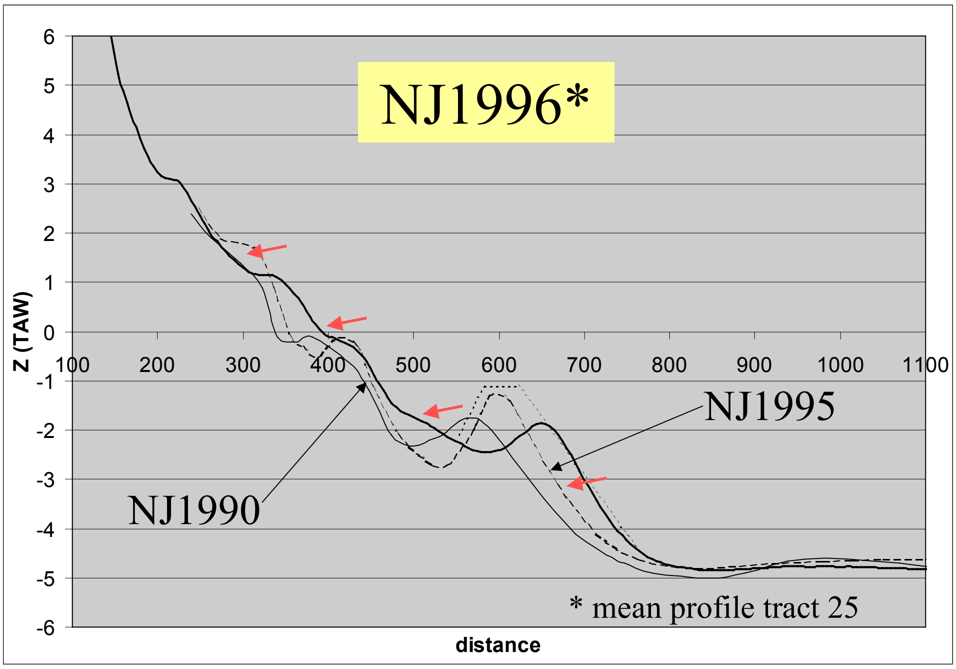

VJ1994*
NJ1995
NJ1990
* mean profile tract 25
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

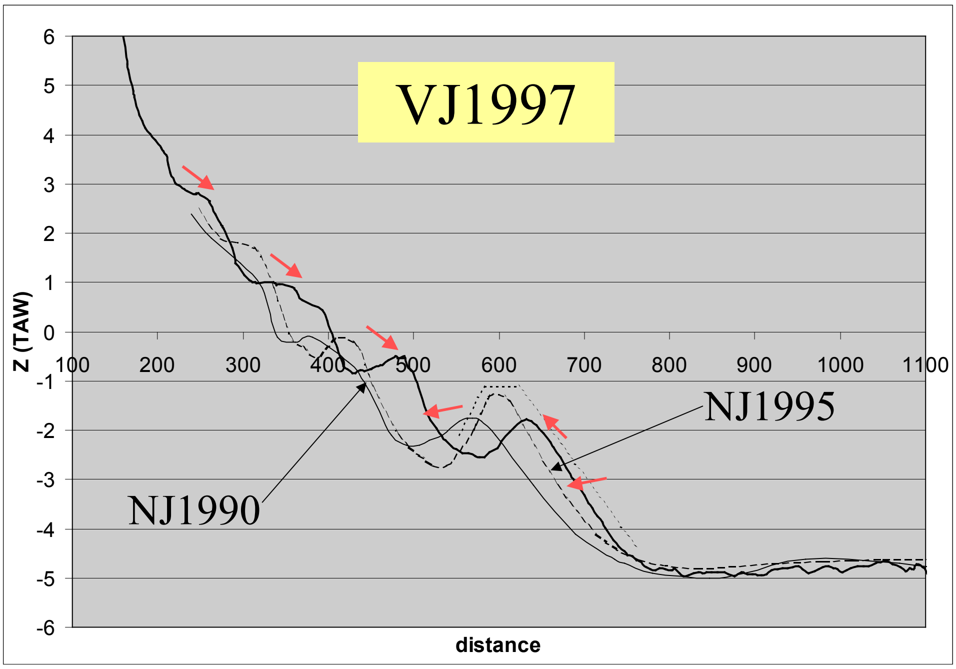

NJ1994
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
Z (TAW)
100
200
300
400
500
600
700
800
900
1000
1100
distance
NJ1995
NJ1990

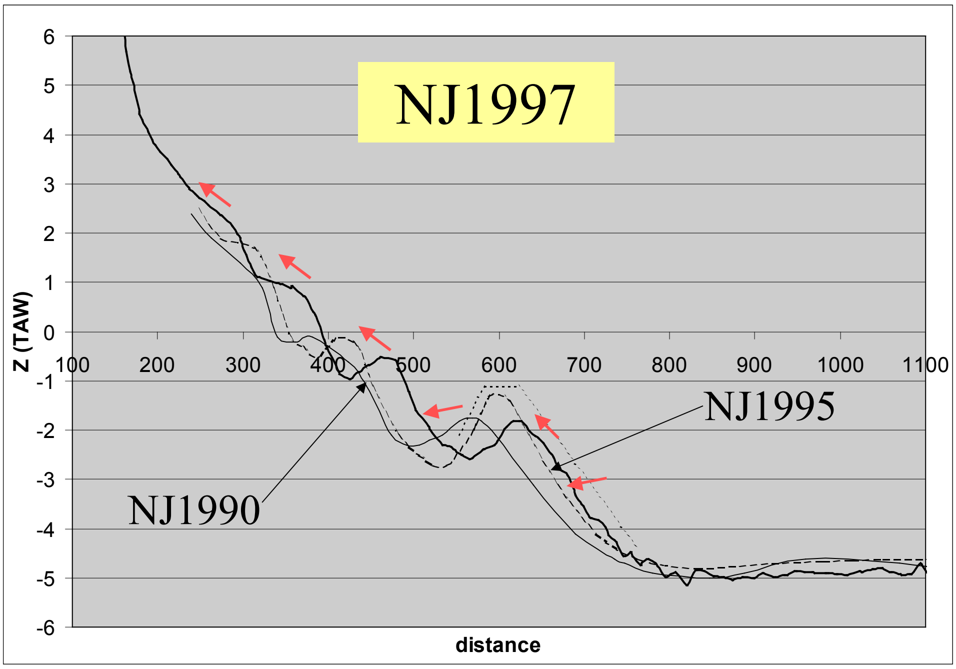

VJ1995
vertical accretion: profile benefits from beach nourishment in S. 137-143 and underwater nourishment in S. 137-141
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
Z (TAW)
100
200
300
400
500
600
700
800
900
1000
1100
distance
NJ1995
NJ1990

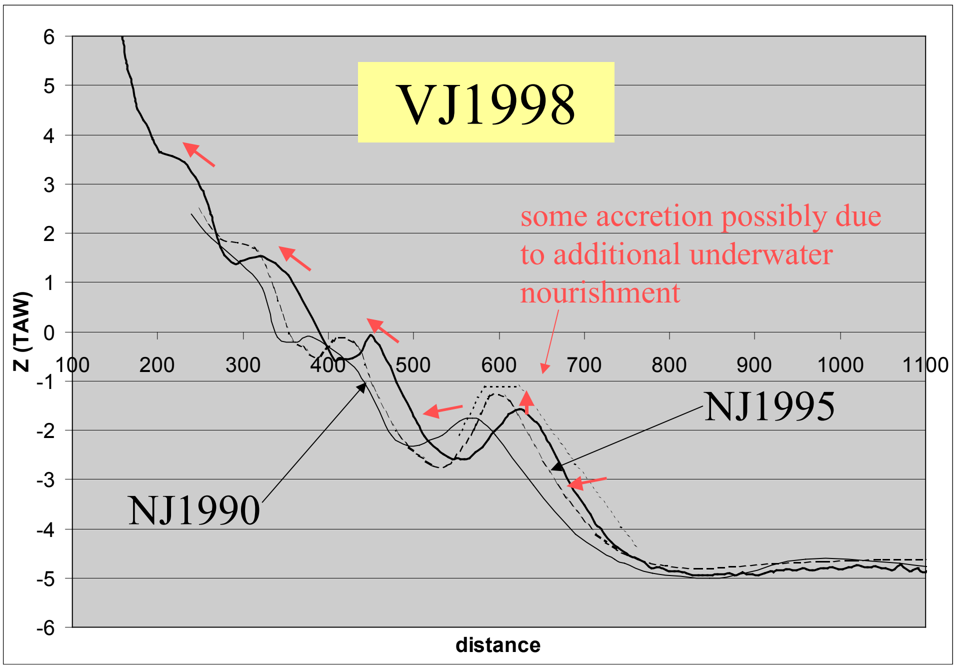

NJ1995
beach nourishment in s. 132-137; first response
underwater nourishment in s. 133-136
NJ1995
NJ1990
Z (TAW)
distance

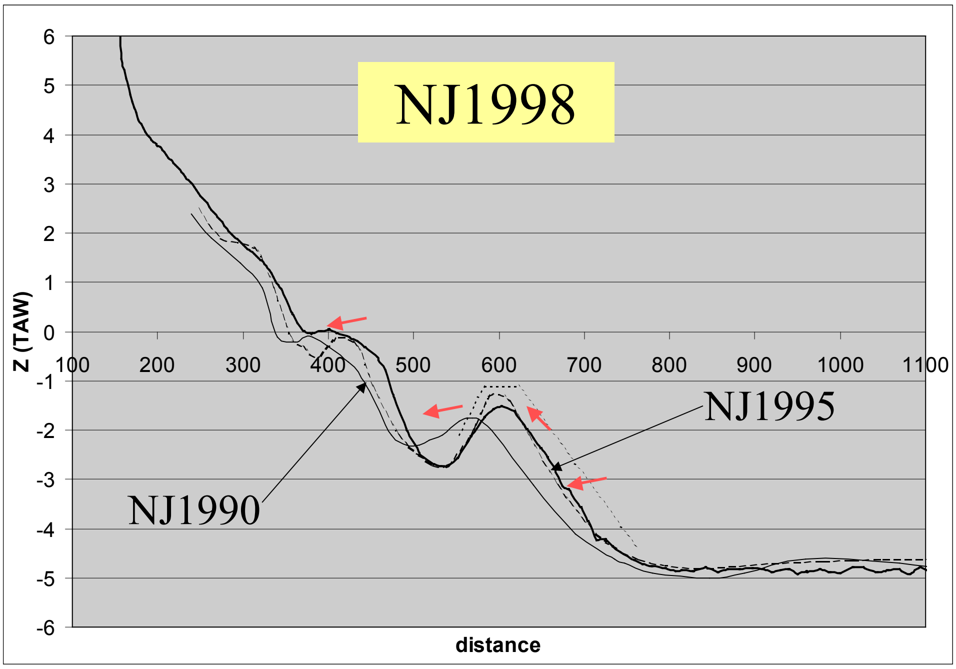

transport out of beach nourishment area (MIWE 96.101)
VJ1996
underwater fill in s. 131-134 finished just after NJ95; in the time to VJ96 already crest lowering and transport to Bredene-Oost (MIWE 96.101)
NJ1995
NJ1990
Z (TAW)
distance

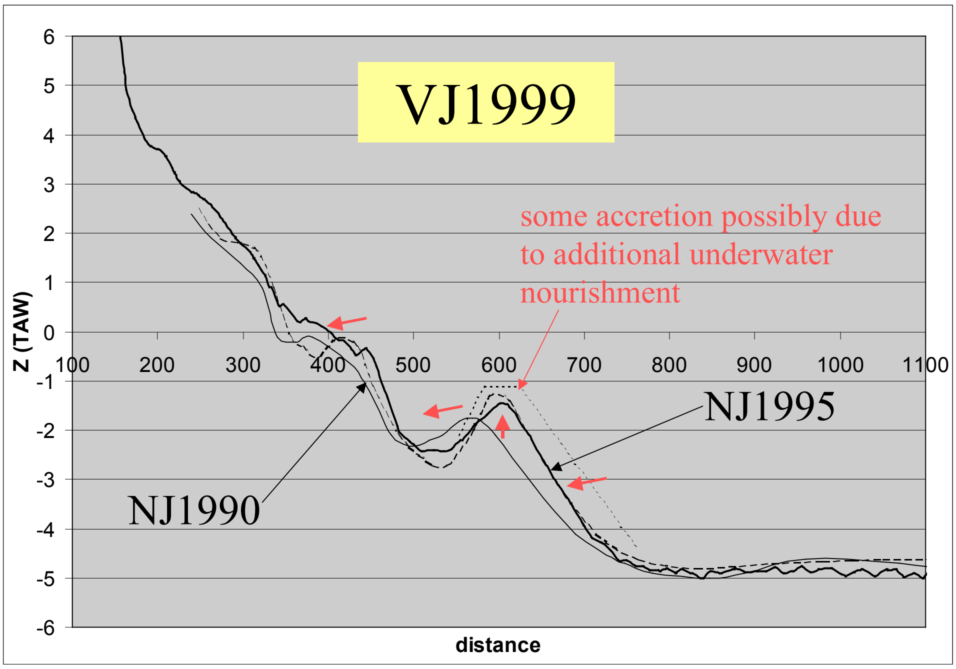

NJ1996*
NJ1995
NJ1990
* mean profile tract 25
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

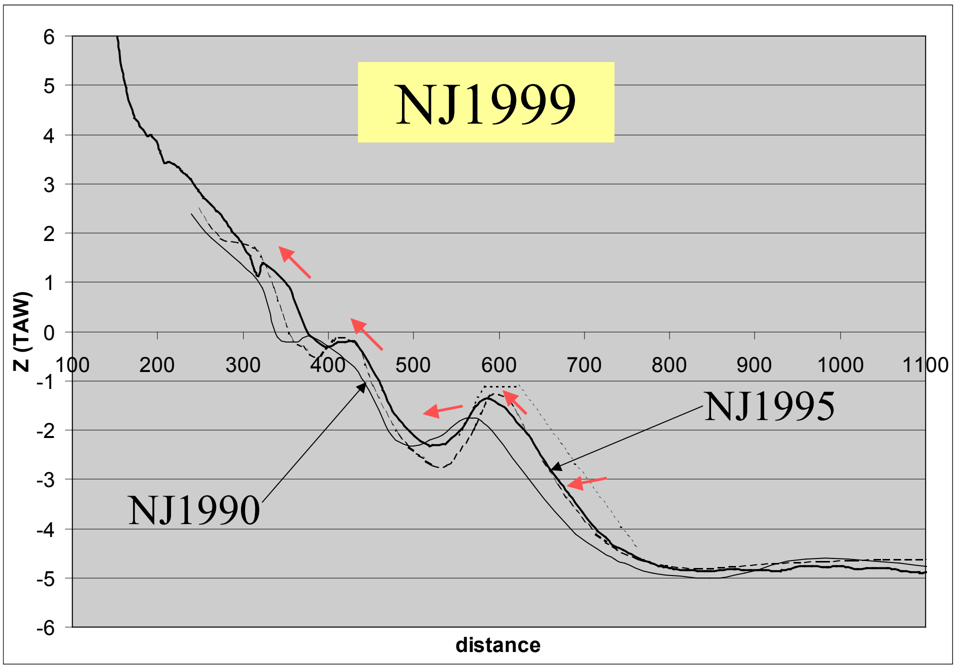

VJ1997
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100


NJ1997
NJ1995
NJ1990
Z (TAW)
distance

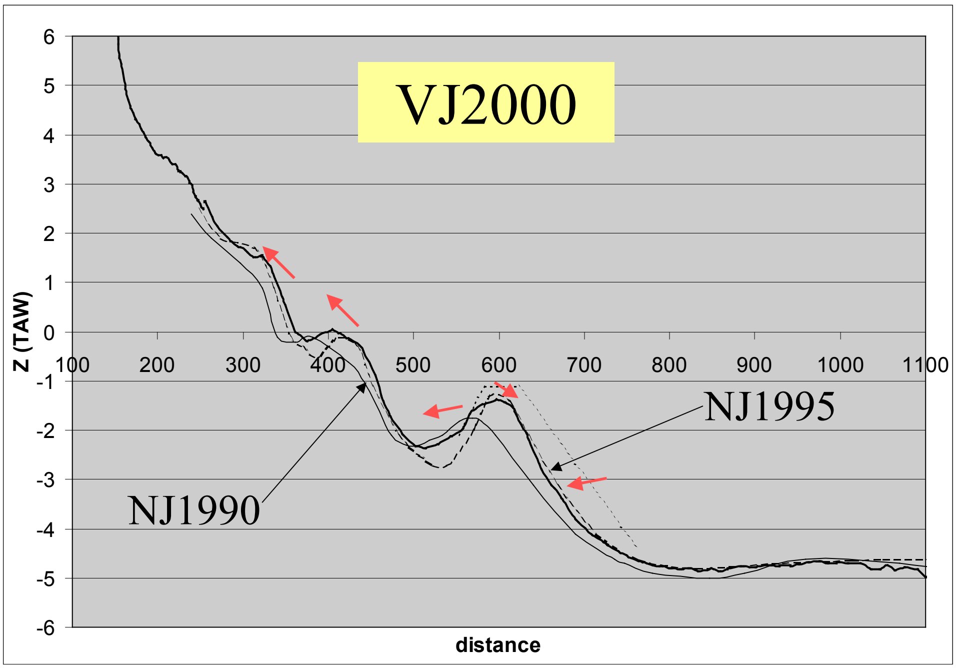

VJ1998
some accretion possibly due to additional underwater nourishment
NJ1995
NJ1990
Z (TAW)
distance


NJ1998
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

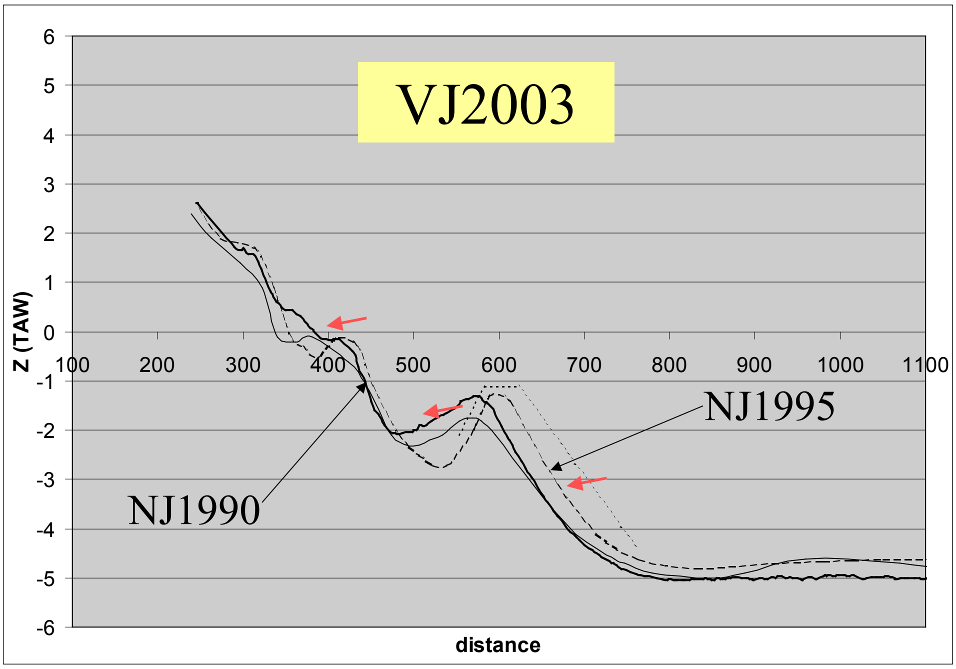

VJ1999
some accretion possibly due
to additional underwater
nourishment
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

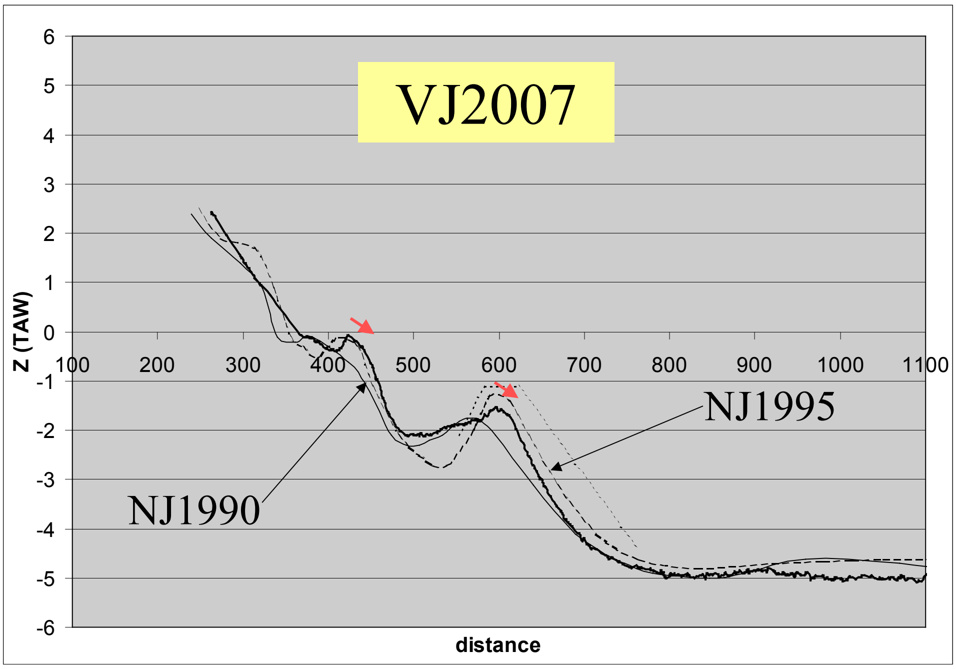


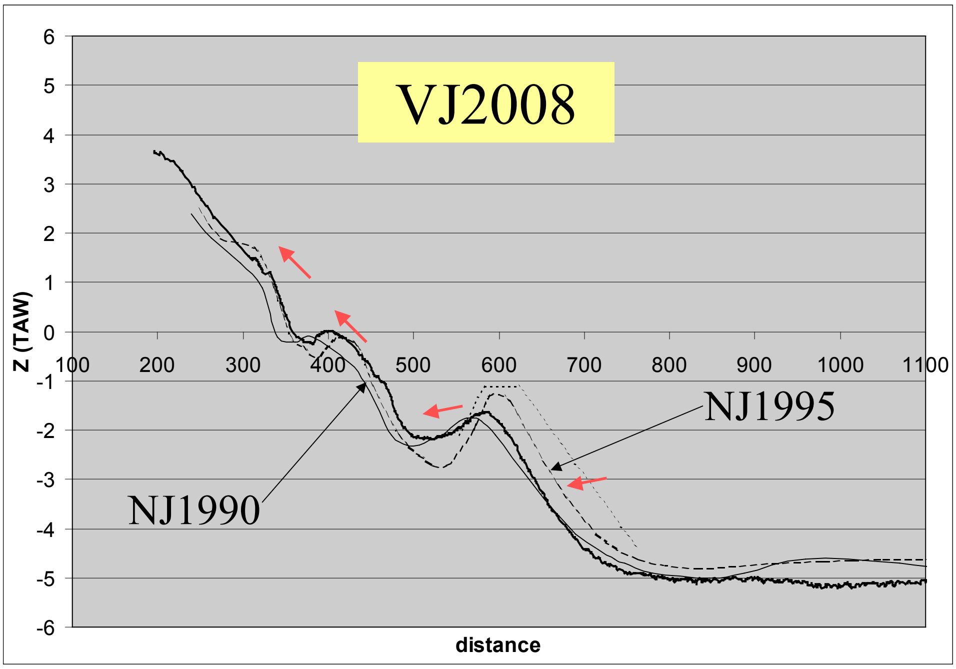
NJ1999
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

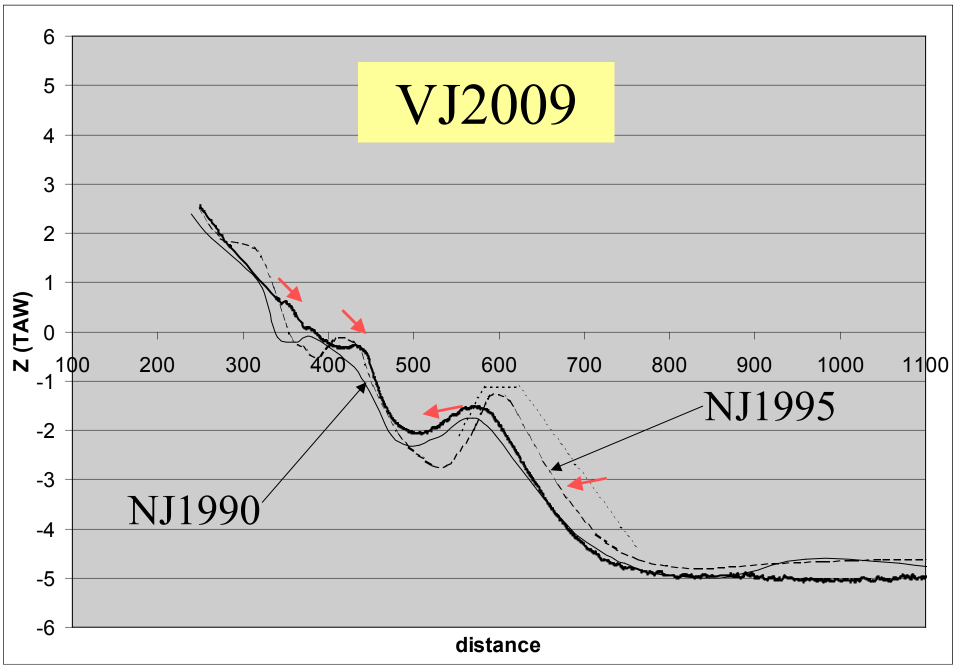


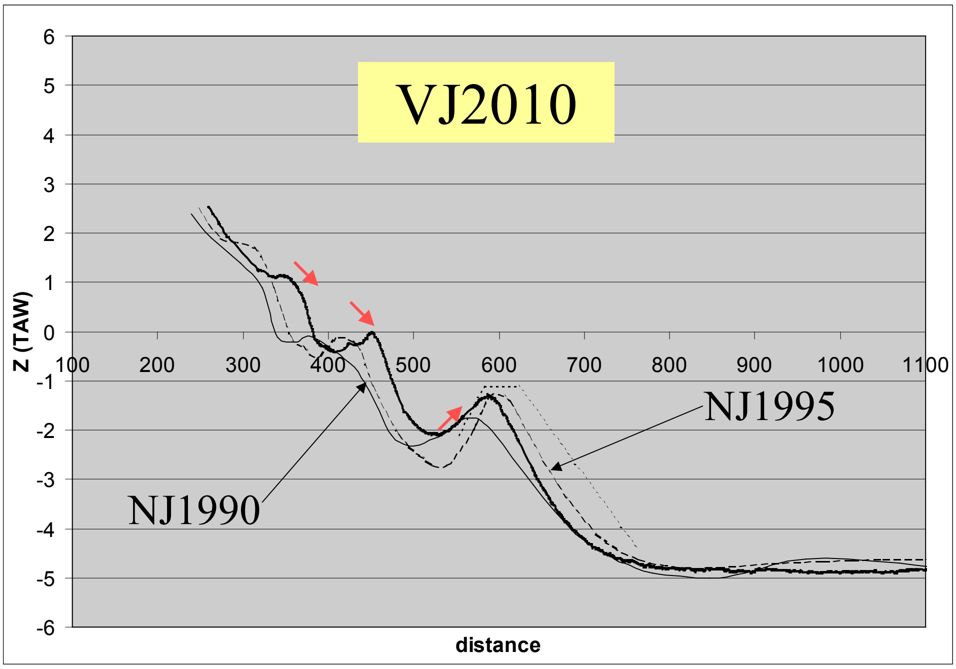
VJ2000
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

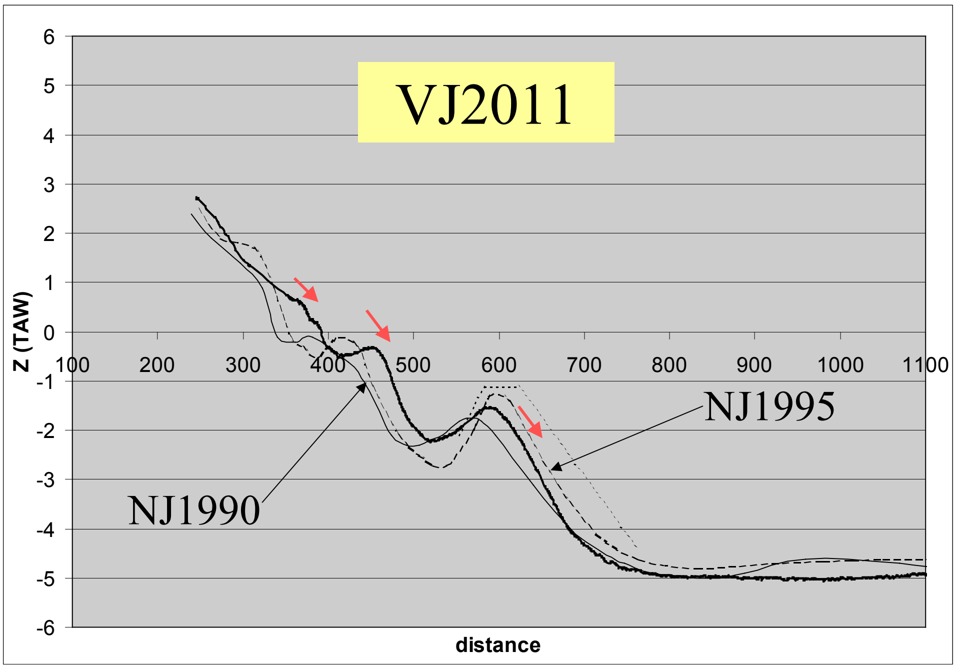

VJ2003
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100


VJ2007
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100


VJ2008
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

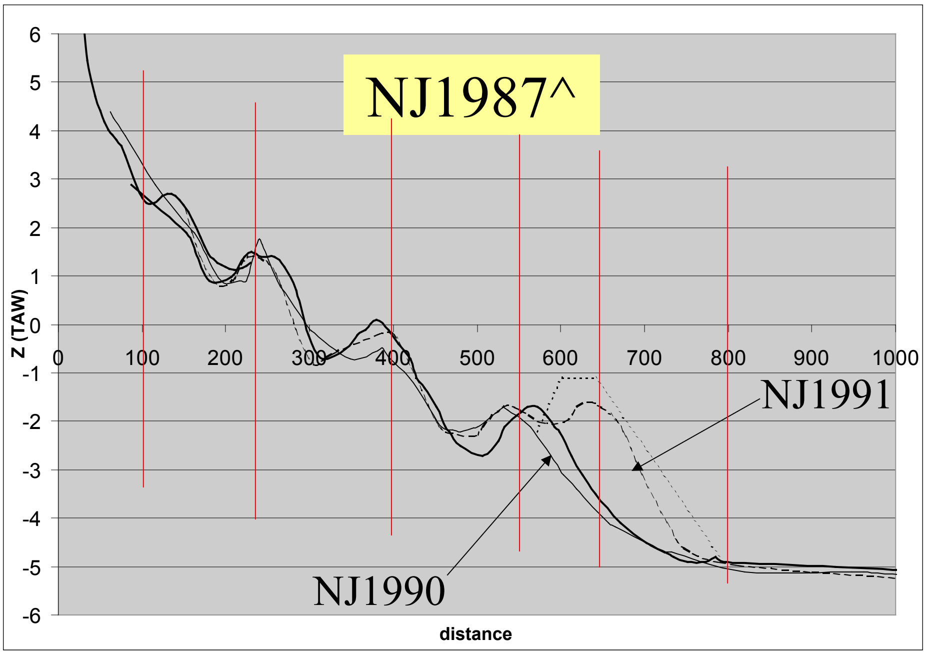

VJ2009
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

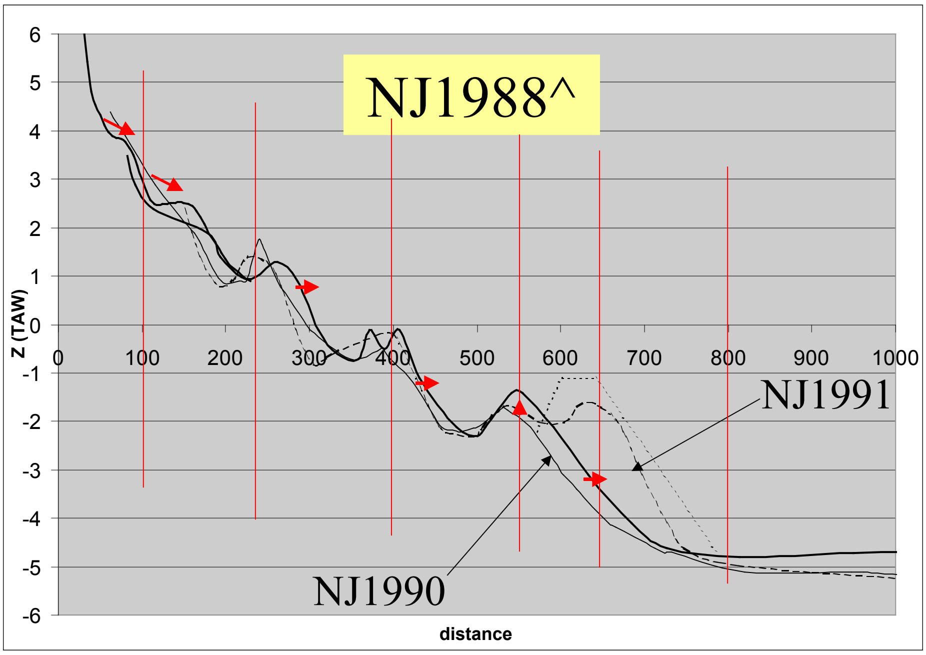

VJ2010
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

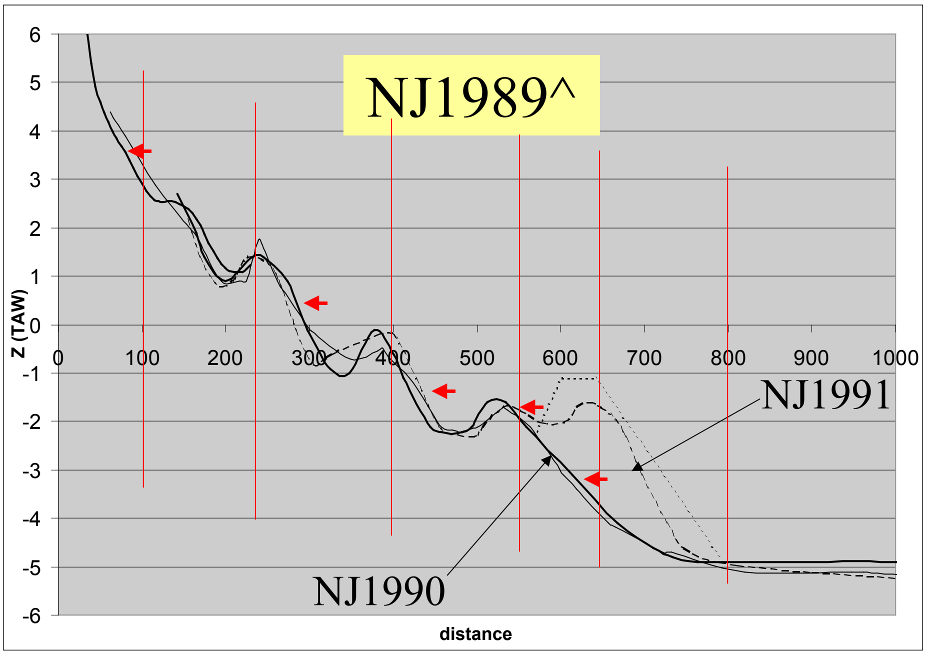

VJ2011
NJ1995
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600
700
800
900
1000
1100

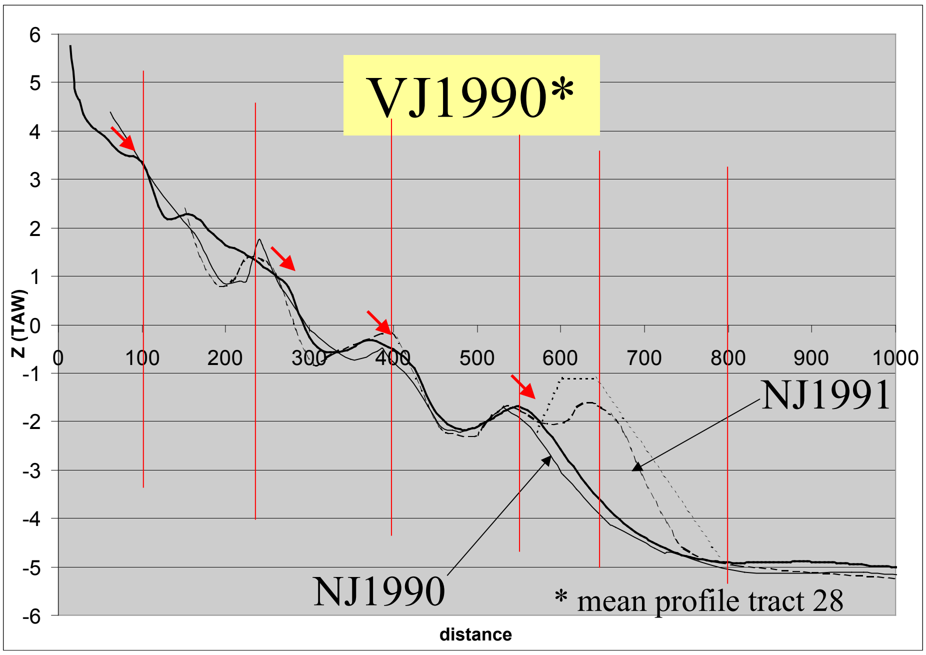
Annex 3. Profile series for section 153

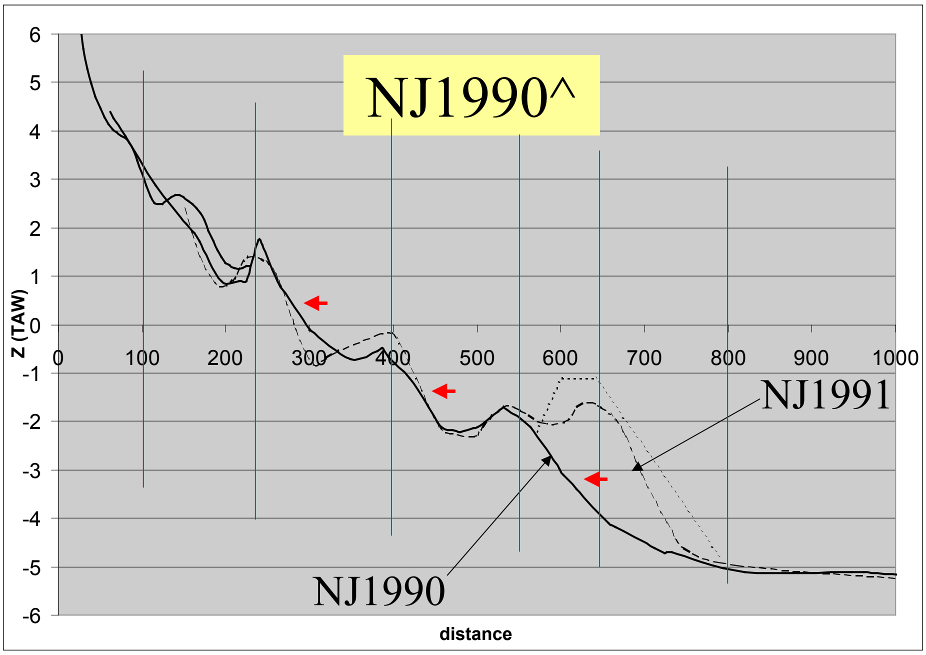
Each figure shows the NJ1990 and NJ1991, as well as the design profile of the feeder berm, in fine lines, for reference. Comments are in red.

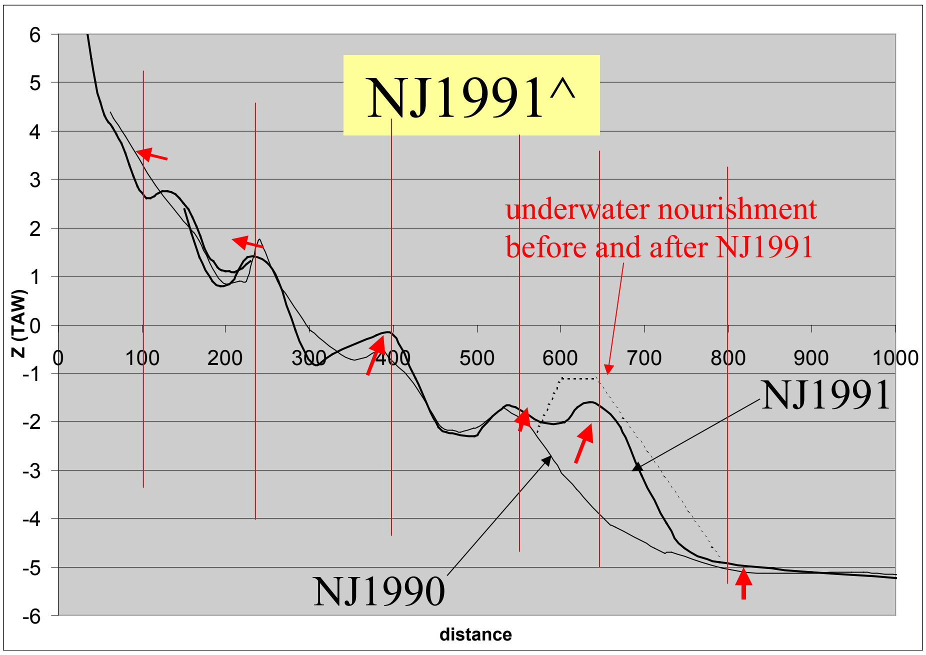


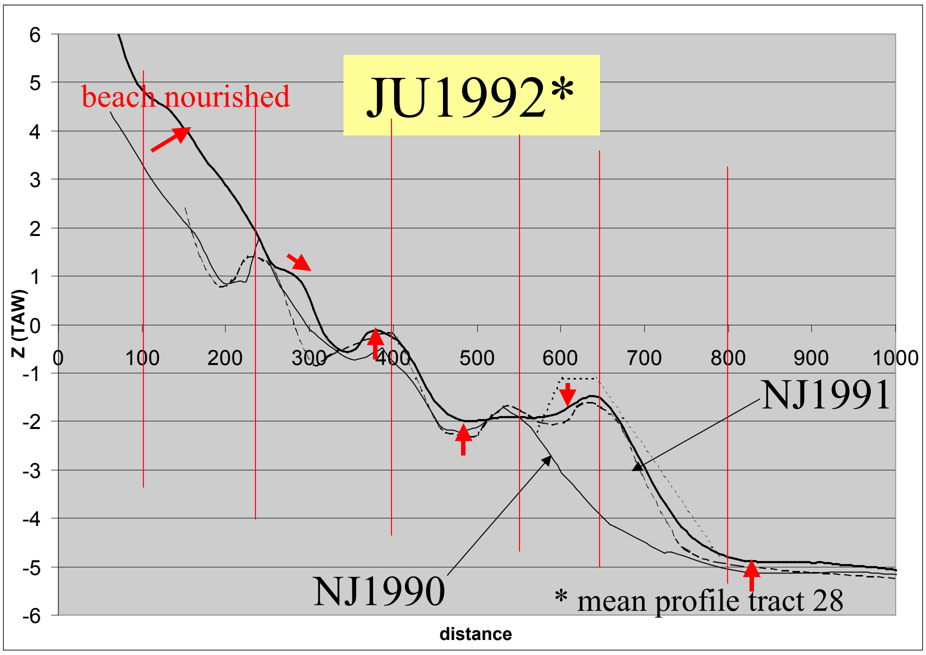


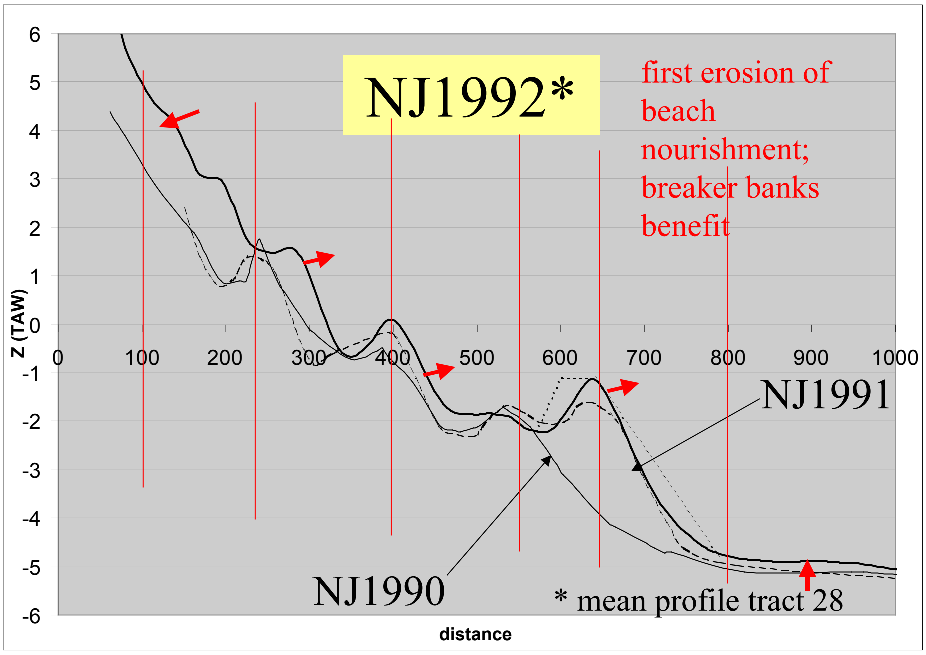

NJ1989^
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

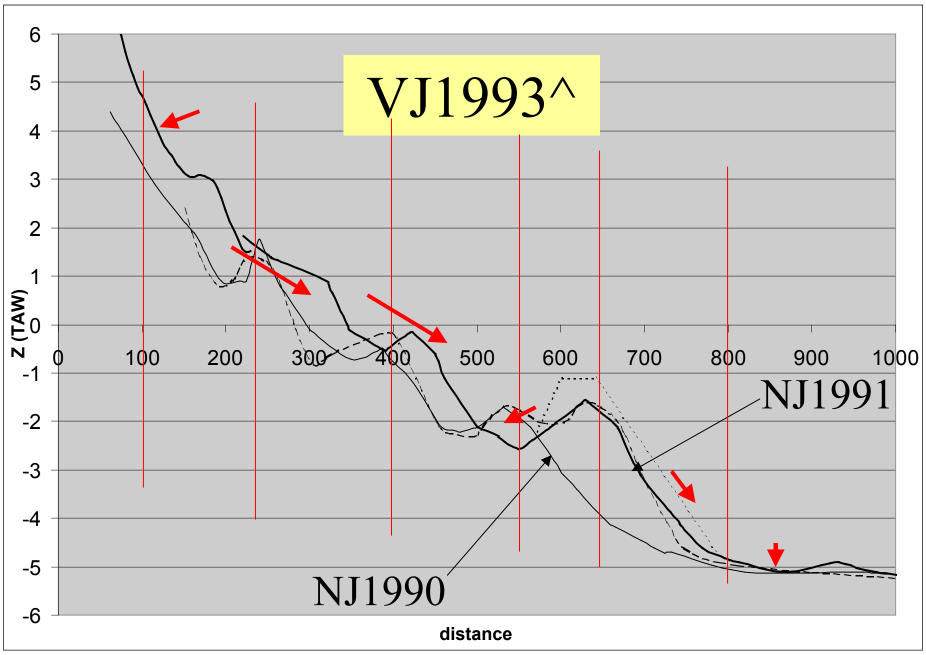

VJ1990*
NJ1991
NJ1990
* mean profile tract 28
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

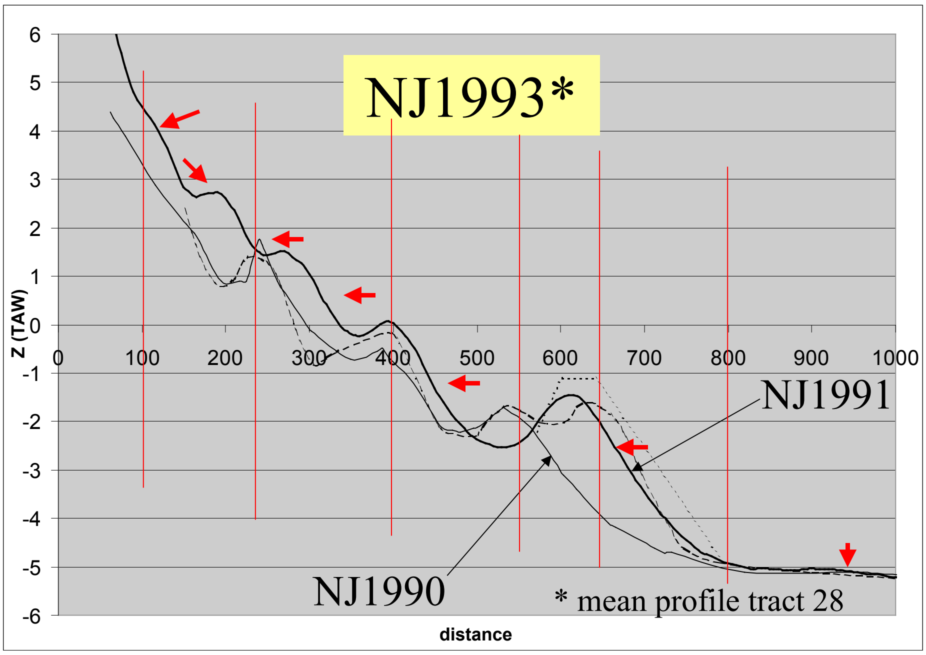

NJ1990^
NJ1991
NJ1990
Z (TAW)
distance

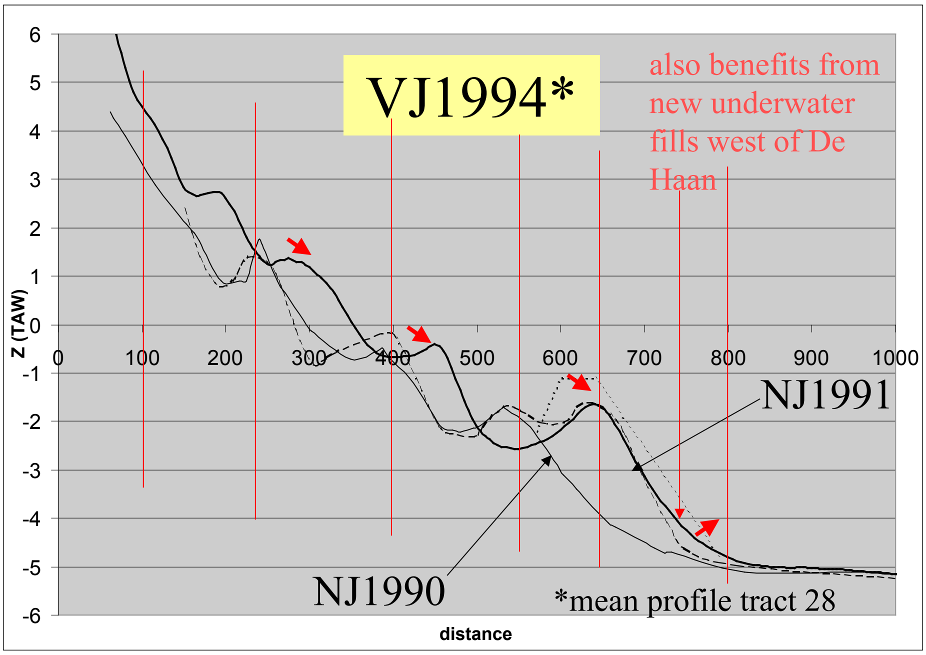

NJ1991^
underwater nourishment
before and after NJ1991
NJ1991
NJ1990
Z (TAW)
distance

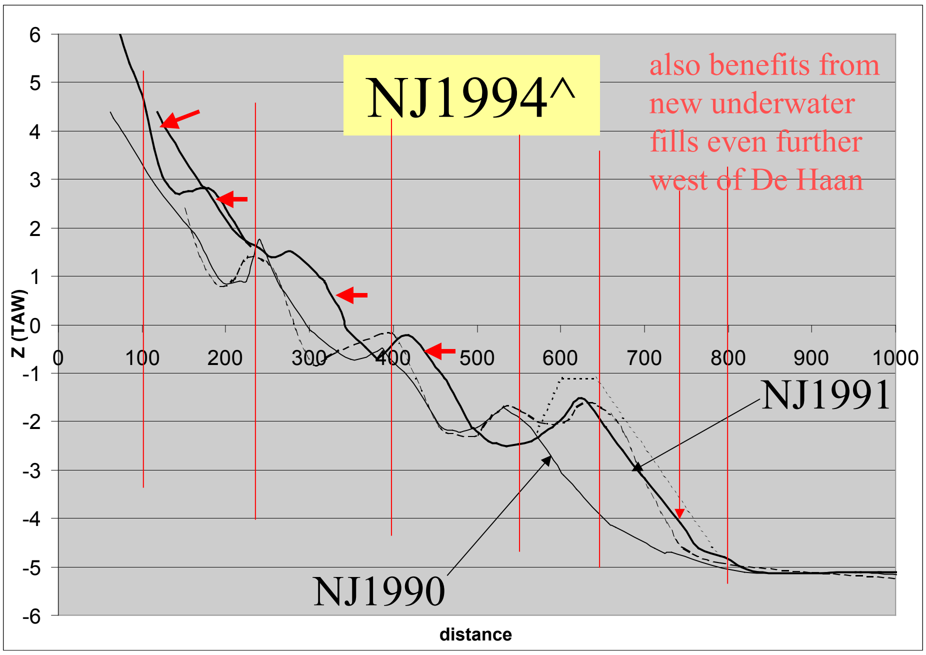

JU1992*
beach nourished
NJ1991
NJ1990
* mean profile tract 28
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

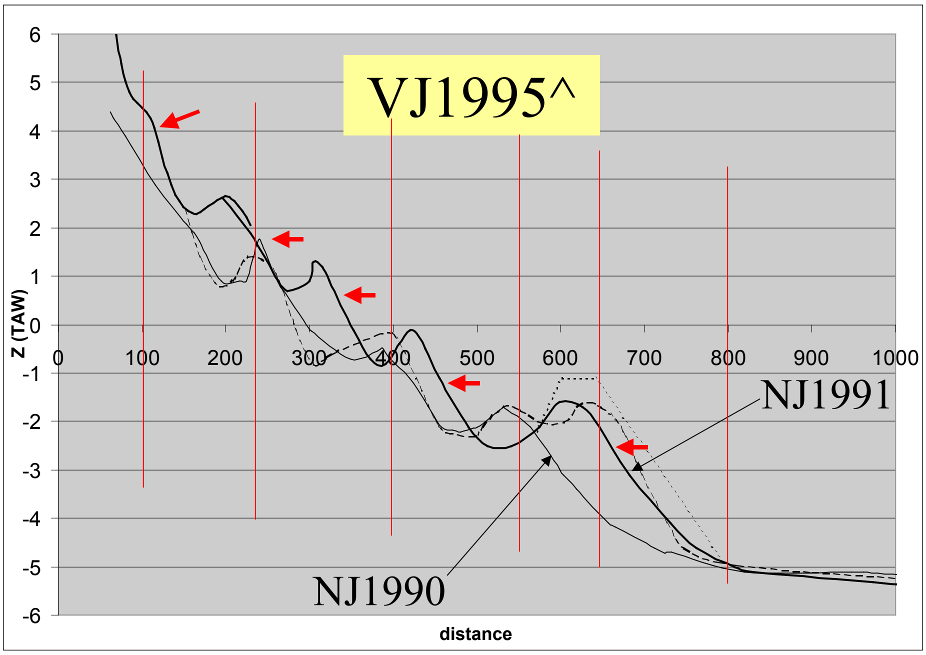

NJ1992*
first erosion of beach nourishment; breaker banks benefit
NJ1991
NJ1990
* mean profile tract 28
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

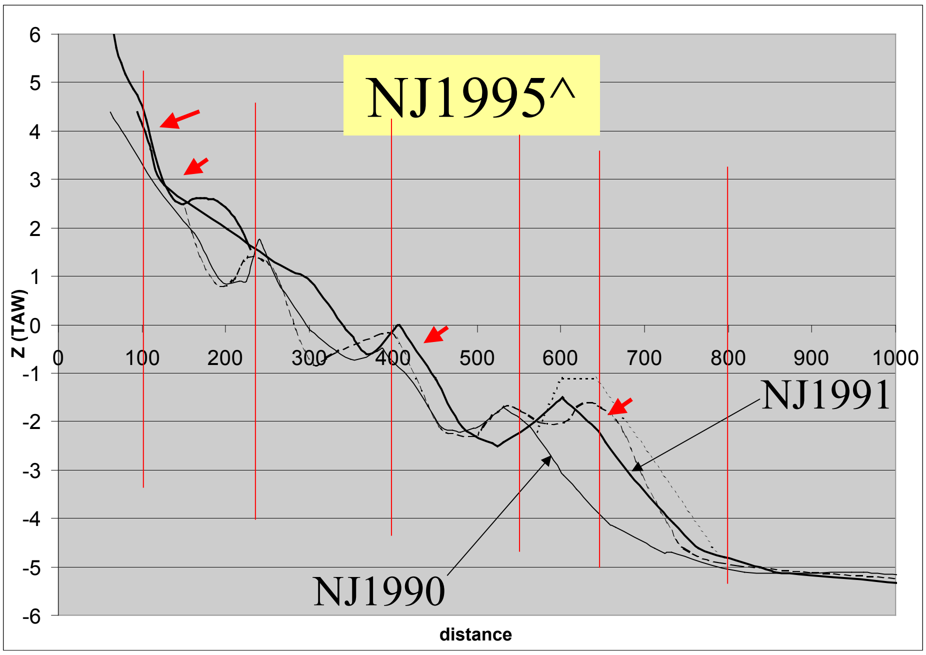

VJ1993^
Z (TAW)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000
NJ1991
NJ1990
distance

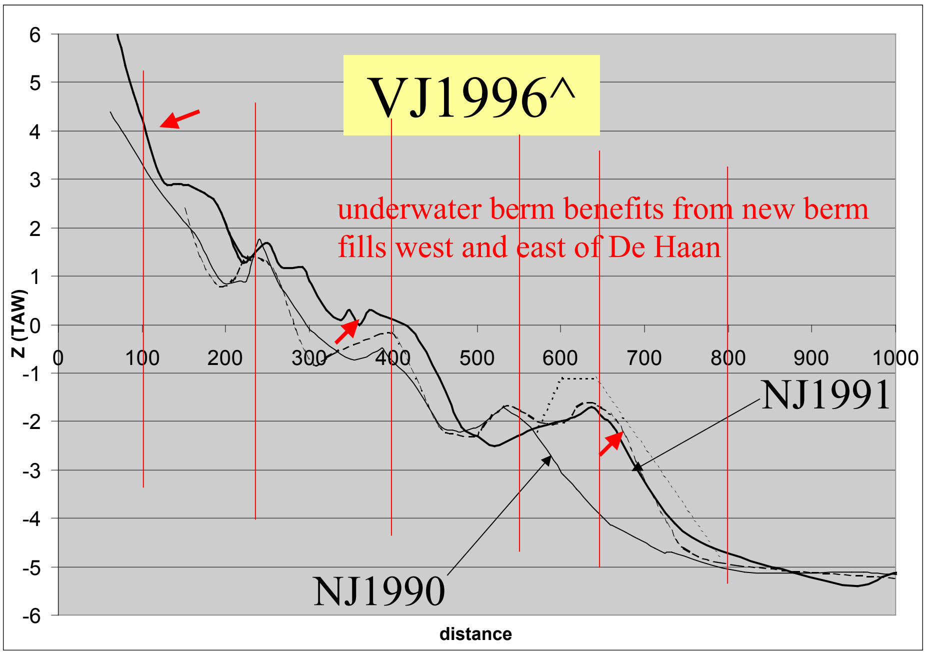

NJ1993*
Z (TAW)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000
NJ1991
NJ1990
* mean profile tract 28
distance

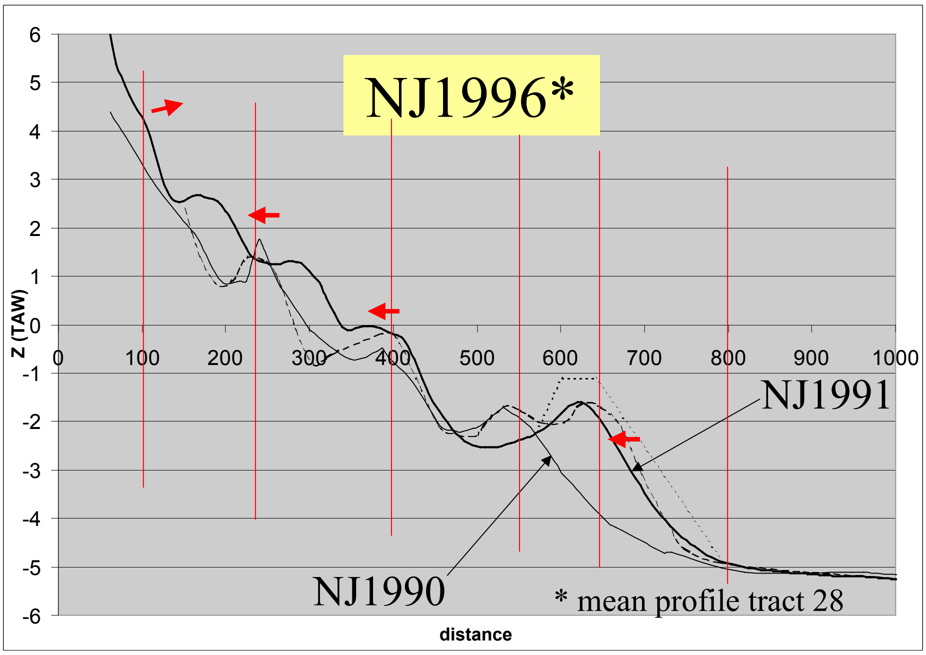

VJ1994*
also benefits from new underwater fills west of De Haan
NJ1991
NJ1990
*mean profile tract 28
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

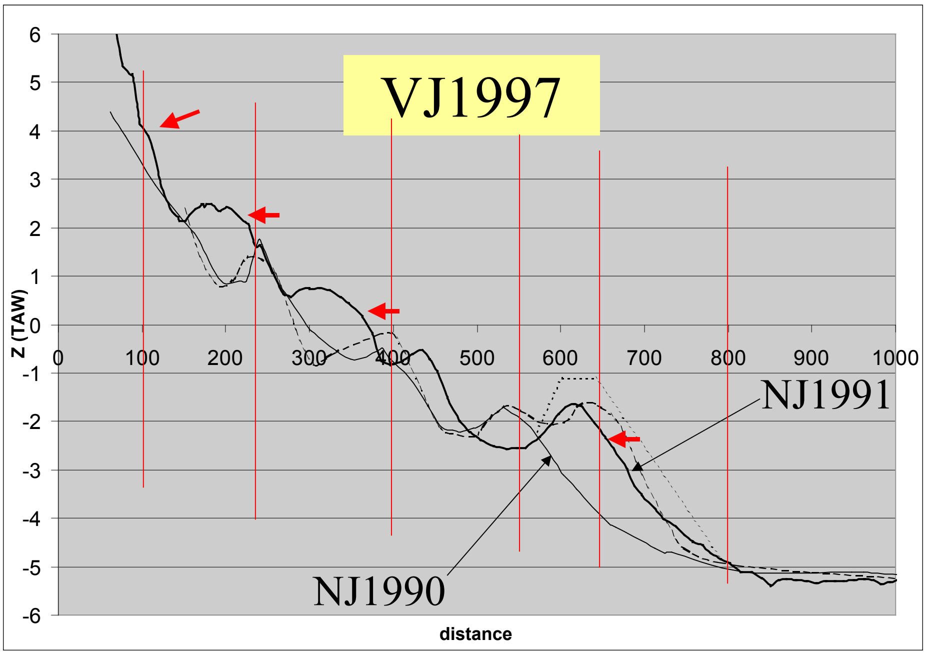

NJ1994^
also benefits from new underwater fills even further west of De Haan
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

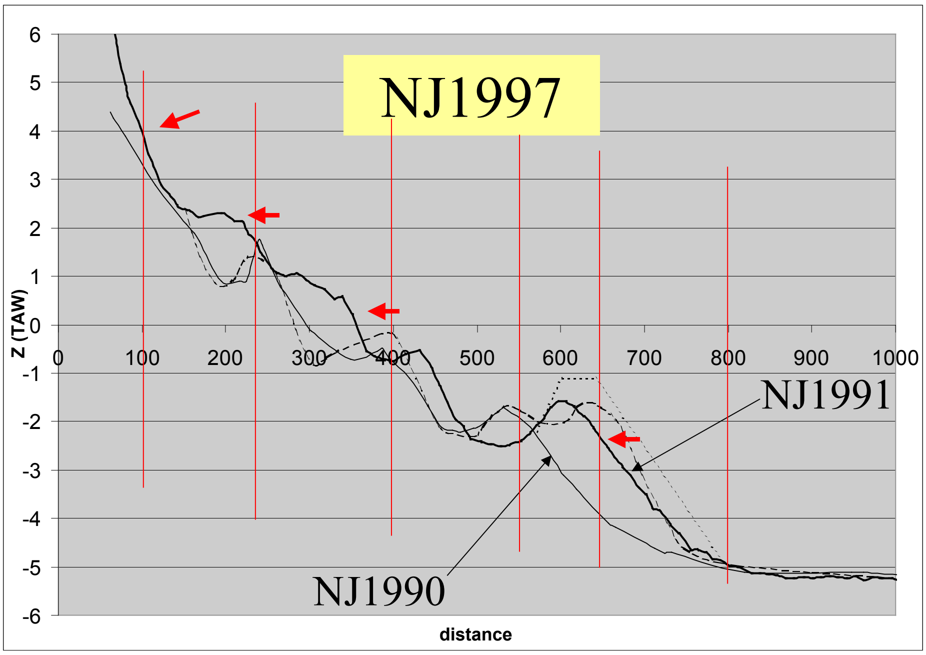

VJ1995^
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

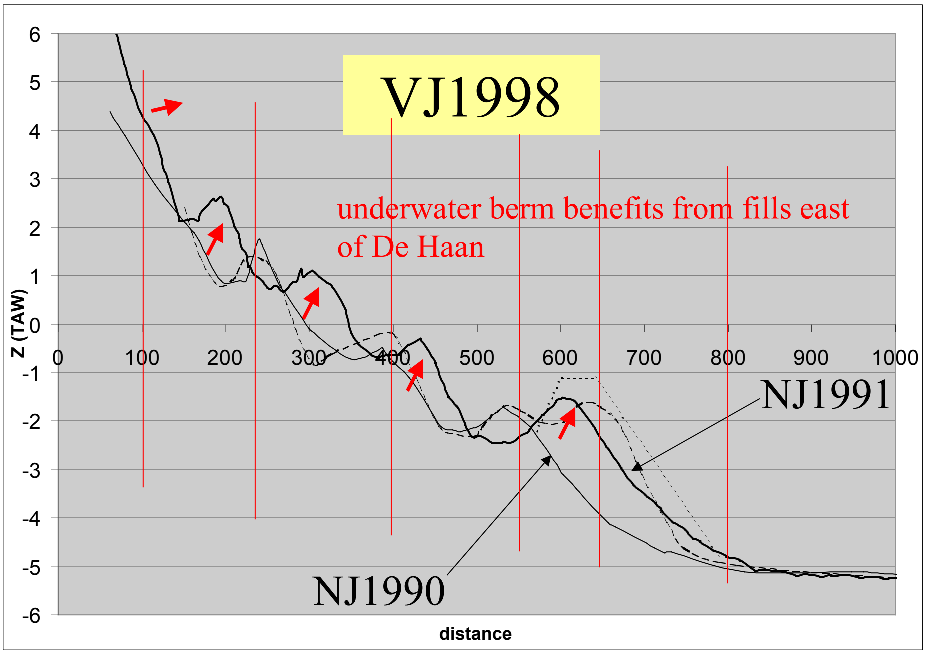

NJ1995^
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

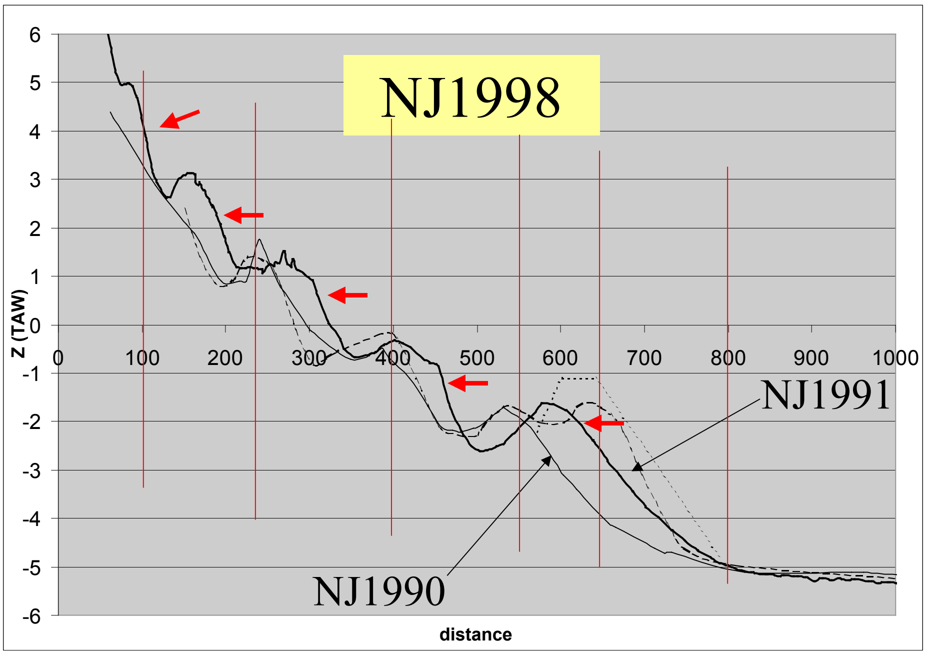

VJ1996^
underwater berm benefits from new berm fills west and east of De Haan
NJ1991
NJ1990
Z (TAW)
distance

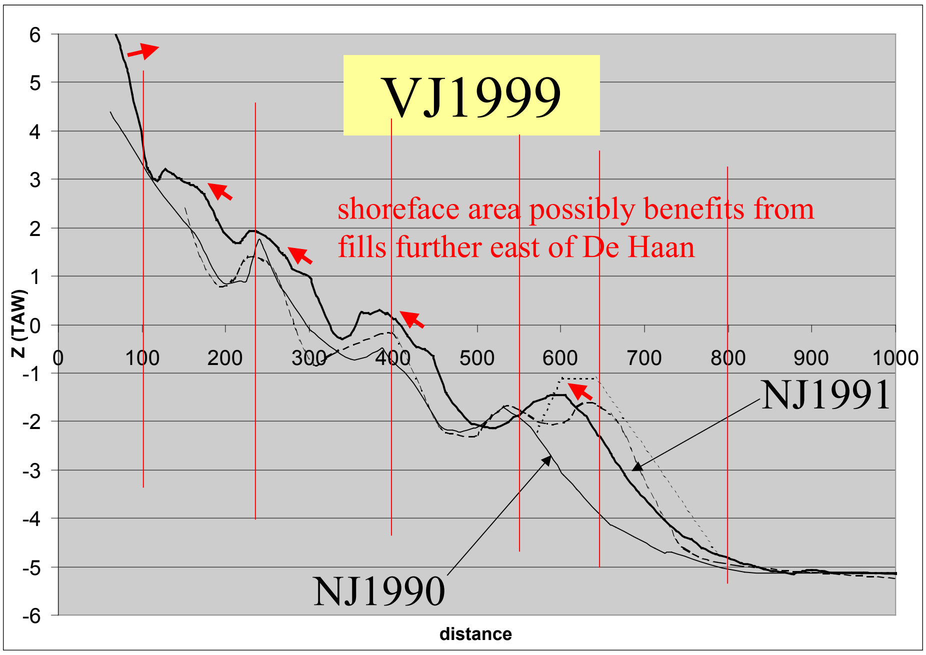

NJ1996*
NJ1991
NJ1990
* mean profile tract 28
Z (TAW)
distance

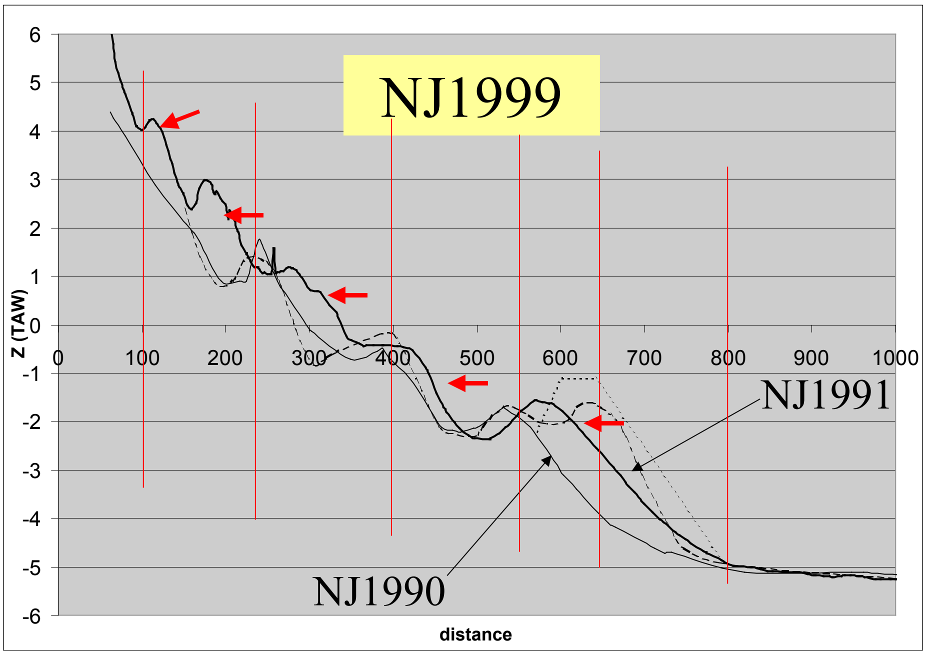

VJ1997
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

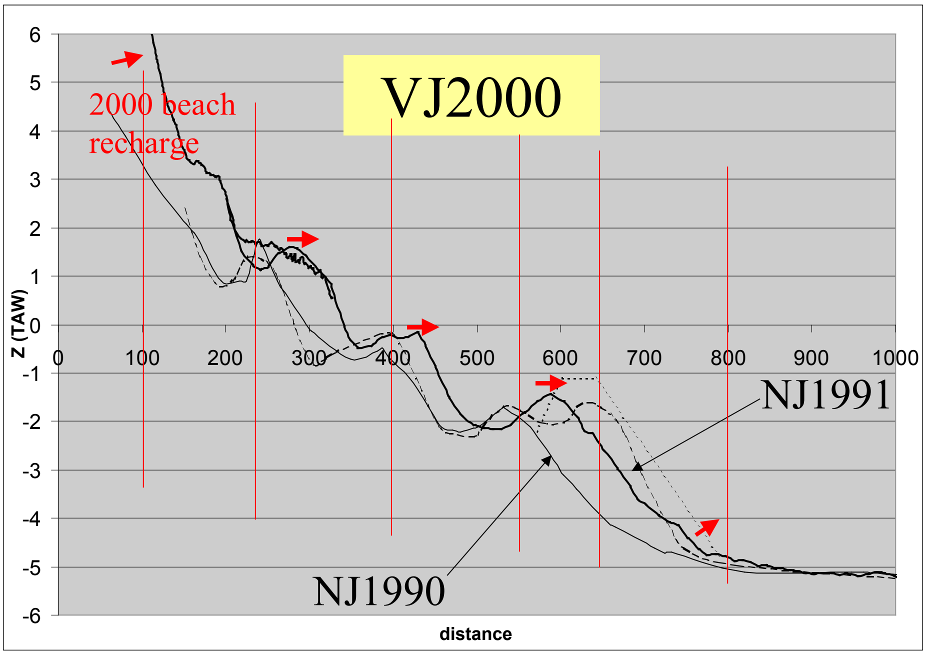

NJ1997
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

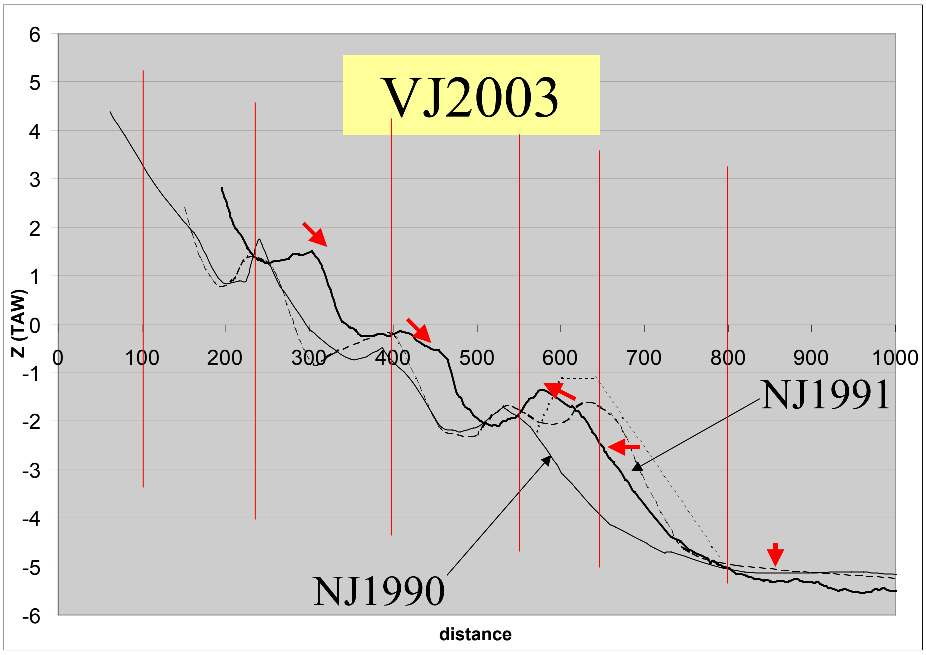

VJ1998
underwater berm benefits from fills east of De Haan
NJ1991
NJ1990
Z (TAW)
distance

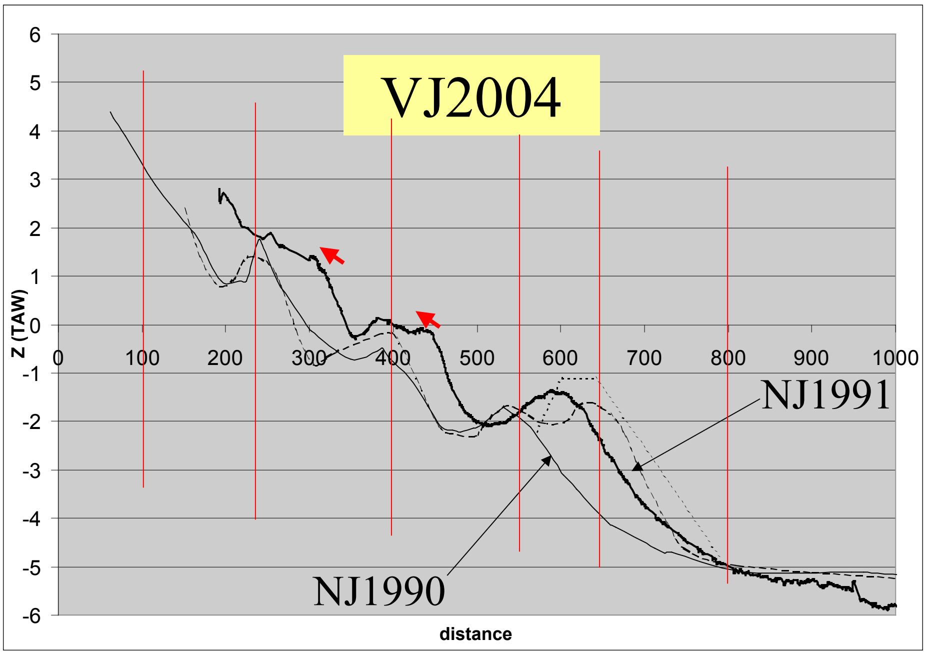

NJ1998
NJ1991
NJ1990
Z (TAW)
distance

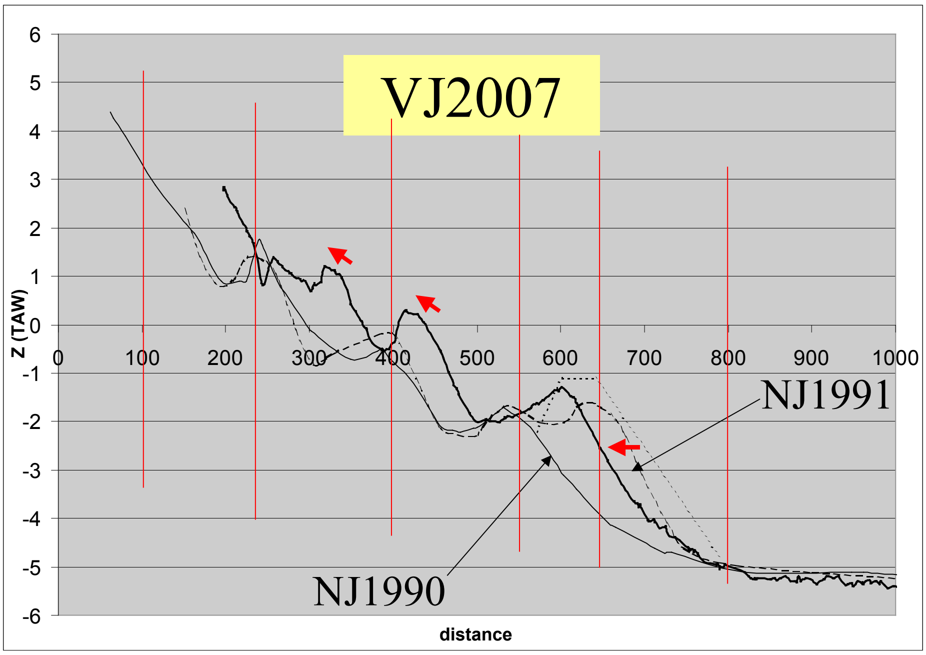

VJ1999
shoreface area possibly benefits from
fills further east of De Haan
NJ1991
NJ1990
Z (TAW)
distance

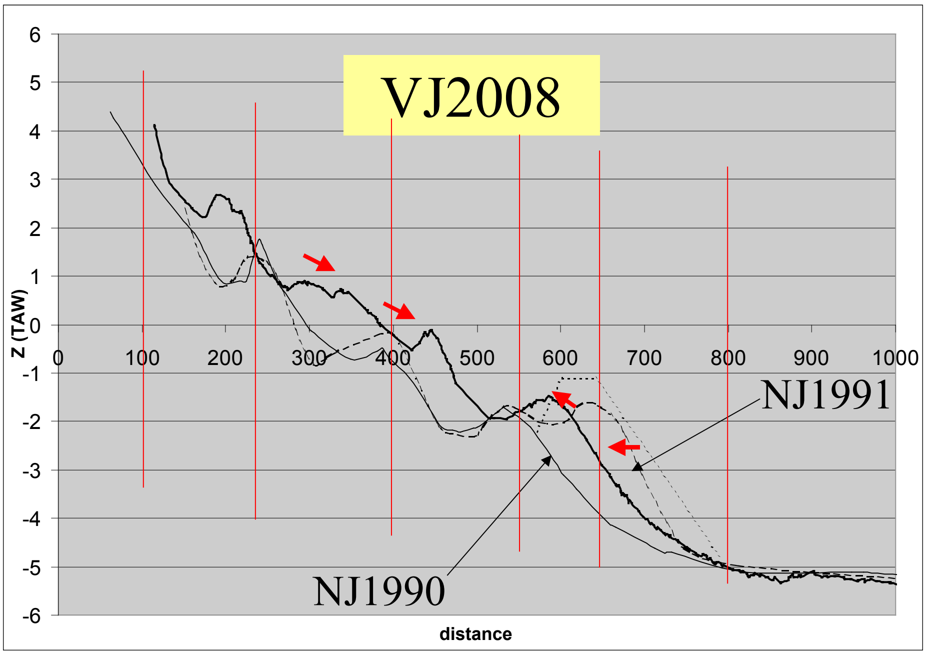

NJ1999
NJ1991
NJ1990
Z (TAW)
distance

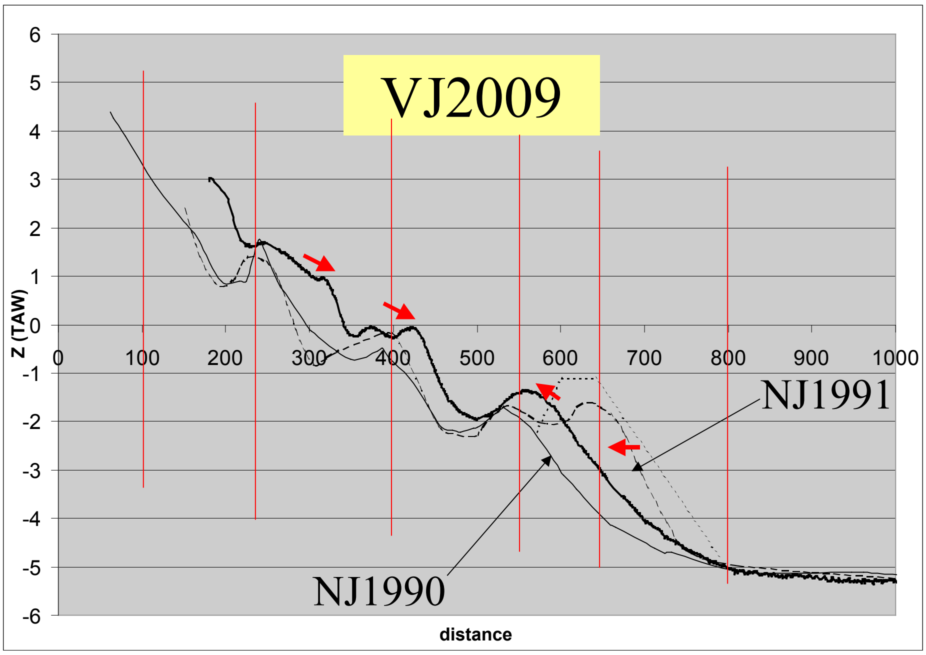

VJ2000
2000 beach recharge
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

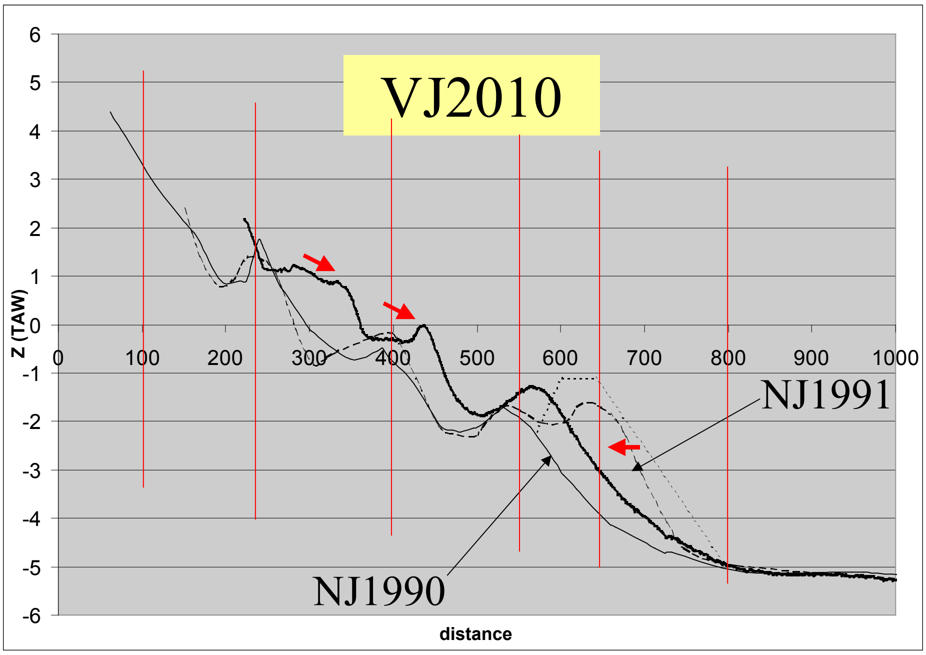

VJ2003
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

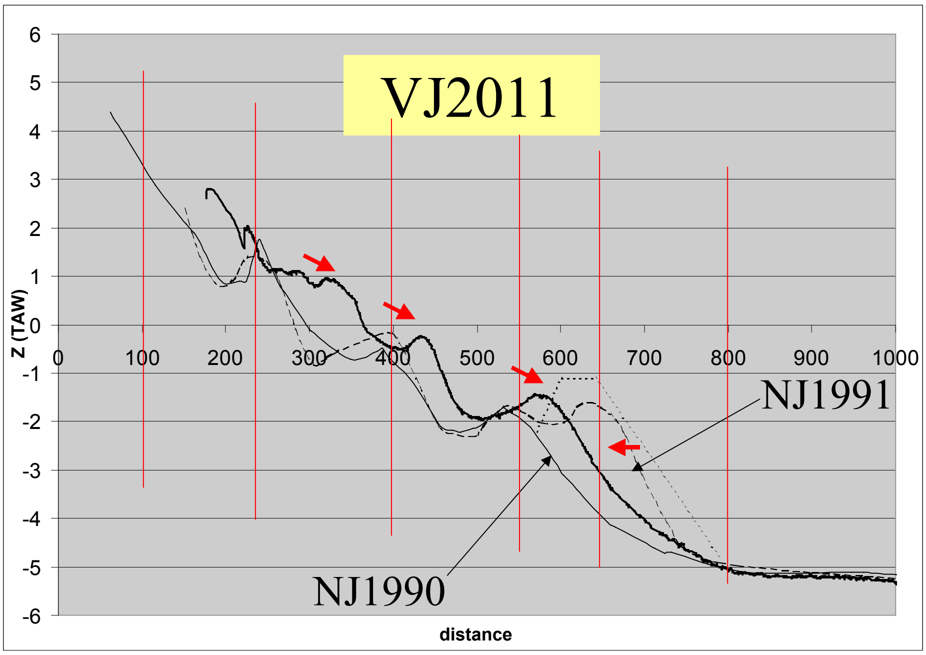

VJ2004
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000


VJ2007
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

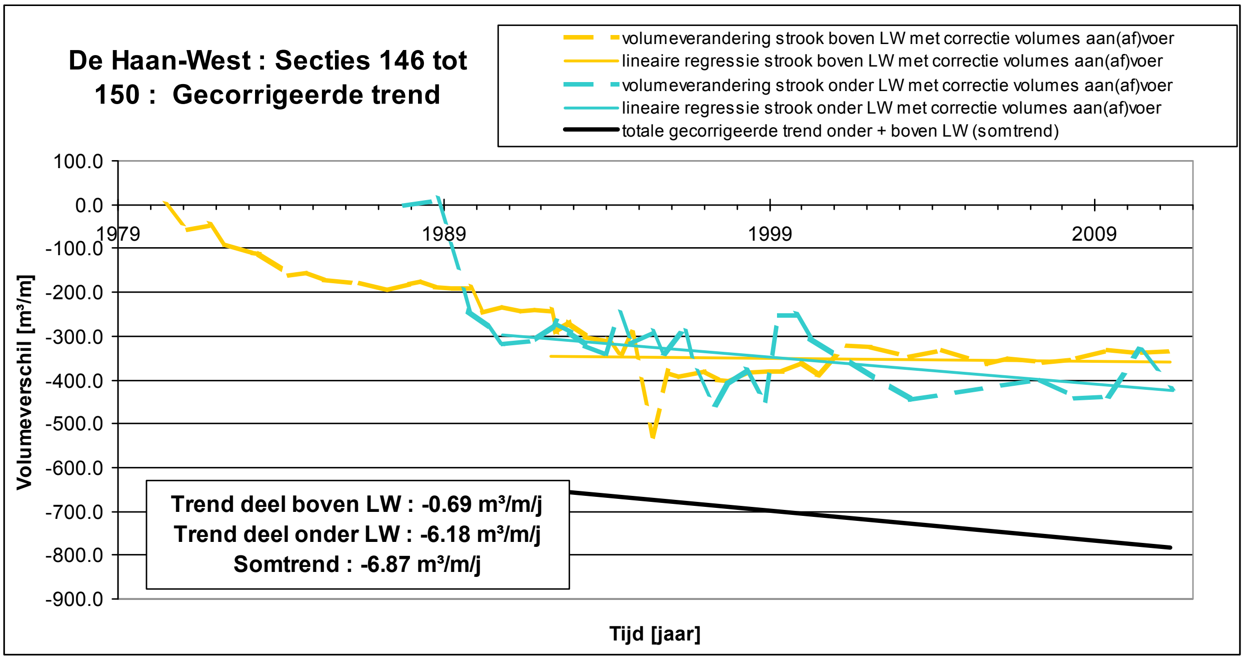

VJ2008
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

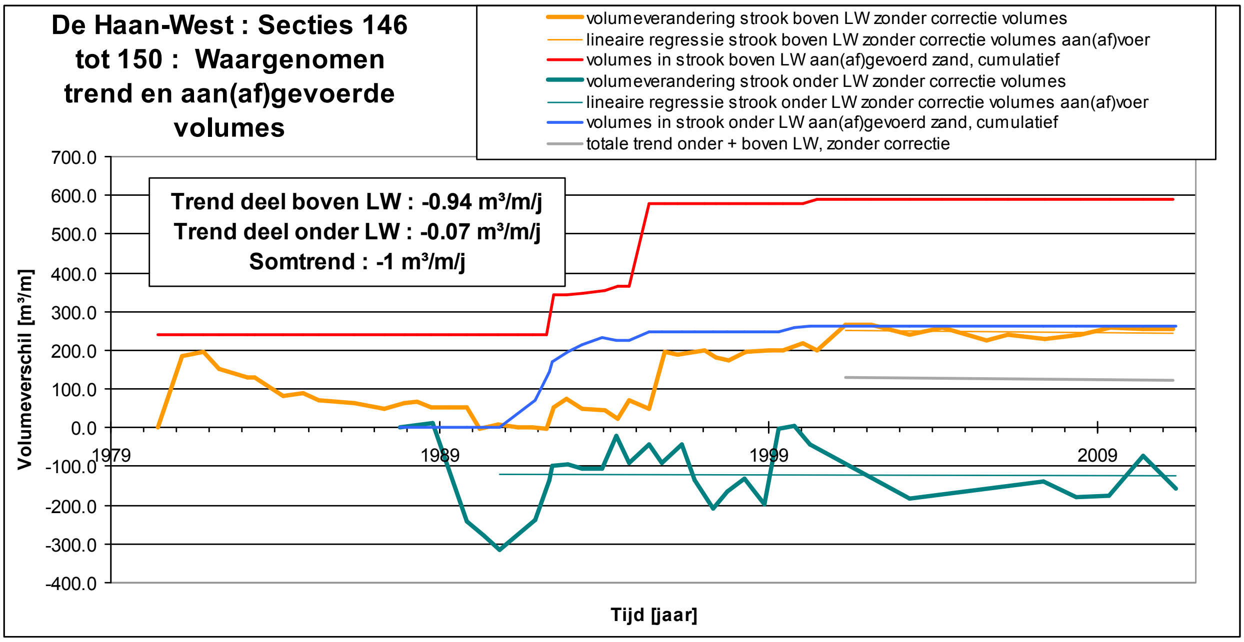

VJ2009
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

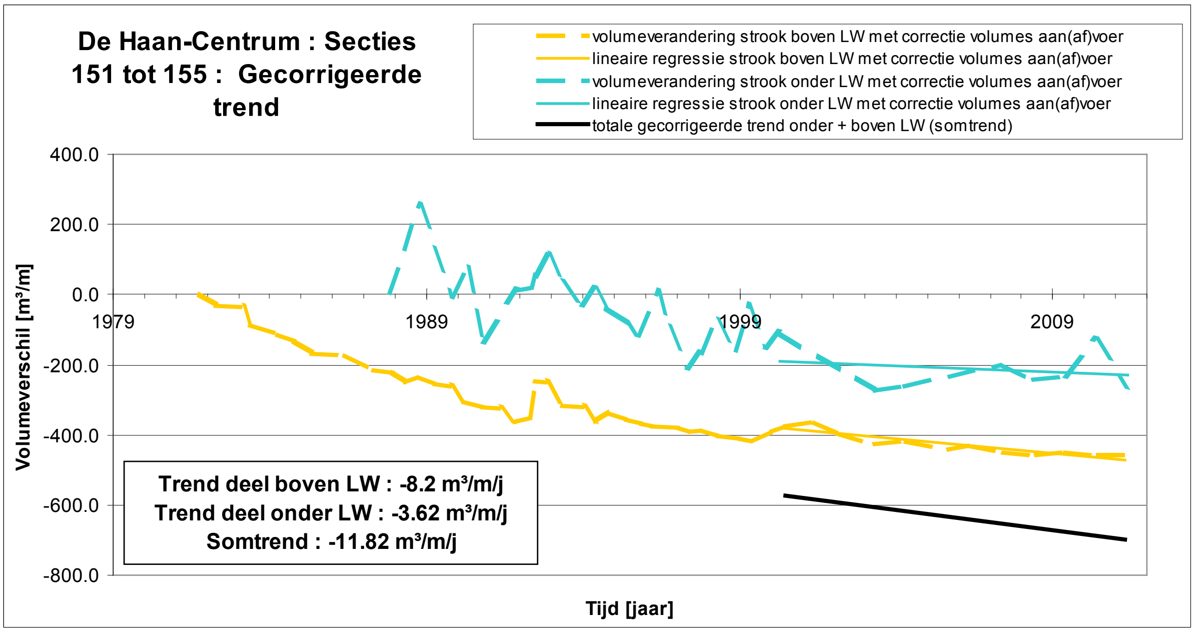

VJ2010
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

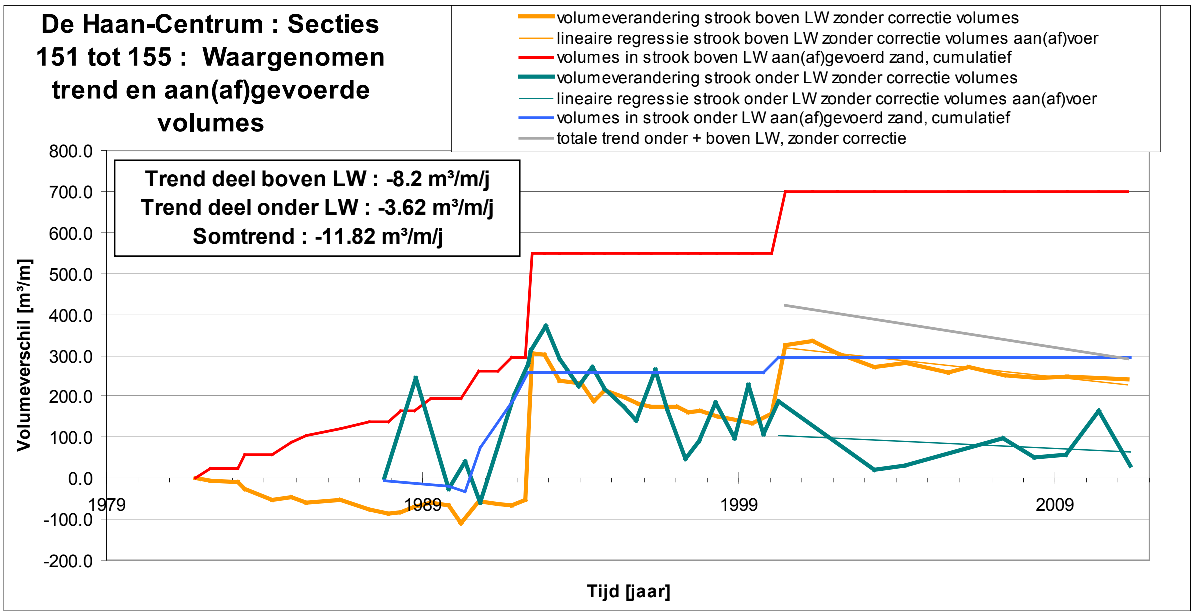

VJ2011
NJ1991
NJ1990
Z (TAW)
distance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0
100
200
300
400
500
600
700
800
900
1000

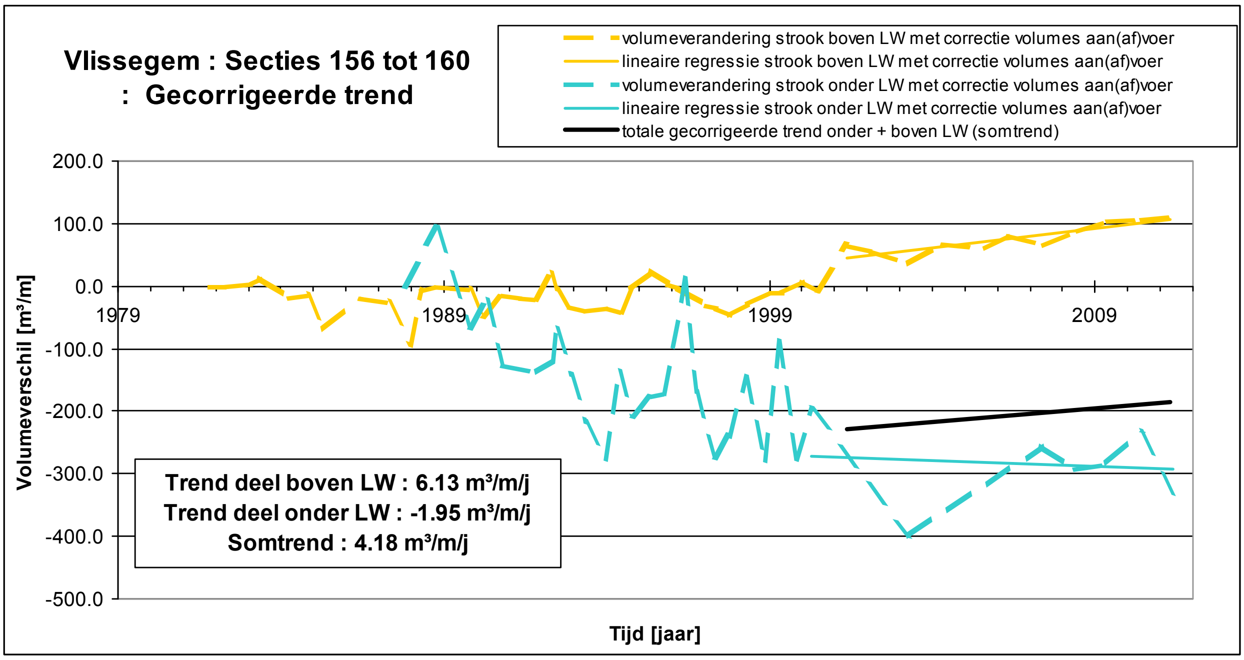
Annex 4. Graphs of volume evolution per coastal tract (tracts n° 31-33) from the “Kusttrend” project

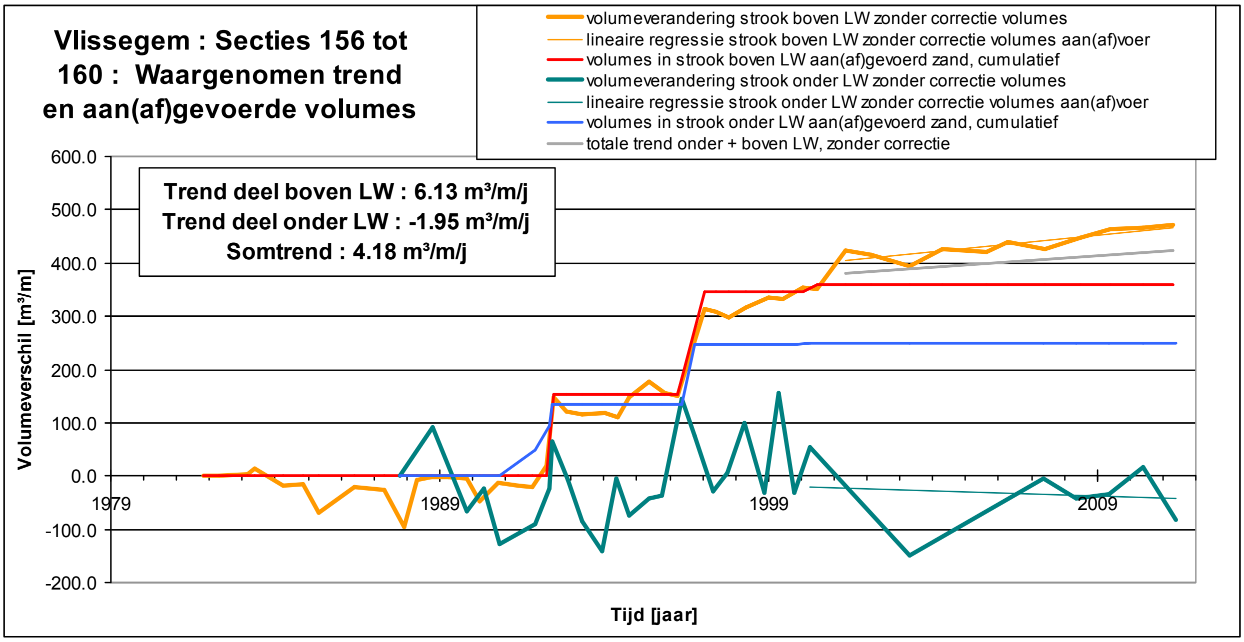





De Haan-Centrum : Secties 151 tot 155 : Gecorrigeerde trend
volumeverandering strook boven LW met correctie volumes aan(af)voer
lineaire regressie strook boven LW met correctie volumes aan(af)voer
volumeverandering strook onder LW met correctie volumes aan(af)voer
lineaire regressie strook onder LW met correctie volumes aan(af)voer
totale gecorrigeerde trend onder + boven LW (somtrend)
Volumeverschil [m³/m]
400.0
200.0
0.0
-200.0
-400.0
-600.0
-800.0
1979
1989
1999
2009
Trend deel boven LW : -8.2 m³/m/j
Trend deel onder LW : -3.62 m³/m/j
Somtrend : -11.82 m³/m/j
Tijd [jaar]


De Haan-Centrum : Secties 151 tot 155 : Waargenomen trend en aan(af)gevoerde volumes
volumeverandering strook boven LW zonder correctie volumes
lineaire regressie strook boven LW zonder correctie volumes aan(af)voer
volumes in strook boven LW aan(af)gevoerd zand, cumulatief
volumeverandering strook onder LW zonder correctie volumes
lineaire regressie strook onder LW zonder correctie volumes aan(af)voer
volumes in strook onder LW aan(af)gevoerd zand, cumulatief
totale trend onder + boven LW, zonder correctie
Volumeverschil [m³/m]
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
-100.0
-200.0
1979
1989
1999
2009
Trend deel boven LW : -8.2 m³/m/j
Trend deel onder LW : -3.62 m³/m/j
Somtrend : -11.82 m³/m/j
Tijd [jaar]


Vlissegem : Secties 156 tot 160 : Gecorrigeerde trend
volumeverandering strook boven LW met correctie volumes aan(af)voer
lineaire regressie strook boven LW met correctie volumes aan(af)voer
volumeverandering strook onder LW met correctie volumes aan(af)voer
lineaire regressie strook onder LW met correctie volumes aan(af)voer
totale gecorrigeerde trend onder + boven LW (somtrend)
200.0
100.0
0.0
-100.0
-200.0
-300.0
-400.0
-500.0
1979
1989
1999
2009
Volumeverschil [m³/m]
Trend deel boven LW : 6.13 m³/m/j
Trend deel onder LW : -1.95 m³/m/j
Somtrend : 4.18 m³/m/j
Tijd [jaar]


Vlissegem : Secties 156 tot 160 : Waargenomen trend en aan(af)gevoerde volumes
volumeverandering strook boven LW zonder correctie volumes
lineaire regressie strook boven LW zonder correctie volumes aan(af)voer
volumes in strook boven LW aan(af)gevoerd zand, cumulatief
volumeverandering strook onder LW zonder correctie volumes
lineaire regressie strook onder LW zonder correctie volumes aan(af)voer
volumes in strook onder LW aan(af)gevoerd zand, cumulatief
totale trend onder + boven LW, zonder correctie
600.0
500.0
400.0
300.0
200.0
100.0
0.0
-100.0
-200.0
1979
1989
1999
2009
Volumeverschil [m³/m]
Trend deel boven LW : 6.13 m³/m/j
Trend deel onder LW : -1.95 m³/m/j
Somtrend : 4.18 m³/m/j
Tijd [jaar]

Annex 5. Mean elevation evolution per box in and near De Haan-Centrum

Table 6 – Overview of mean elevation per box through time

Data source	Survey	Mean survey date	-1	0	1	2	3	4	5	11	12	13	14	15	21
S153profile	NJ1987	03-11-87	-0.073	-0.166	0.200	-0.074	0.535	0.079	0.112						
S153profile	NJ1988	28-10-88	-0.008	-0.061	-0.059	0.030	0.082	0.081	0.398						
S153profile	NJ1989	27-10-89	0.069	-0.123	-0.142	-0.085	-0.057	-0.004	0.169						
KD28meanprofile	VJ1990	13-03-90	-0.687	0.022	0.050	0.150	0.413	0.133	0.182						
DTM	NJ1990	19-10-90	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Design profile		31-05-91					1.533	1.465							
S153profile	NJ1991	03-12-91	0.076	-0.142	-0.041	0.055	1.169	0.915	0.004						
KD28meanprofile	VJ1992	16-03-92	0.091	0.007	0.252	0.217	1.336	1.147	0.139						
KD28meanprofile	JU1992	10-06-92	1.912	1.574	0.376	0.242	1.266	1.170	0.163						
KD28meanprofile	NJ1992	18-11-92	2.128	1.376	0.499	0.404	1.226	1.141	0.180						
DTM	VJ1993	13-06-93	2.091	0.973	0.648	0.458	0.822	1.091	0.020	0.236	0.185	0.715	0.578	0.055	0.371
KD28meanprofile	NJ1993	04-12-93	2.075	0.927	0.634	0.150	1.187	0.811	0.025						
KD28meanprofile	VJ1994	29-04-94	2.078	0.923	0.597	0.387	0.890	1.092	0.071						
DTM	NJ1994	10-10-94	2.176	0.731	0.620	0.353	0.823	1.054	0.102	0.460	0.138	0.877	0.889	0.013	0.544
S153profile	VJ1995	08-06-95	1.952	0.759	0.500	0.259	1.055	0.783	-0.128						
DTM	NJ1995	01-10-95	2.005	0.629	0.550	0.218	0.985	0.836	-0.031	0.489	0.238	0.795	0.863	0.211	0.653
DTM	VJ1996	25-04-96	2.029	0.569	0.647	0.302	1.023	1.004	0.021						
KD28meanprofile	NJ1996	05-10-96	1.922	0.595	0.596	-0.016	1.050	0.818	-0.030						
DTM	VJ1997	26-04-97	1.887	0.520	0.535	0.163	0.872	0.758	-0.165	0.481	0.192	0.578	0.768	-0.108	0.678
DTM	NJ1997	01-10-97	1.768	0.478	0.509	0.095	0.935	0.681	-0.111	0.454	0.156	0.713	0.713	-0.040	0.610
DTM	VJ1998	04-04-98	1.777	0.540	0.455	0.250	1.033	0.764	-0.028	0.444	0.233	0.677	0.751	-0.039	0.726
DTM	NJ1998	10-11-98	1.785	0.485	0.482	0.256	0.978	0.623	-0.114	0.487	0.188	0.800	0.571	-0.114	0.636
DTM	VJ1999	18-04-99	1.799	0.379	0.619	0.367	1.110	0.706	-0.016	0.612	0.330	0.952	0.706	0.045	0.773
DTM	NJ1999	20-10-99	1.770	0.783	0.566	0.229	1.018	0.672	-0.080	0.562	0.266	1.080	0.764	0.059	0.681
DTM	VJ2000	07-04-00	2.888	1.504	0.561	0.381	0.995	0.549	-0.026	0.581	0.362	0.953	0.512	0.009	0.732
STR2000	JU2000	16-06-00			0.994										
DTM	VJ2001	10-05-01	2.951	1.267											
DTM	VJ2002	12-02-02	2.589	1.073											
DTM	VJ2003	14-04-03			0.781	0.551	1.127	0.520	-0.270	0.574	0.356	0.853	0.361	-0.089	0.657
DTM	VJ2004	06-04-04	2.422	1.036	0.659	0.513	1.038	0.443	-0.304						
DTM	VJ2005	23-08-05	2.480	0.923											
DTM	VJ2006	18-04-06	2.491	1.119											
DTM	VJ2007	10-05-07	2.626	0.961	0.642	0.728	1.068	0.506	-0.210	0.456	0.506	0.800	0.353	-0.024	0.521
DTM	VJ2008	07-05-08	2.468	0.945	0.756	0.671	0.936	0.420	-0.191	0.592	0.486	0.711	0.285	-0.023	0.699
DTM	VJ2009	12-05-09	2.505	0.952	0.818	0.603	0.926	0.433	-0.144	0.696	0.498	0.750	0.297	-0.034	0.791
DTM	VJ2010	23-05-10	2.562	0.850	0.836	0.705	0.970	0.444	-0.073	0.673	0.580	0.778	0.330	0.072	0.835
DTM	VJ2011	24-05-11	2.612	0.819	0.749	0.537	0.883	0.333	-0.157	0.609	0.446	0.699	0.268	0.020	0.741

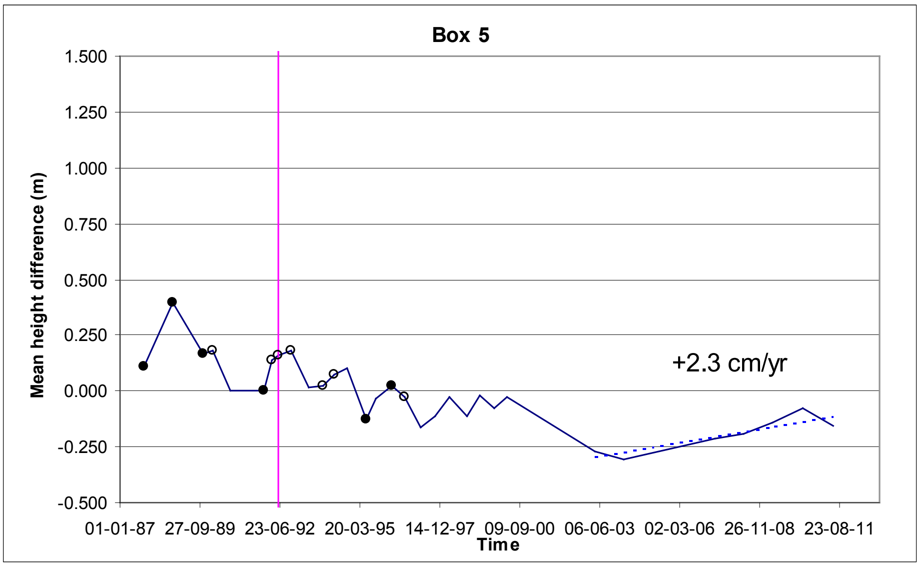
Table 7 – Elevation changes from survey to survey

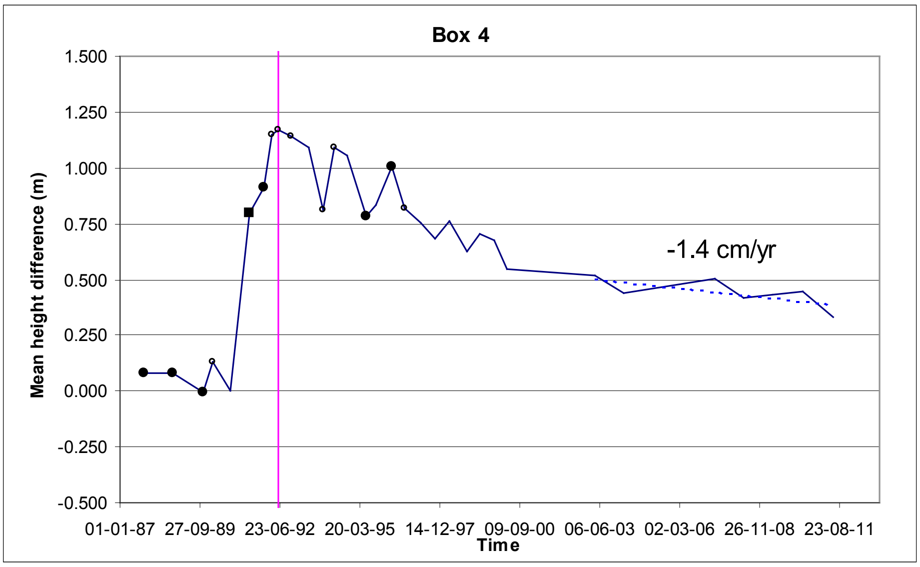
Survey	Mean survey date	-1	0	1	2	3	4	5	11	12	13	14	15	21	22	23
NJ1987	03-11-87															
NJ1988	28-10-88	0.065	0.105	-0.259	0.104	-0.453	0.003	0.286								
NJ1989	27-10-89	0.076	-0.061	-0.083	-0.115	-0.139	-0.086	-0.229								
VJ1990	13-03-90	-0.756	0.145	0.192	0.235	0.470	0.137	0.014								
NJ1990	19-10-90	0.687	-0.022	-0.050	-0.150	-0.413	-0.133	-0.182								
	31-05-91					1.533	1.465									
NJ1991	03-12-91	0.076	-0.142	-0.041	0.055	-0.365	-0.550	0.004								
VJ1992	16-03-92	0.091	0.007	0.293	0.163	0.167	0.232	0.135								
JU1992	10-06-92	1.836	1.716	0.123	0.024	-0.069	0.023	0.024								
NJ1992	18-11-92	2.037	1.369	0.124	0.162	-0.040	-0.029	0.018								
VJ1993	13-06-93	0.179	-0.601	0.149	0.054	-0.404	-0.050	-0.161	0.236	0.185	0.715	0.578	0.055	0.371	0.143	0.621
NJ1993	04-12-93	-0.053	-0.449	-0.014	-0.307	0.365	-0.281	0.005								
VJ1994	29-04-94	-0.013	-0.050	-0.037	0.237	-0.297	0.281	0.046								
NJ1994	10-10-94	0.101	-0.196	0.023	-0.034	-0.067	-0.038	0.031	0.224	-0.046	0.162	0.311	-0.042	0.173	0.195	-0.015
VJ1995	08-06-95	-0.126	-0.164	-0.120	-0.094	0.231	-0.270	-0.230								
NJ1995	01-10-95	-0.171	-0.102	0.050	-0.041	-0.069	0.052	0.097	0.029	0.100	-0.082	-0.027	0.198	0.110	-0.021	0.135
VJ1996	25-04-96	0.077	-0.190	0.097	0.084	0.038	0.169	0.052								
NJ1996	05-10-96	-0.082	-0.034	-0.051	-0.318	0.027	-0.187	-0.051								
VJ1997	26-04-97	-0.142	-0.049	-0.061	0.179	-0.178	-0.060	-0.135	-0.008	-0.047	-0.218	-0.095	-0.319	0.025	0.101	0.332
NJ1997	01-10-97	-0.154	-0.118	-0.026	-0.068	0.063	-0.077	0.054	-0.027	-0.036	0.135	-0.055	0.068	-0.068	-0.031	-0.008
VJ1998	04-04-98	-0.110	0.020	-0.054	0.155	0.098	0.084	0.083	-0.011	0.078	-0.036	0.038	0.001	0.116	0.240	-0.097
NJ1998	10-11-98	0.017	0.008	0.027	0.006	-0.055	-0.141	-0.087	0.044	-0.045	0.124	-0.179	-0.075	-0.090	-0.016	-0.060
VJ1999	18-04-99	0.022	-0.161	0.137	0.111	0.133	0.083	0.098	0.125	0.141	0.151	0.135	0.159	0.137	0.101	0.144
NJ1999	20-10-99	-0.015	0.298	-0.053	-0.138	-0.092	-0.034	-0.063	-0.050	-0.064	0.129	0.058	0.014	-0.092	-0.226	-0.113
VJ2000	07-04-00	1.089	1.126	-0.006	0.152	-0.023	-0.123	0.054	0.019	0.097	-0.128	-0.252	-0.050	0.051	0.147	-0.075
JU2000	16-06-00			0.433												
VJ2001	10-05-01	0.063	-0.238													
VJ2002	12-02-02	-0.361	-0.194													
VJ2003	14-04-03			-0.213	0.170	0.132	-0.029	-0.244	-0.007	-0.006	-0.100	-0.151	-0.097	-0.076	-0.198	-0.091
VJ2004	06-04-04	-0.167	-0.036	-0.122	-0.038	-0.089	-0.078	-0.034								
VJ2005	23-08-05	0.057	-0.114													
VJ2006	18-04-06	0.012	0.196													
VJ2007	10-05-07	0.134	-0.158	-0.017	0.214	0.030	0.063	0.094	-0.118	0.150	-0.053	-0.008	0.064	-0.136	0.217	0.018
VJ2008	07-05-08	-0.157	-0.016	0.115	-0.057	-0.132	-0.086	0.019	0.136	-0.020	-0.088	-0.068	0.001	0.178	0.013	-0.068
VJ2009	12-05-09	0.037	0.007	0.062	-0.068	-0.010	0.013	0.047	0.104	0.012	0.039	0.012	-0.011	0.092	0.016	0.085
VJ2010	23-05-10	0.058	-0.101	0.018	0.102	0.044	0.011	0.071	-0.022	0.082	0.028	0.033	0.106	0.044	-0.027	0.033
VJ2011	24-05-11	0.050	-0.031	-0.087	-0.168	-0.087	-0.111	-0.084	-0.064	-0.134	-0.079	-0.062	-0.052	-0.095	-0.123	-0.069

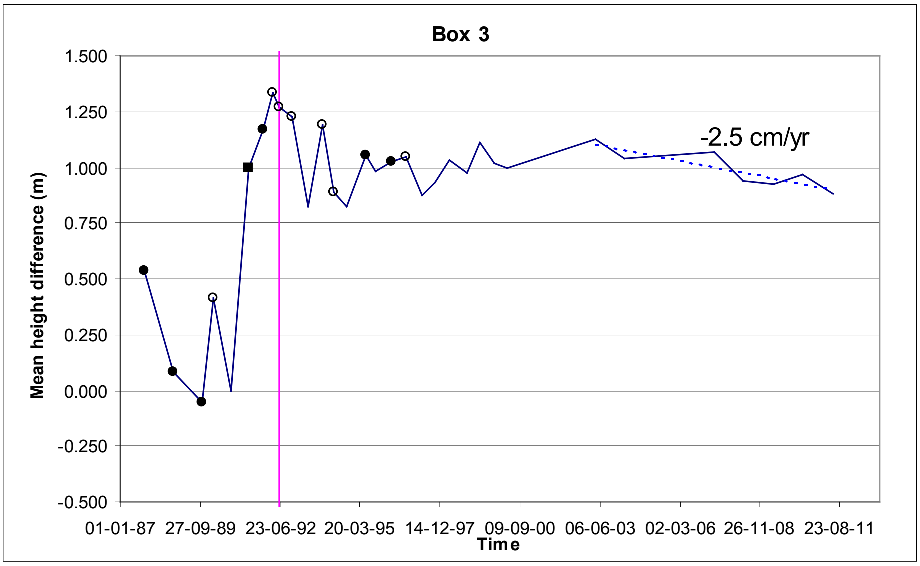
Note: Table 6 and 7 are digitally available (along with all data and graphs) in the Excel file "VolumesPerBoxAndSurvey.xls".

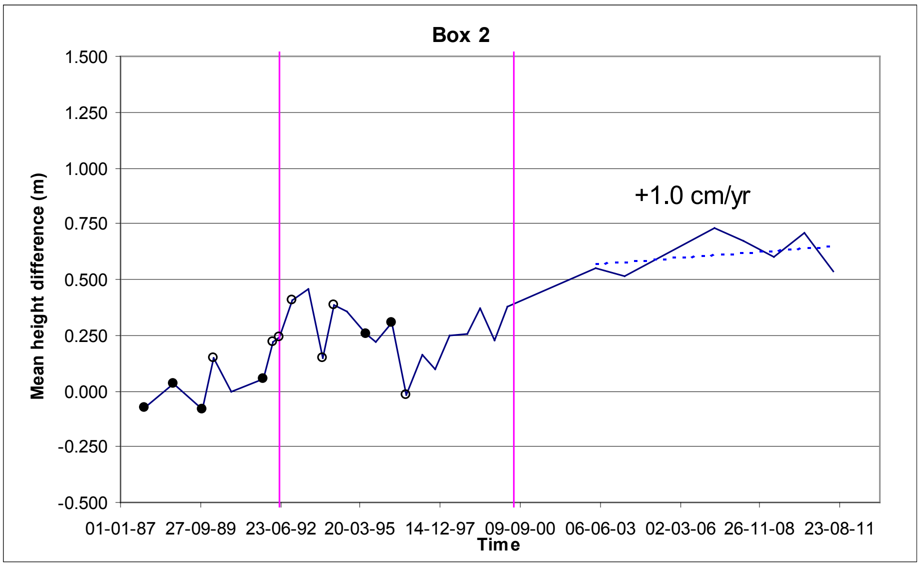
Graph per box of the elevation evolution.

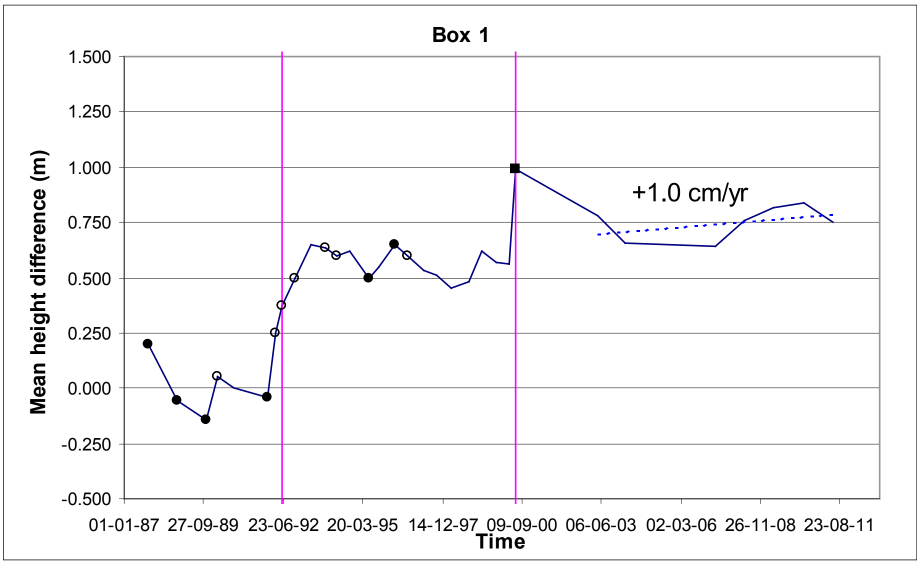
Overview of volume evolution per coastal tract (below) and mean elevation evolution per box (above) for sections 146-150 (left), 151-155 (middle) and 156-160 (right), arranged in a geographically meaningful pattern nut strongly reduced. Full detail graphs per box follow below. The graphs per coastal tract (bottom) are given in full detail in Annex 4.

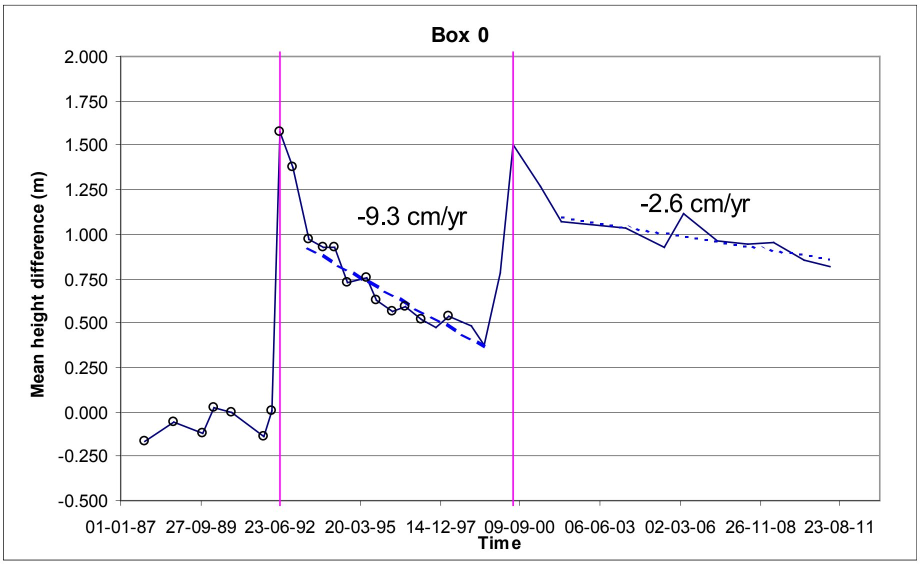

Box 5
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
+2.3 cm/yr
01-01-87 27-09-89 23-06-92 20-03-95 14-12-97 09-09-00 06-06-03 02-03-06 26-11-08 23-08-11
Time

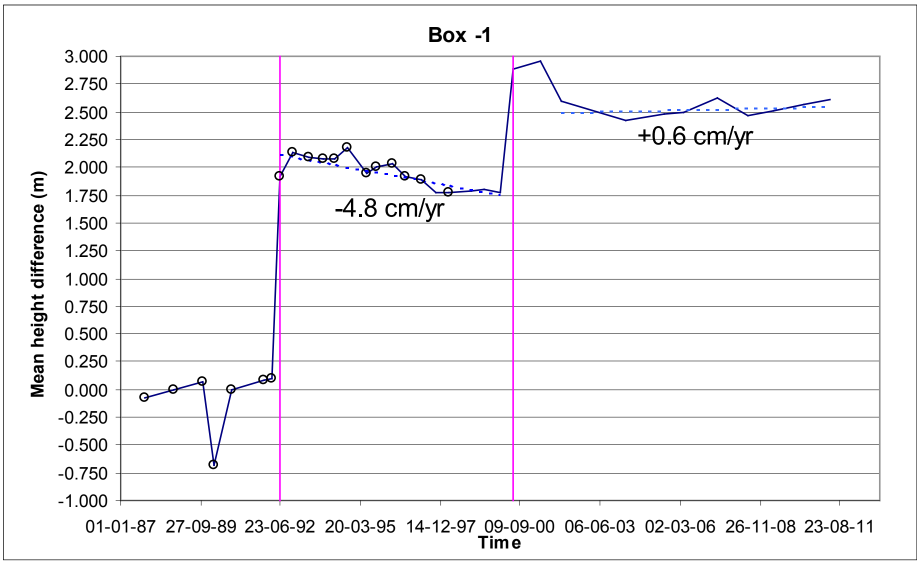

Box 4
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
-1.4 cm/yr
01-01-87 27-09-89 23-06-92 20-03-95 14-12-97 09-09-00 06-06-03 02-03-06 26-11-08 23-08-11
Time

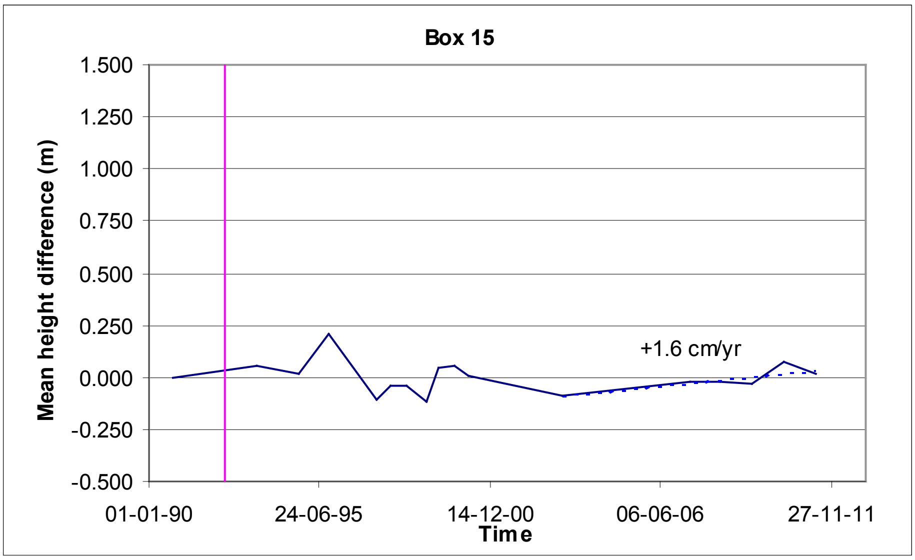

Box 3
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
-2.5 cm/yr
01-01-87 27-09-89 23-06-92 20-03-95 14-12-97 09-09-00 06-06-03 02-03-06 26-11-08 23-08-11
Time

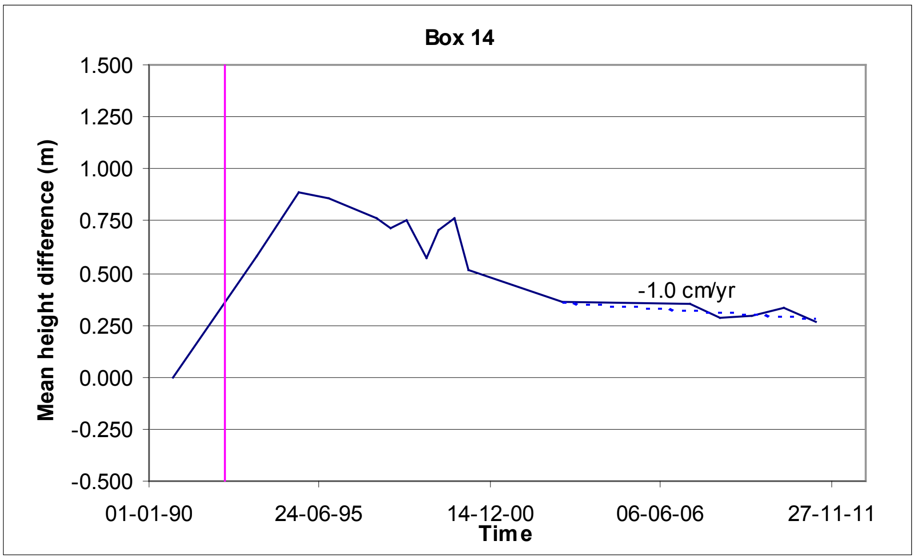

Box 2
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
+1.0 cm/yr
01-01-87 27-09-89 23-06-92 20-03-95 14-12-97 09-09-00 06-06-03 02-03-06 26-11-08 23-08-11
Time

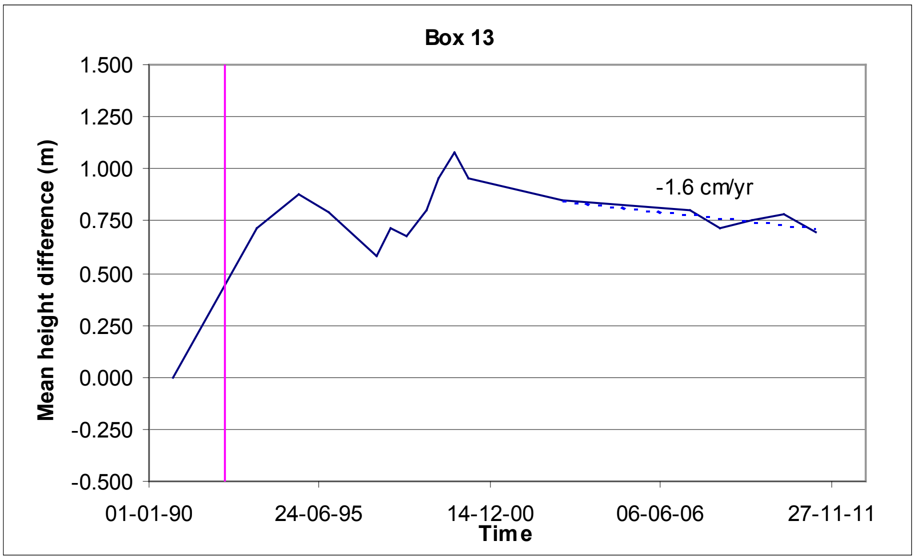

Box 1
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
+1.0 cm/yr
01-01-87 27-09-89 23-06-92 20-03-95 14-12-97 09-09-00 06-06-03 02-03-06 26-11-08 23-08-11
Time

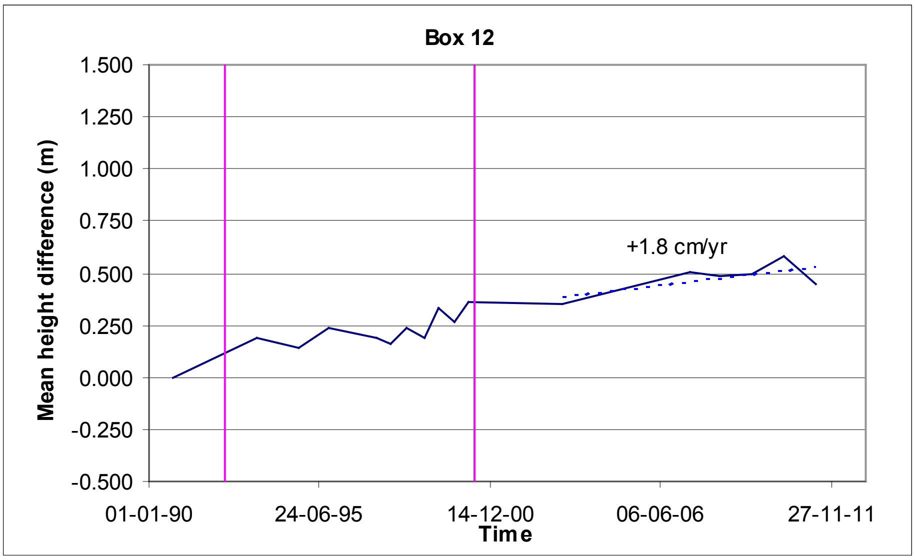

Box 0
Mean height difference (m)
2.000
1.750
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
-9.3 cm/yr
-2.6 cm/yr
01-01-87 27-09-89 23-06-92 20-03-95 14-12-97 09-09-00 06-06-03 02-03-06 26-11-08 23-08-11
Time

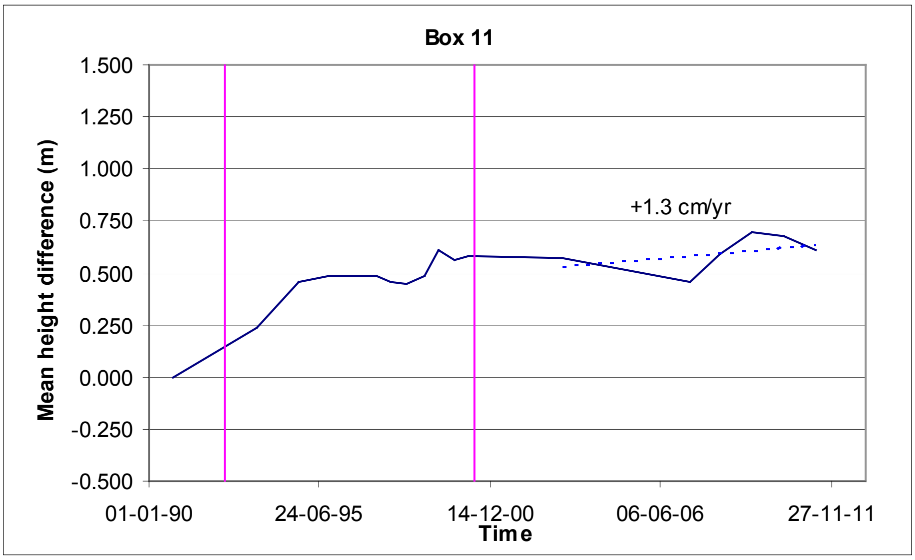

Box -1
Mean height difference (m)
3.000
2.750
2.500
2.250
2.000
1.750
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
-0.750
-1.000
+0.6 cm/yr
-4.8 cm/yr
01-01-87 27-09-89 23-06-92 20-03-95 14-12-97 09-09-00 06-06-03 02-03-06 26-11-08 23-08-11
Time

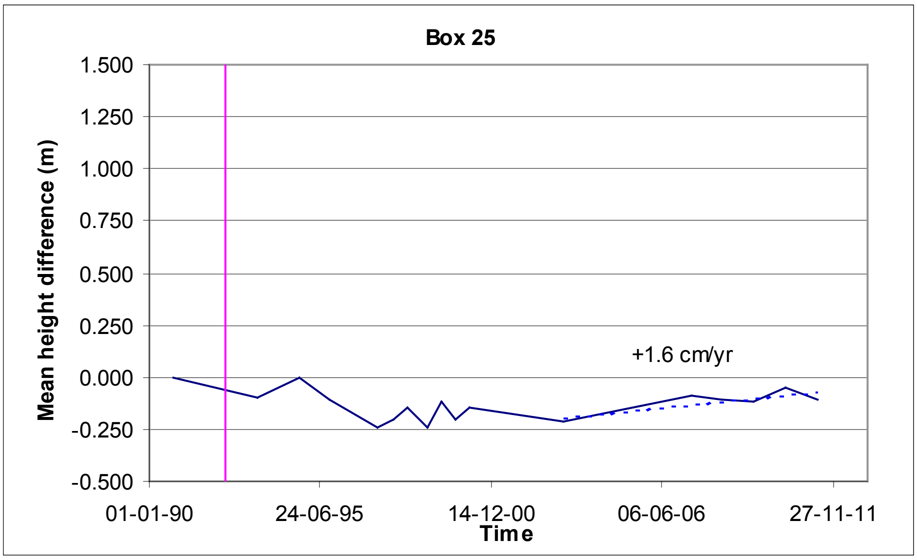

Box 15
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
+1.6 cm/yr
01-01-90 24-06-95 14-12-00 06-06-06 27-11-11
Time


Box 14
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
-1.0 cm/yr
01-01-90 24-06-95 14-12-00 06-06-06 27-11-11
Time

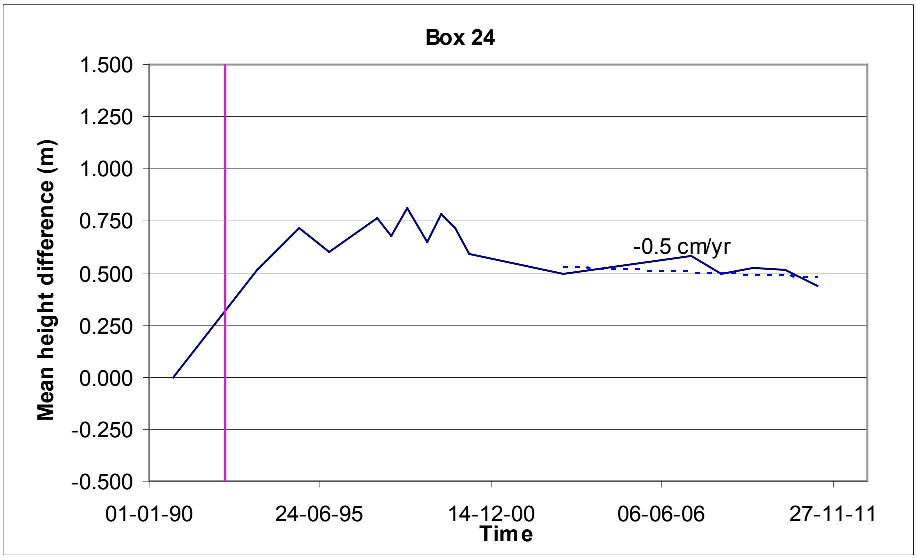

Box 13
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
Mean height difference (m)
-1.6 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time


Box 12
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
Mean height difference (m)
+1.8 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time

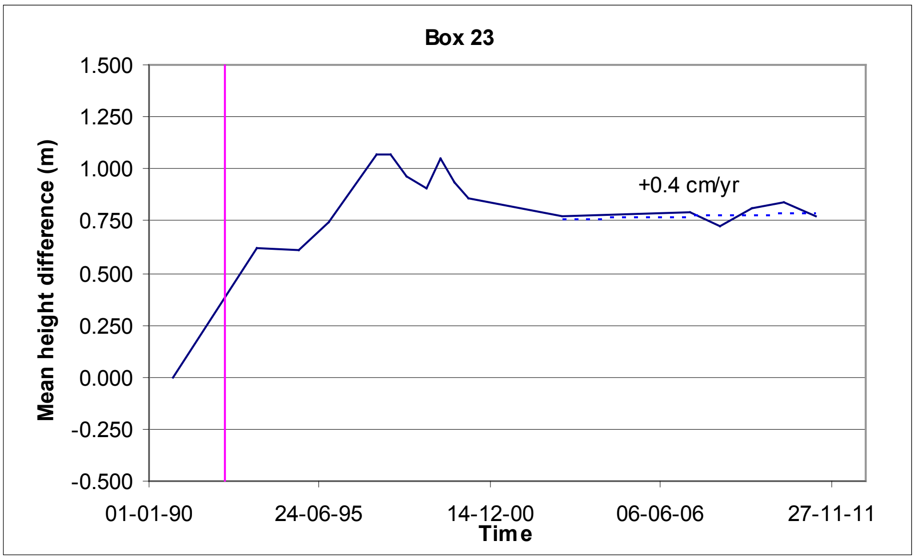

Box 11
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
Mean height difference (m)
+1.3 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time



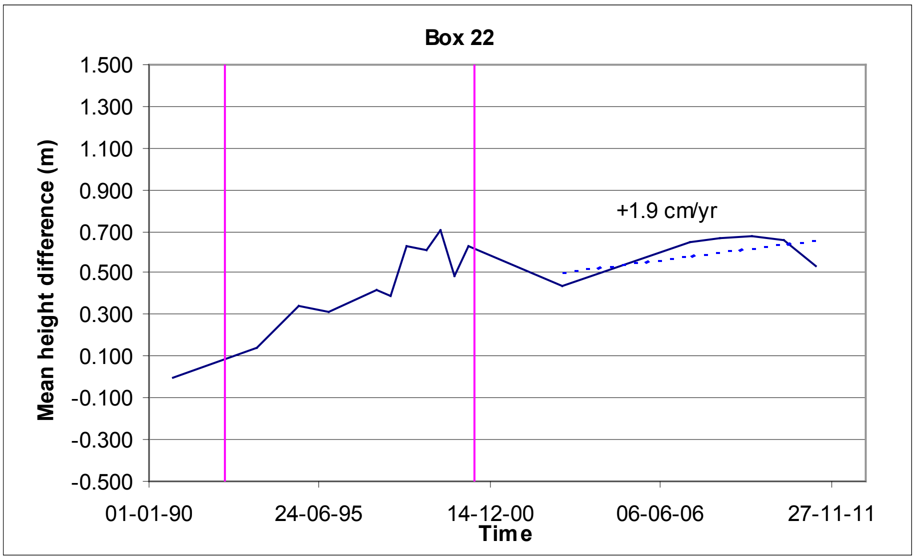
Box 25
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
+1.6 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time

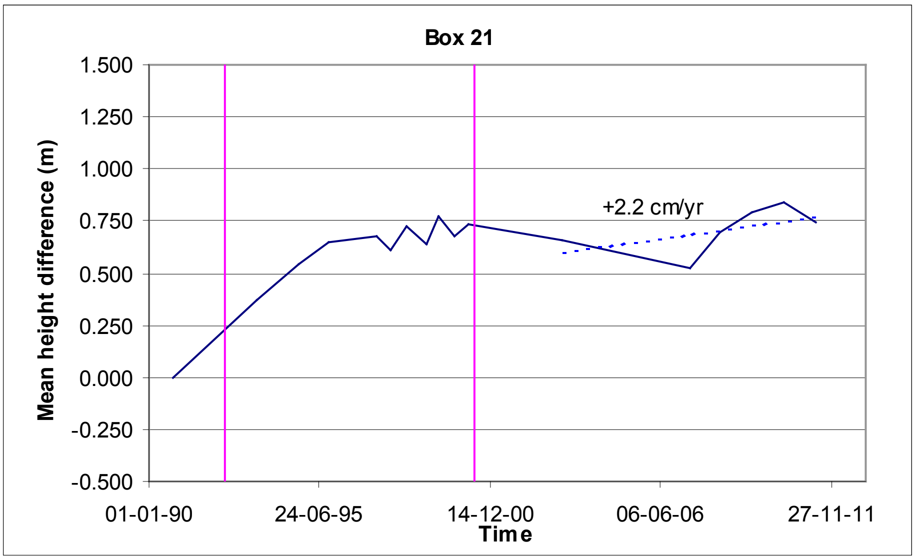


Box 24
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
-0.5 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time



Box 23
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
+0.4 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time


Box 22
Mean height difference (m)
1.500
1.300
1.100
0.900
0.700
0.500
0.300
0.100
-0.100
-0.300
-0.500
+1.9 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time


Box 21
Mean height difference (m)
1.500
1.250
1.000
0.750
0.500
0.250
0.000
-0.250
-0.500
+2.2 cm/yr
01-01-90
24-06-95
14-12-00
06-06-06
27-11-11
Time

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