The effects of sand hunger and ecosystem engineering on the tidal flats of the Oosterschelde basin

DRAFT VERSION

João Nuno Salvador de Paiva
Junior Researcher
Research Group Building with Nature
HZ University of Applied Sciences

Delta Academy
Edisonweg 4
4382 NW Vlissingen
The Netherlands
https://hz.nl/HZ/NL/Academies/Delta+Academy/Onderzoek/Building+with+Nature.htm

E: j.n.salvadordepaiva@hz.nl
P:0031-(0)118-489000
M:0031-(0)6-14266053
F:0031 (0) 642609762

May 2012

Title
The effects of sand hunger and ecosystem engineering on the tidal flats of the Oosterschelde basin

Pages
75

Keywords
ecosystem engineer, coastal protection, erosion, sedimentation, Crassostrea gigas

Summary
The realization of the storm surge barrier and the two secondary dams changed not only the hydrodynamics but also the geomorphological characteristics of the Oosterschelde estuary. These engineering works have created a disequilibrium between erosion and sedimentation. At this moment there is a sand deficit in the Oosterschelde that leads to the erosion of the tidal flats as a response to this new state.

In order to give an adequate answer to this large scale erosion in the Oosterschelde new approaches that are more cost-efficient and sustainable should be explored. In the framework of the program Building with Nature, several solutions are being investigated in order to conserve or restore the intertidal area. One possibility is the use of ecosystem engineering.

In this research the effects of sand hunger and ecosystem engineering on the tidal flats of the Oosterschelde basin is researched. A long term analysis of existing height data (transects crossing tidal flats) is performed in order to reach the aimed goals.

From the analysis it is concluded that the areas without oyster reefs are more prompt to erosion than areas with oyster reefs. Where oysters are present along the transects, they preferentially settled low in the intertidal, often near intertidal channels or after the settlement, the oyster reefs promoted channel formation, especially at the edges of the reefs. This fact is very interesting and important when constructing artificial reefs in the Oosterschelde. It demonstrates that artificial reefs should be constructed preferentially low in the intertidal, as here the chance of developing a living oyster reef will be the best.

The results are encouraging from the point of view of using these ecosystem engineers as a short term solution to prevent the fast erosion of the tidal flats in the Oosterschelde.

Version	Date	Author	Initials	Review	Initials	Approval	Initials

State
Preliminary
This is a preliminary report, intended for discussion purposes only. No part of this report may be relied upon by either principal or third parties.

Tables:

Figures:

1 BACKGROUND

This research project will be part of the covering research RAAKPRO Building with Living Nature. The RAAKPRO Building with Living Nature research is divided in four packages;

1. “Development of concepts”
2. “Development of assessments”
3. “Execute knowledge extending experiments”
4. “Tools”

The evaluation of the effects over time of an ecosystem engineer on the intertidal environment is part of package three.

1.1 INTRODUCTION

1.1.1 LOSS OF INTERTIDAL HABITAT IN THE *OOSTERSCHELDE*

After the 1953 flood that occurred in this area the Delta project was created. The aim of this plan was to reduce the length of the dykes directly exposed to the sea in order to improve the safety in this region. Besides the Westerschelde, all the main estuaries were closed or partly closed from the river inputs and the North Sea. One of these former estuaries is the *Oosterschelde* (Eastern Scheldt), located between *Schouwen-Duiveland* and *Tholen* in the north and *Noord-Beveland* and *Zuid-Beveland* in the south (Figure 1).

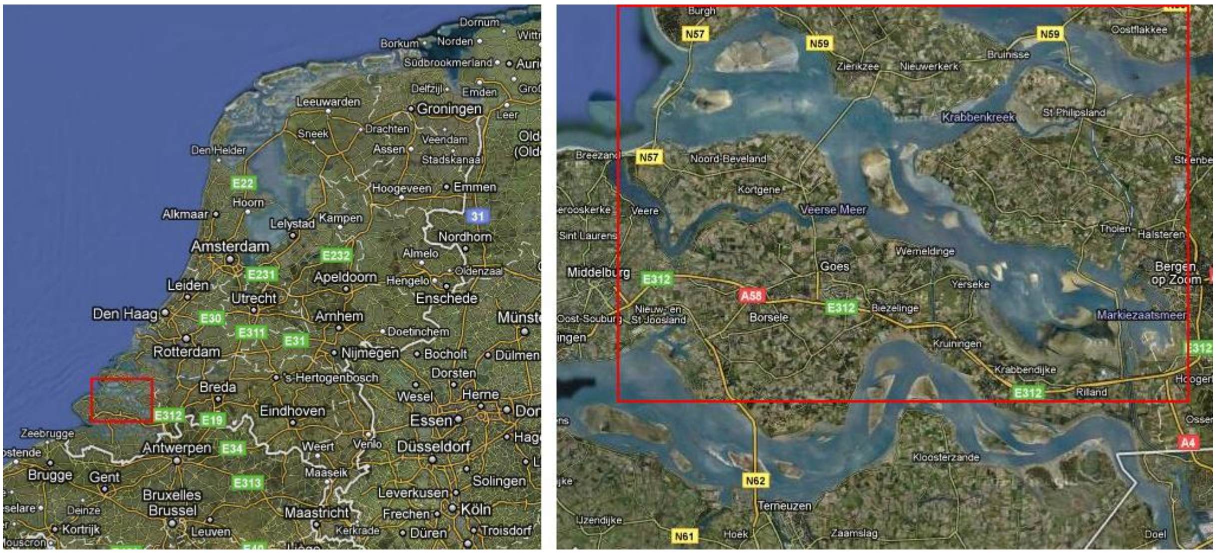

Figure 1 ***Oosterschelde*** **location**

The *Oosterschelde* project was included in the Delta project and it was finished in 1987. Initially the *Oosterschelde* was supposed to be dammed off completely from the North Sea and become a stagnant freshwater lake. Instead a storm surge barrier and two secondary dams were constructed. The plans were changed due to opposition from the shellfish farmers, conservationists, scientists and many other people that were against the initial plan (Nienhuis and Smaal 1994).

The main purpose of the two secondary dams were to reduce the area and volume of the basin and in this way increase the tidal prism to levels close to the prebarrier levels.

Although the new design is less drastic for the estuarine environment of the *Oosterschelde*, it still induced many morphological and ecological changes that are still going on at present.

The changes, in range and volume, resulted in an adjusted tidal landscape. The change in hydrodynamic characteristics forced the estuary out of equilibrium and the channels are in a need of more sediment. It is estimated that an amount between 400 to 600 million m^3 of sand is needed to restore the morphodynamic equilibrium in the Oosterschelde.

Due to the sand deficit the channels are slowly filling up with sediments from the tidal flats(Figure 2), causing its erosion and a reduction of emersion time (the so-called 'sand hunger' of the Oosterschelde; Van Zanten and Adriaanse 2008). As a consequence the habitat for intertidal soft-bottom benthic fauna is slowly disappearing, and with it food sources for estuarine birds that use these areas as foraging grounds (Mulder and Louters. 1994). Erosion of tidal flats also locally exposes deeper peat layers, potentially resulting in a reduced water clarity and primary production (Nienhuis and Smaal 1994).

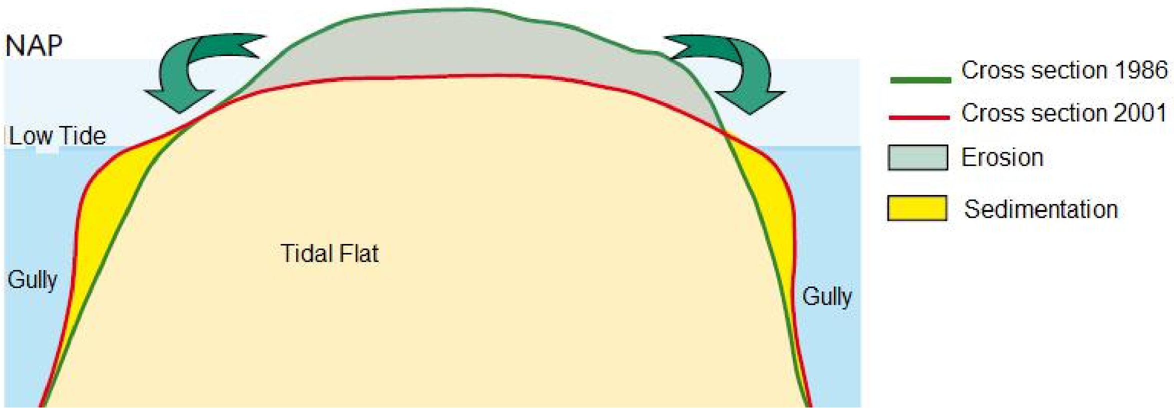

Figure 2 Erosion of the tidal flats due to the new equilibrium (Zanten and Adriaanse 2008)

There are also concerns to human safety as the slow disappearance of tidal flats and salt marshes will also result in an increased risk of dike ruptures and flooding during storm surges, because the dikes become more exposed to wave action (Van Zanten and Adriaanse 2008).

Measurements show that since the construction of the *Oosterschelde* storm surge barrier about 10km^2 of intertidal area has been lost in the *Oosterschelde*. Today the net reduction rate of intertidal area is about 0.5km^2 per year. The area of salt marshes also decreases three hectare per year. Today, only 5km^2 of salt marshes remain. The measurements also show that the rate of erosion is steady. Without additional interventions the *Oosterschelde* will change in time from a tidal basin with channels and shoals into a shallow lagoon with deeper and shallower parts.

1.1.2 COASTAL PROTECTION WITH THE USE OF THE ECOSYSTEM ENGINEER *CRASSOSTREA GIGAS*

In order to give an adequate answer to the large scale coastal erosion in the Oosterschelde new approaches that are more cost-efficient and sustainable should be explored.

Jones et al. (1994) defines ecosystem engineers as “organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials. In doing so they modify, maintain and create habitats. Autogenic engineers change the environment via their own physical structures. Allogenic engineers change the environment by transforming living or non-living materials from one physical state to another, via mechanical or other means.”

The physical ecosystem engineering concept interconnects a number of important ecological and evolutionary concepts and is particularly relevant to environmental management. Within the Dutch innovation program Building with Nature the use of bivalve reefs as possible ecodynamic measure for the stabilization of tidal flats and for shoreline protection, a serious problem in many places around the world, is investigated.

Bivalve reefs are ecosystem engineers that influence tidal flow and wave action and, in doing so, modify patterns of sediment deposition. At the same time these reefs form valuable habitats that play an important role in shaping estuarine landscapes. On the specific case of the *C.gigas* in the *Oosterschelde* they have formed large and dense natural oyster reefs, increasing from 0,25 km^2 in 1980 to 8,1 km^2 in 2003 (Smaal et al. 2009).

Taking in account the capability of influencing the hydrological and geomorphological conditions by *C.gigas*, the purpose of this research is to assess the suitability of the oyster reefs as a sustainable coastal protection method for the intertidal areas and as a short term answer for fighting the effects of the sand deficit in the *Oosterschelde*.

The research will focus on how the Pacific oysters, as an ecosystem engineer, affect the geomorphological characteristics of an ecosystem over time.

1.2 OBJECTIVES

The end purpose of this research is to assess the suitability of the oyster reefs as a sustainable coastal protection method for the intertidal areas of the Oosterschelde. In order to assess the suitability of these structures as a coastal protection method the research will focus on sedimentation/erosion processes over time, in and around natural oyster reefs, using available long-term data on height profiles of tidal flats.

The research is focused on the erosion and sedimentation patterns over existing natural oyster reefs and in their immediate surroundings.

1.3 HYPOTHESIS

It is hypothesized that the oyster reefs will have an effect on the sedimentation and erosion processes, more precisely the presence of a reef will increase the sedimentation rates, or at least decrease the erosion rates in the area of the reef and also in the surrounding area.

It is also expected that the differences between the areas affected by the oyster reefs and other areas will become more clear over time.

2 METHODS AND MATERIALS

In order to evaluate how ecosystem engineers, in this case the Pacific oyster (*Crassostrea gigas*), influence the hydrological and geomorphological conditions, of the intertidal habitats on the *Oosterschelde*, several methods must be used. In this report the focus is the analysis of the effects over time. It is used the Rijkswaterstaat transects on the *Oosterschelde*.

2.1 LONG TERM ANALYSIS ON THE HEIGHTS OF THE TIDAL FLATS

2.1.1 DETERMINATION OF THE HEIGHT PROFILES

Since 1987 Rijkswaterstaat is measuring bed levels at different cross-sections on several tidal flats, in the *Oosterschelde*. These transect measurements – done by RTK – have a measuring accuracy in the order of one centimeter. Hence, they give a detailed overview of the development of the bed level changes along these cross-sections. These data will help us to understand the trends over time on sedimentation and erosion for the different areas in the *Oosterschelde*.

Taking in account the height profiles of the several transects and the location of the oyster reefs it is possible to understand and make some conclusions on how the oyster reefs influence the erosion and sedimentation processes that occur not only on the reefs but also on the surroundings of the reefs.

The location of the oyster reefs was possible due to the existing oyster maps. These maps were created in order to evaluate the spreading of the *C.gigas* along the *Oosterschelde* and were based in several measurements like GPS and Aerial photography. Unfortunately this oyster maps are only available for certain years such as 1980, 1990, 2002, 2004 and 2005. This fact creates some difficulties when comparing the oyster maps with the height profiles.

The use of the ArcGIS software made it possible to identify where and when these transects crossed oyster reefs.

2.1.2 DETERMINATION OF THE EROSION/SEDIMENTATION RATE

Another possible analysis based on the height profiles is the determination of the erosion/sedimentation rate.

In order to calculate the erosion/sedimentation rate first is necessary to determine the average height along a specified interval for the different years. Based on the average heights and applying a regression analysis, more specifically a linear regression, it is possible to determine a linear function that gives a yearly averaged rate of sedimentation or erosion along that interval.

The erosion/sedimentation rate is obtained by a process of differentiation of the previous function. If the value is positive it is considered a sedimentation rate, if it is negative it is considered an erosion rate.

Figure 3 shows as an example on the left side the interval for which the average heights are calculated, and on the right side the linear regression, the regression function and also the coefficient of determination (R^2).

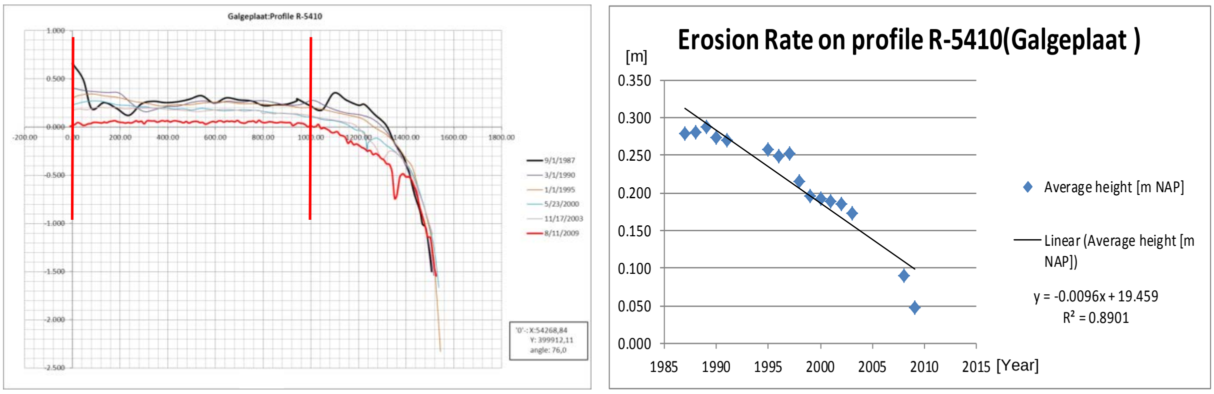

Figure 3 Left chart shows the interval for which average height is calculated. Right chart shows the linear regression based on the average height for each measured year. In this case approximately 1 cm per year on average is eroding along this interval (See text for more explanation).

The coefficient of determination is a statistical measure of how well the regression line approximates the real data points. For example, a coefficient of determination of 1.0 indicates that the regression line perfectly fits the data. When this value is low it means that the linear regression doesn't fit the data. For situations of a low R^2 no specific analysis is going to be performed. On appendix 1 is possible to see all the charts related to the determination of the erosion/sedimentation rate

3 RESULTS AND DISCUSSION

3.1 LONG TERM ANALYSIS ON THE HEIGHTS OF THE TIDAL FLATS

Figure 4 shows the location of the analyzed transects. For practical reasons not all the sampling dates are shown in the different graphs. However the detailed graphs are available in the appendix 1.

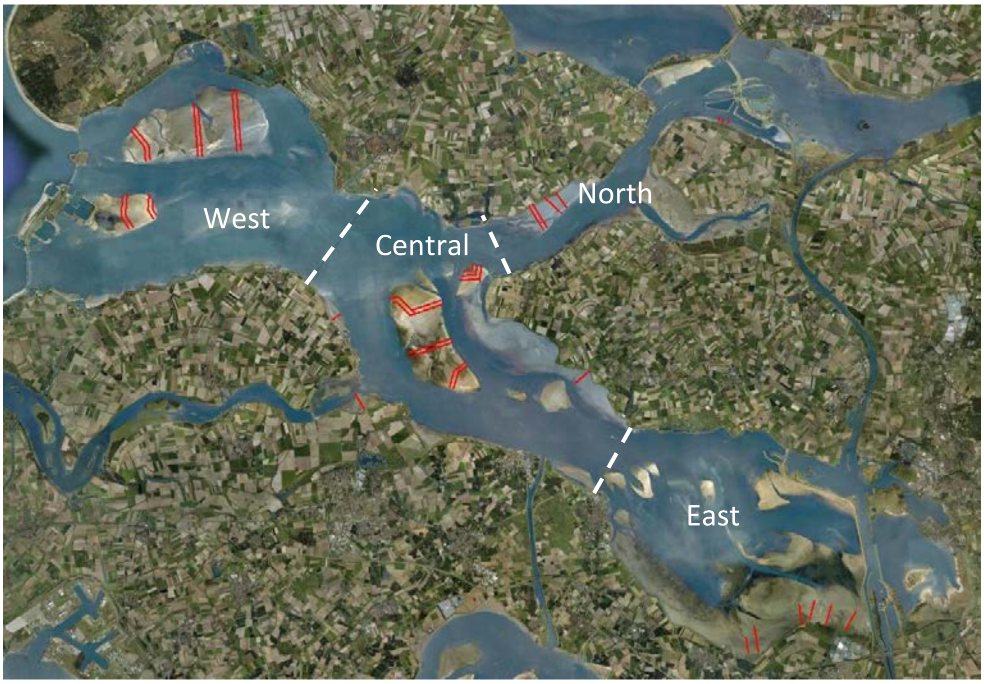

Figure 4 Location of the analyzed cross-section transects in the Oosterschelde

3.1.1 TRANSECTS WITHOUT OYSTER REEFS

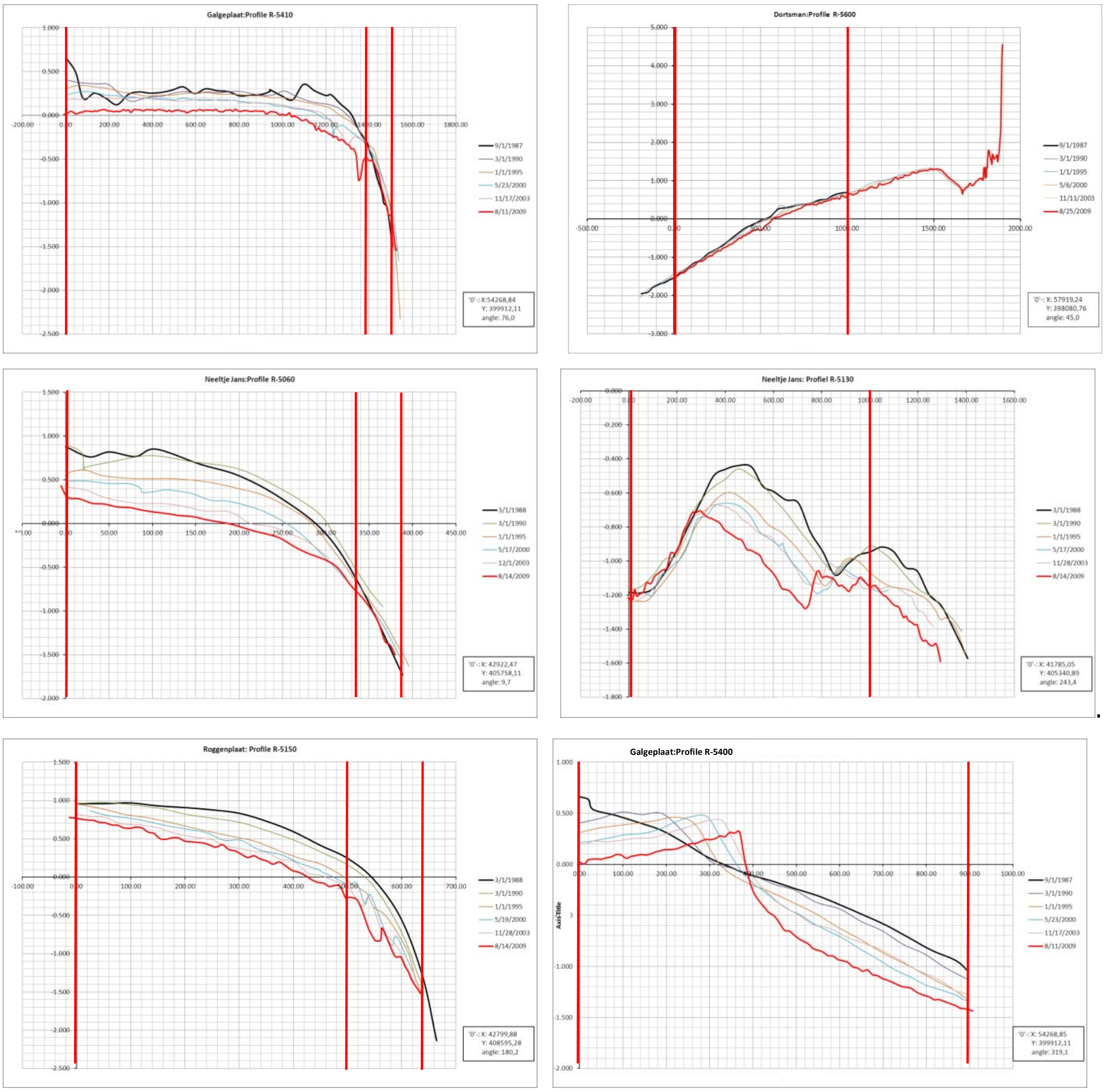

Figure 5 Height profiles of the transects without oyster reefs (y axes: [m NAP]; x axes [m]). The red vertical lines denotes the interval for which average heights were calculated (see table 2)

As can be seen in Figure 12 all transects that do not cross oyster reefs suffered erosion over the time. The erosion process, since 1987, can vary from a few centimeters, profile R-5400, up to more than 60 centimeters profile R-5400.

It is also possible to see accumulation of sediment in some areas, for example on profile R-5400. This fact can be explained by the shift of sediment from the higher intertidal areas to the depositional areas in the lower intertidal, like the channels , and cannot be seen as a real sedimentation process. The remaining transects without oyster reefs are displayed in the appendix 1. It is clear that all transects, containing no oyster reef, are dominated by erosion processes.

The erosion/sedimentation rate is determined taking in account the intervals that are shown in Figure 5. When it was possible a distinction between the tidal flats and the channels was made in order to analyze the differences. Table 2 represents the erosions rates, functions and R^2 for the transects without oyster reefs.

Table 1 Erosion/sedimentation rates for the transects without oysters

Profile Name	Location	Observations	Linear regression f(x), [m]	R^2	Erosion (-) /sedimentation(+) rate [mm/year]
R-5050	Neeltje Jans	Tidal Flat (0-300m)	y = -0,0429x + 85,72	0,8977	-42,90
		Gully (300-end)	y = -0,0281x + 54,885	0,6112	-28,10
R-5060	Neeltje Jans	Tidal Flat (0-340m)	y = -0,0309x + 61,848	0,9531	-30,90
		Gully (340-end)	y = -0,0005x - 0,0316	0,0009	-0,50
R-5070	Neeltje Jans	Tidal Flat (0-330m)	y = -0,0109x + 22,723	0,7497	-10,90
		Gully (330-450 m)	y = 0,0187x - 37,497	0,5481	18,70
R-5080	Neeltje Jans	Tidal Flat (0-575m)	y = -0,0075x + 15,914	0,6478	-7,50
		Gully (575-670 m)	y = 0,0211x - 42,511	0,4391	21,10
R-5100	Neeltje Jans	Tidal Flat (0-600 m)	y = -0,0062x + 11,35	0,5292	-6,20
		Gully (600-end)	y = 0,0047x - 10,352	0,0470	4,70
R-5130	Neeltje Jans	0 - 1000 m	y = -0,0112x + 21,341	0,8529	-11,20
R-5150	Roggenplaat	0 - 600 m	y = -0,0169x + 33,971	0,6805	-16,90
R-5160	Roggenplaat	Tidal Flat (0-500 m)	y = -0,017x + 34,532	0,9450	-17,00
		Gully (500-650 m)	y = -0,0143x + 28,164	0,2745	-14,30
R-5170	Roggenplaat	Tidal Flat (0-900 m)	y = -0,0075x + 15,473	0,4983	-7,50
		Gully (900-1050 m)	y = 0,0037x - 7,9531	0,1489	3,70
R-5180	Roggenplaat	Tidal Flat (0-840 m)	y = -0,0184x + 37,064	0,9354	-18,40
		Gully (840-end)	y = -0,0112x + 21,593	0,5802	-11,20
R-5190	Roggenplaat	350 - 2350 m	y = -0,0068x + 13,908	0,6198	-6,80
R-5200	Roggenplaat	80 - 2100 m	y = -0,0063x + 12,955	0,2606	-6,30
R-5230	Roggenplaat	Entire profile	y = -0,0127x + 25,445	0,7302	-12,7
R-5240	Roggenplaat	Entire profile	y = -0,0076x + 15,442	0,6825	-7,60
R-5360	Galgeplaat	0 - 200 m	y = -0,0098x + 18,207	0,8672	-9,80
R-5370	Galgeplaat	0 - 900 m	y = -0,0045x + 8,5067	0,3365	-4,50
R-5380	Galgeplaat	Tidal Flat (0-1300 m)	y = -0,0058x + 11,839	0,8128	-5,80
		Gully (130-1400 m)	y = 0,0128x - 26,014	0,2770	12,80
R-5390	Galgeplaat	0 - 100 m	y = -0,0147x + 27,916	0,7149	-14,70
R-5400	Galgeplaat	0 - 897 m	y = -0,0131x + 25,893	0,7337	-13,10
R-5410	Galgeplaat	Tidal Flat (0-1400 m)	y = -0,0109x + 21,972	0,9169	-10,90
		Gully (1400- end)	y = 0,0144x - 29,685	0,3963	14,40
R-5480	Galgeplaat	Tidal Flat (0-700 m)	y = -0,0065x + 12,619	0,5921	-6,50
		Gully (700- end)	y = 0,0023x - 5,9056	0,0178	2,30
R-5600	Dortsman	100 - 1000 m	y = -0,0065x + 12,833	0,8291	-6,50
R-5610	Dortsman	50 - 1000 m	y = -0,0046x + 8,9613	0,2293	-4,60
R-5740	Viane	Entire profile	y = -0,0063x + 12,007	0,1014	-6,3
R-5745	Viane	Entire profile	y = -0,0035x - 8,0035	0,9162	-3,5

The results in table 1 show the channels have a lower erosion rate or sedimentation rates when compared with their respective tidal flats. This results are in line with the theory that the tidal flats are being eroded and the sediment is being transported to the channel that are slowly filling up.

From the negative slopes observed in Table 1 it is concluded that in all the analyzed transects erosion is the main process occurring. The erosion rate of the tidal flats or the other transects vary between 4,5 mm per year, a relatively sheltered place at the Galgeplaat, and 42,9 mm per year for a exposed place in the Neeltje Jans tidal flat.

3.1.2 Transects with Oyster reefs

Galgeplaat

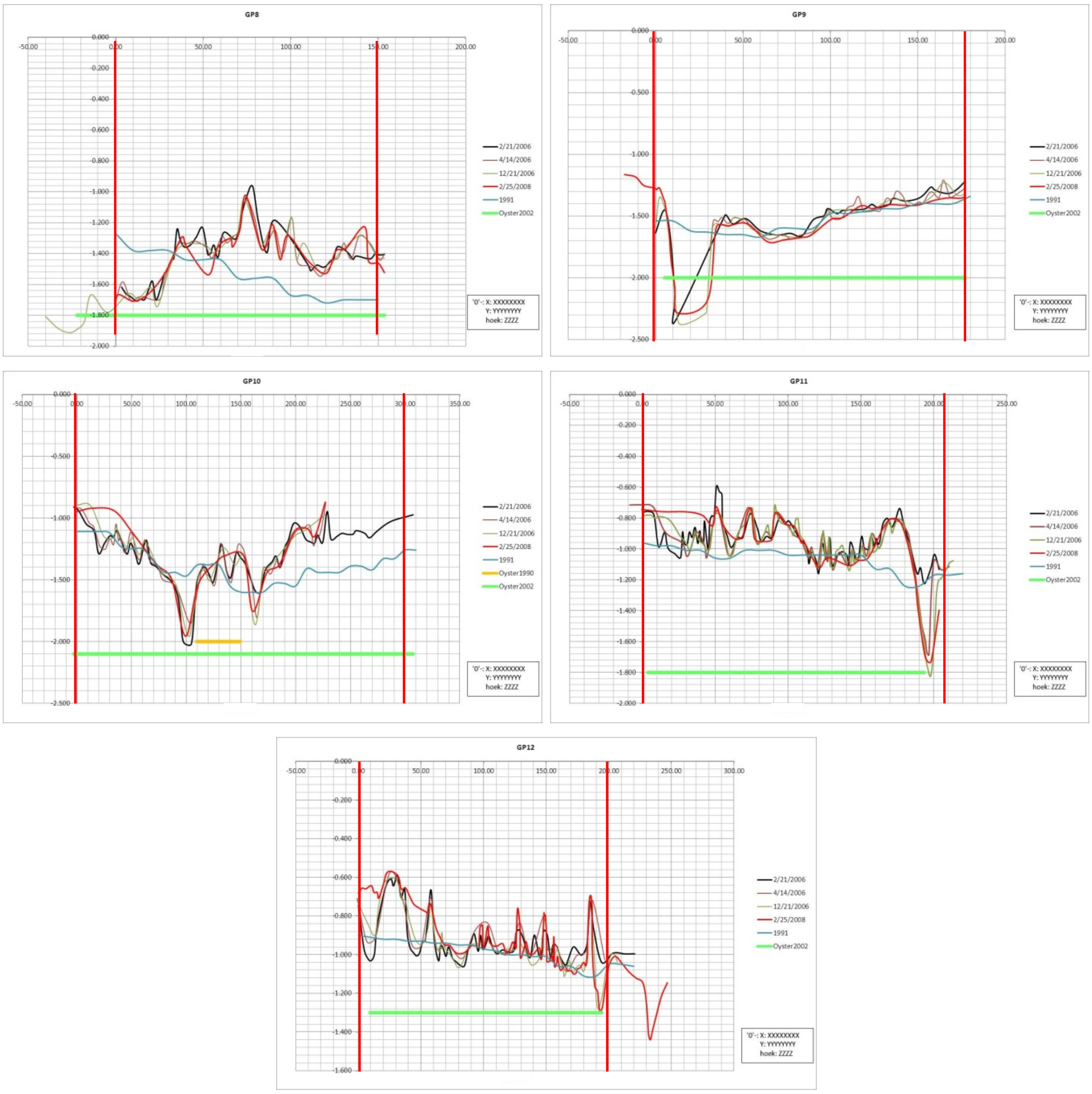

Figure 6 Height Profiles of some of the small transects on the Galgeplaat (y axes: [m NAP]; x axes [m])

For the Galgeplaat several cross-sections are available.. The five transects in figure 6 are clearly short(150 – 300m long) and are situated almost entirely over oyster reefs.

Along these profiles it is clear that a sedimentation process is occurring in almost the entire profile (Figure 6). When comparing the height profiles of recent years to the height profile of 1991 it is clear that accretion of sediment occurs along these transects and especially on the areas occupied by the oyster reefs. Although on Transect GP10 a channel is forming in the middle of the reef, the remaining transects show that usually the channel are forming at the edges of the reefs.

Besides the five short transects, also longer transects were measured on the Galgeplaat on a more regular interval. The height profile of the remaining transects on the Galgeplaat are more difficult to analyze (Figure 7).

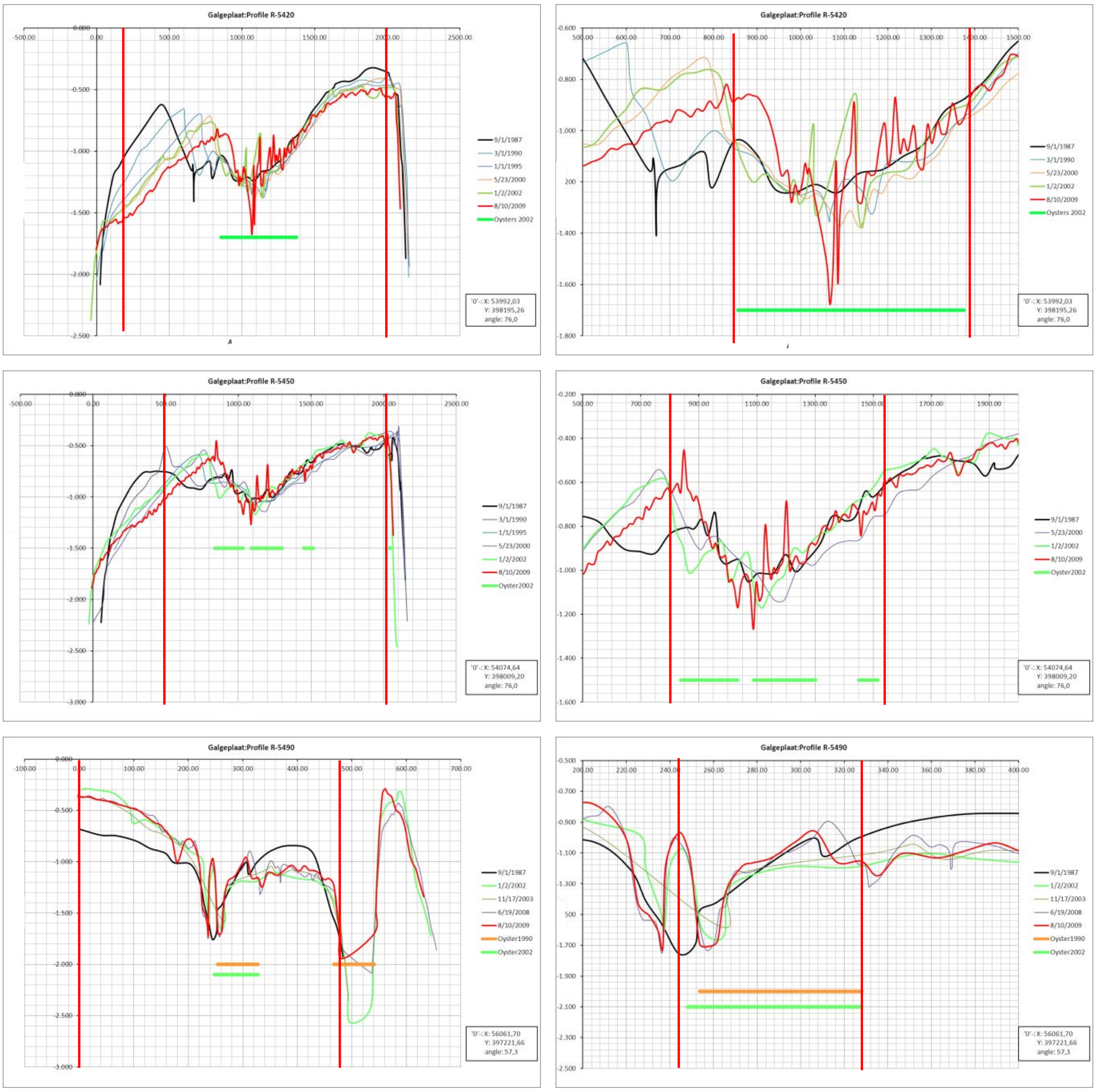

Figure 7 Remaining height profiles of the Galgeplaat. The right graphs are a detailed display of the reef area from the left graphs. (y axes: [m NAP]; x axes [m]).

From Figure 7 it is not clear which main process occurs along these transects. However, it is clear that after the appearance of a reef the main process within this reef is sedimentation. Before the reef appearance the main process was erosion (comparison between 1998 and 2002) but after 2002 the sedimentation is the main process occurring on the reef area and there is a clear recovery or even increasing of the heights when comparing the year 2009 with

2002 or even 1987. When analyzing the reef location within the transect it is possible to see that they are located always near, or in a channel.

Viane

At profile R-5750 and R-5755 (Figure 15) the overall ratio between erosion and sedimentation is negative. However, when analyzing the present reefs in more detail it is possible to observe sedimentation on the reef area and even around the reef.

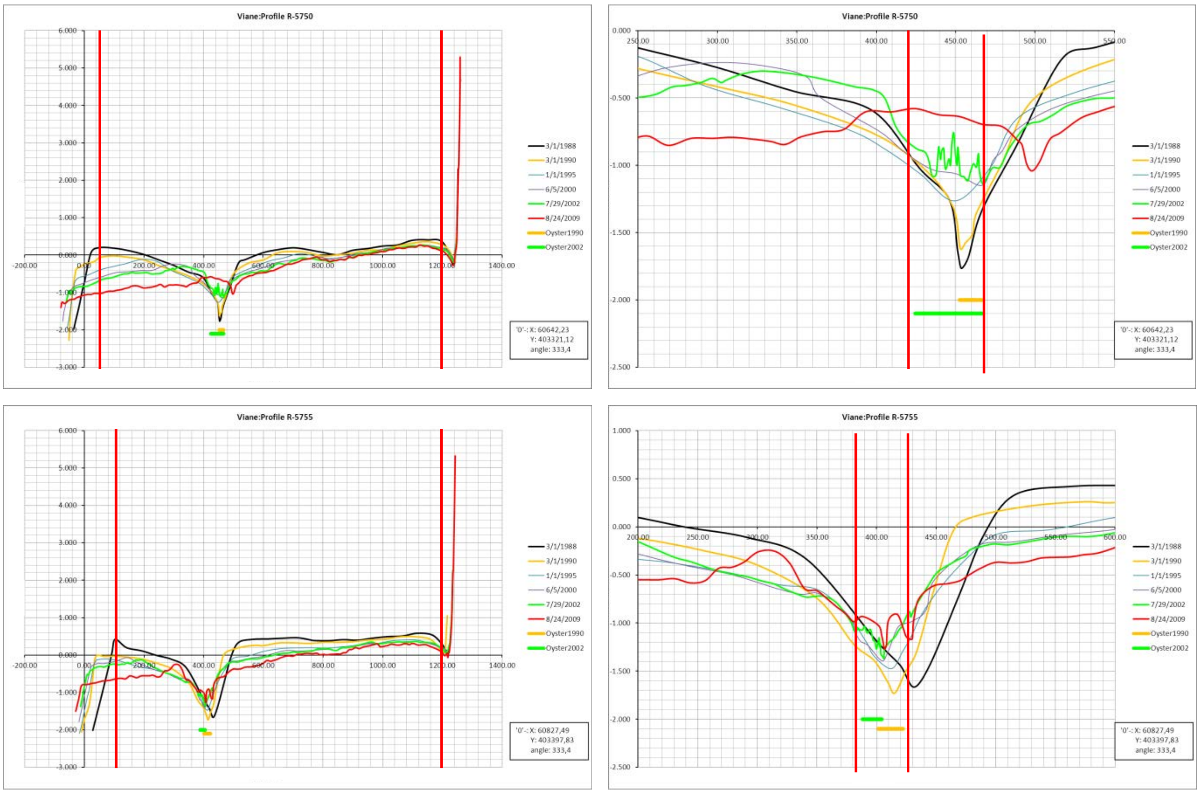

Figure 8 Height profiles of the transects R-5750 and R-5755 on Viane. The graphs on the right are a detailed display of the reef area from the left graphs. (y axes: [m NAP]; x axes [m]).

The transects in Figure 8 are characterized by crossing at least two oyster reefs. The analysis of these transects is also interesting because in these profiles it is possible to assess the existence of more than one reef and the possible interactions and effects in the surroundings of areas with more than one reef.

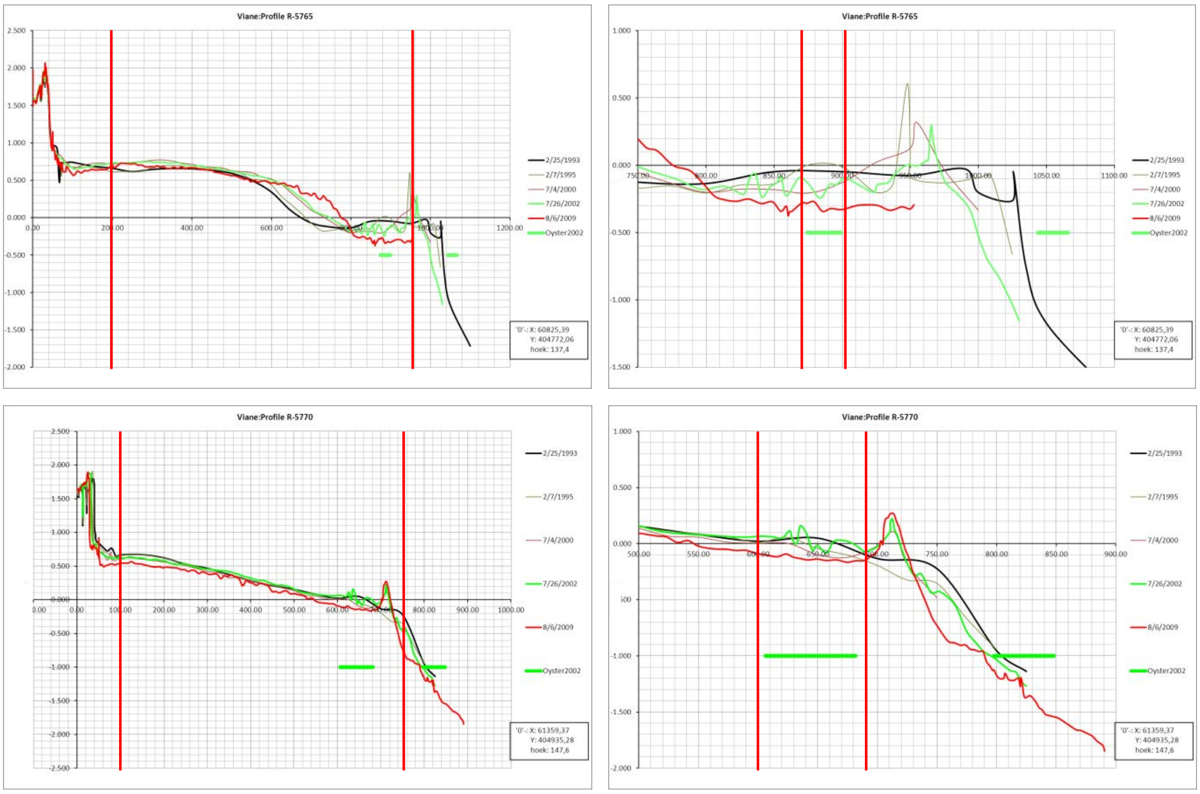

Figure 9 Height profiles of the transects R-5765 and R-5770 on Viane. The right graphs are a detailed display of the reef area from the left graphs. (y axes: [m NAP]; x axes [m]).

For the previous four transects of Figure 9 it is not clear which main process occurs along the transects. However it is more or less clear that on the reef area after 2002 erosion occurs and that the profile of 2009 is, in most of the cases, lower than 2002. It is also possible to observe sedimentation in some specific areas along the transects. On profile R-5765, in the higher located reef, sedimentation is occurring in front of the reef and also behind it and only behind it if considering the profile of 2009. On profile R-5770 sedimentation is occurring in front of the higher located reef. For the same profile when comparing the data from 2002 with the data from 2009 it is possible to see, in front of the reef, an increase in the heights and therefore an increase in the sedimentation.

From the observation of the transects located in Viane is possible to conclude that the oyster reefs are usually located in gullies or close to them. This fact proves that the location of the artificial reefs near the channels , in order to prevent erosion from the tidal flats to the bottom of the channel, is a suitable habitat for the oysters.

Neeltje Jans

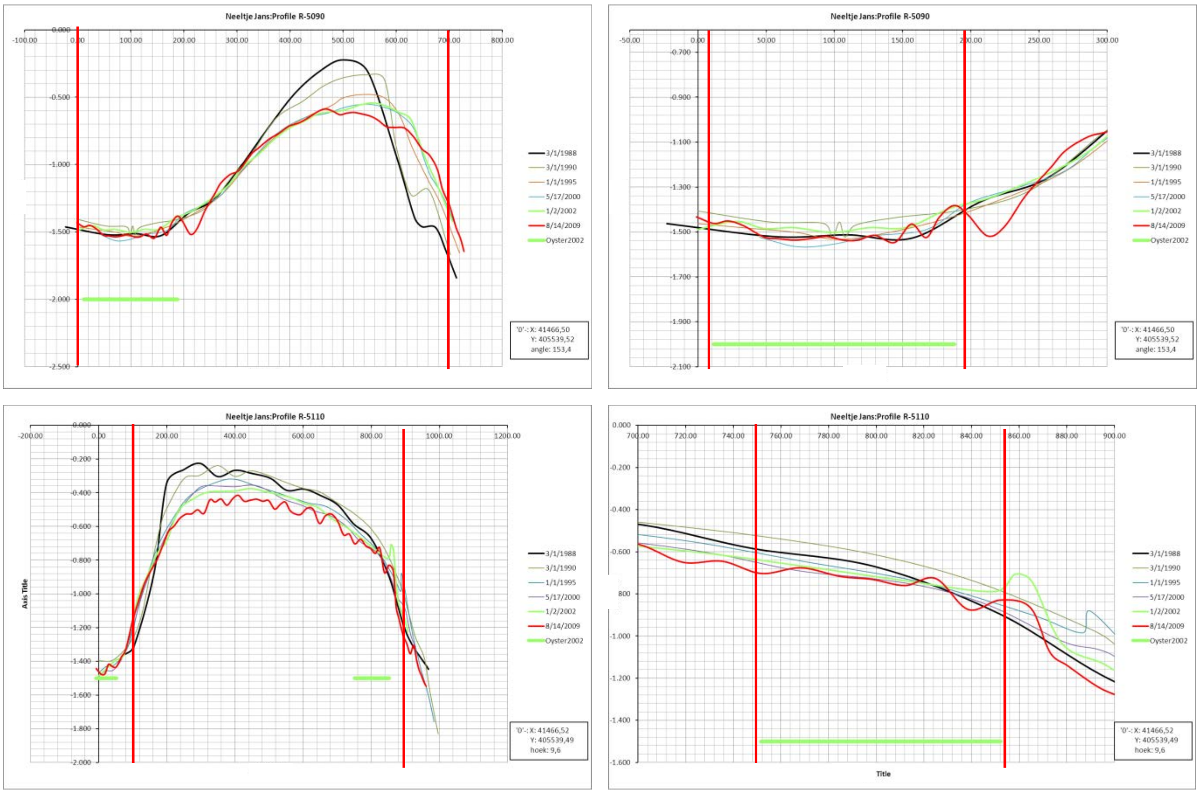

Figure 10 Height profiles of the transects R-5090 and R-5110 on Neeltje Jans. The graphs on the right are a detailed display of the reef area from the left graphs (y axes: [m NAP]; x axes [m])

Figure 10 represents two profiles located at Neeltje Jans tidal flat. During the reef formation, between 2000 and 2002 sedimentation is occurring in these transects. However, when the same comparison is made between 2002 and 2009 it is possible to see that there was erosion even in the oyster reef area. In addition near the area of the reef there is a strong erosion process of the higher places. The previous fact can also be the reason for the primary sedimentation process over the reef.

The other transect on the Neeltje jans (Figure 11) are characterized by erosion process. Comparing 1988 with 2002 and after 2002 with 2009 it is possible to see that the general trend is erosion of the tidal flat along with this transect. However the data suggest that between the year 2000 and the year 2002 the erosion rates were lower especially in the reef area. That means that during the reef formation the erosion process were at least reduced or even changed to sedimentation in some areas within the reef.

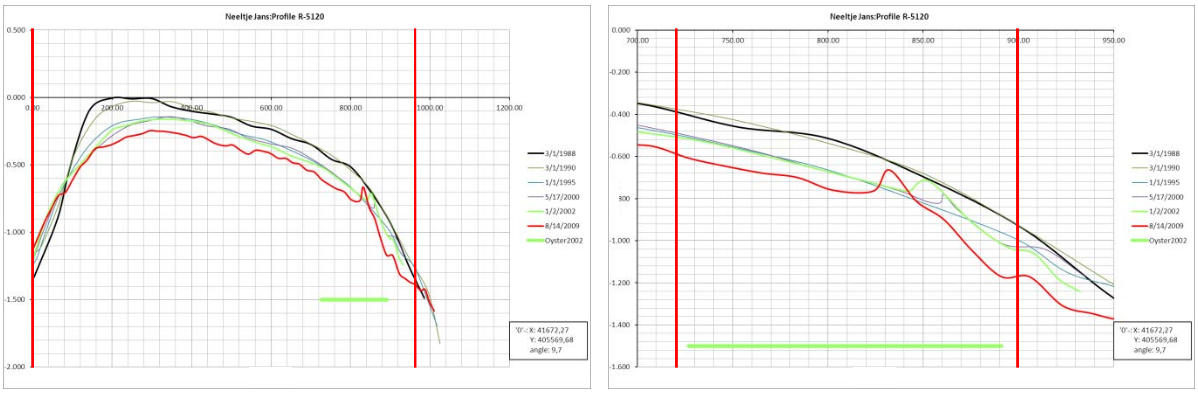

Figure 11 Height profile of the transect R-5120 on Neeltje Jans. The right graph is a detailed display of the reef area from the left graph. (y axes: [m NAP]; x axes [m])

Dortsman

In this transect (Figure 12) - although the reefs are quite small - it is observed sedimentation not only over the reefs but also around it.

When comparing the height values between 1993 and 2009, sedimentation rates of more than 30 cm were observed in some place.

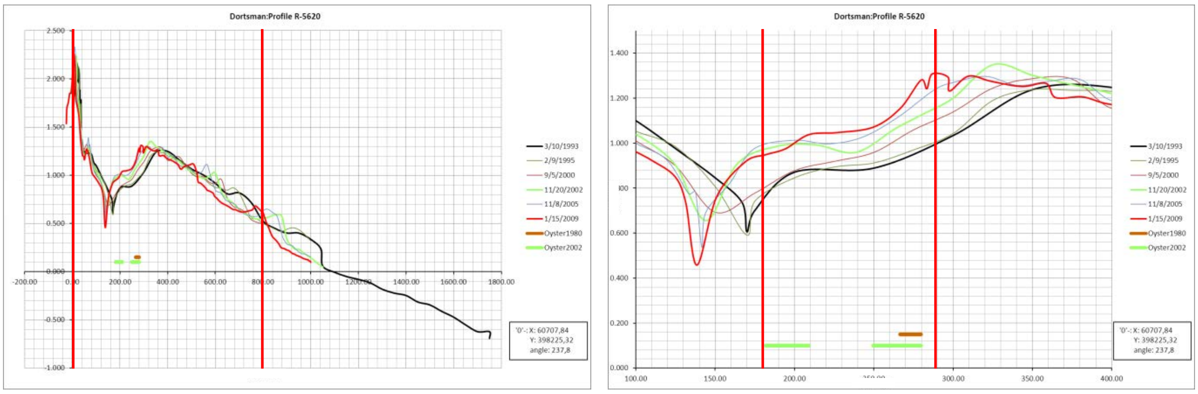

Figure 12 Height profile of the transect R-5620 on Dortsman. The graph on the right is a detailed display of the reef area from the left graph. (y axes: [m NAP]; x axes [m])

Table 2 represents the erosion/sedimentation rates for the profiles that cross oyster reefs.

Table 2 Erosion/sedimentation rates for the transects that cross oyster reefs

Profile Name	Location	Observations	Linear regression f(x) [m]	R^2	Erosion(-) /sedimentation (+) rate [mm/year]
R-5090	Neeltje Jans	Entire profile	y = -0,0006x + 0,2128	0,0251	-0,6
		Oyster reef (10 - 190 m)	y = -0,006x + 10,46	0,6821	-6,0
R-5110	Neeltje Jans	Entire profile (0-900m)	y = -0,0048x + 8,7892	0,3535	-4,8
		Oyster reef (0-50/ 750-850 m)	y = -0,0117x + 22,46	0,9885	-11,7
R-5120	Neeltje Jans	Entire profile (80 - 940 m)	y = -0,0109x + 21,355	0,6984	-10,9
		Oyster reef (720 - 900 m)	y = -0,0075x + 14,358	0,8848	-7,5
R-5420	Galgeplaat	150 - 2100 m	y = -0,0028x + 4,5775	0,2832	-2,8
		Oyster reef (855 - 1375 m)	y = 0,0061x - 13,36	0,2635	6,1
R-5450	Galgeplaat	200 - 2000 m	y = -0,0042x + 7,6514	0,5332	-4,2
		Oyster reef (840 - 1033/ 1090 - 1300 m)	y = 0,0038x - 8,5818	0,1215	3,8
R-5490	Galgeplaat	0- 480 m	y = 0,0078x - 16,681	0,7795	-7,8
		Oyster reef	y = 0,0136x - 28,61	0,7965	13,6
R-5510	Galgeplaat	Entire profile 150 - 550 m	y = -0,0037x + 6,3346	0,3092	-3,7
		Oyster reef (220- 260 / 325 - 460 m)	y = 0,01x - 20,92	0,8211	10,0
GP8	Galgeplaat	Entire profile	y = 0,0068x + 15,092	0,9736	6,8
GP9	Galgeplaat	Entire profile	y = 0,0007x + 2,8767	0,1515	0,7
GP10	Galgeplaat	Entire profile	y = 0,0059x + 13,174	0,9956	5,9
GP11	Galgeplaat	Entire profile	y = 0,0063x + 13,636	0,8303	6,3
GP12	Galgeplaat	Entire profile	y = 0,0043x + 9,569	0,9999	4,3
R-5620	Dortsman	Entire profile	y = -0,0321x + 65,569	0,8257	-32,1
		Oyster reef	y = 0,0082x - 15,48	0,6188	8,2
R-5750	Viane	Entire profile	y = -0,0104x + 20,517	0,6614	-10,4
		Oyster reef	y = 0,0509x - 102,77	0,9741	50,9
R-5755	Viane	Entire profile	y = -0,0049x + 9,6484	0,2342	-4,9
		Oyster reef	y = 0,016x - 33,209	0,9432	16,0
R-5765	Viane	Entire profile	y = -0,0218x + 44,285	0,5169	-21,8
		Oyster reef	y = -0,0248x + 49,572	0,8714	-24,8
R-5770	Viane	Entire profile	y = -0,0479x + 96,42	0,9236	-47,9
		Oyster reef	y = -0,0247x + 49,495	0,9334	-24,7

On the same way of the erosion/sedimentation rate for the transects without oyster reefs the erosion/sedimentation rate is determined taking in account the intervals that are shown in the previous figures and appendix 1.

From Table 2 is possible to say that for erosion/sedimentation rates lower than 1 mm the results are not accurate enough as it is possible to see from a simple observation of the R^2. For these cases it is considered that the transects are stabilized.

For the transects that cross oyster reefs there are several different situations. In some cases in the transect the main process occurring is sedimentation (GP8, GP9, GP10, GP11, GP12). However in some other transects the analysis is not so simple as the main process can be, for example, erosion but when analyzing only the area of the reef the main process in that area can be erosion, sedimentation or simply a reduction of the erosion rate.

On the profiles R-5770, R-5120 the main process occurring on the transect is erosion, however on the area of the reef the erosion is lower than other areas.
On the profiles R-5750, R-5755, R-5420, R-5450, R-5490, R-5510 and R-5620 the main process occurring in the transect is erosion, but in the reef area sedimentation is the main process.
In the remaining transects the main process occurring is usually erosion and when looking for the reef area the main process occurring is also erosion. Due to the fact of the coefficient of determination in these transects is not close to one no conclusion should be taken based only on this analysis.
These previous analyses suggest that, in fact, the oyster reefs can influence the sedimentation and erosion patterns. While in some transects it is quite clear that the existence of oyster reefs promote stabilization or sedimentation processes in the reefs and also around them in other transects that relation is not that clear. For example, in some years sedimentation occurs in other years erosion occurs. However it is quite clear that the tidal flats with no oyster reefs are more exposed to erosion processes than the ones with an oyster reef.
From this analysis it is possible to state that the effects on the sedimentation patterns are not only related with the presence of the oyster reefs. The local hydrodynamics of the system also have great influence on the patterns, along with punctual events like storms that are able to re-suspend the sediment and transport it to other areas, otherwise the results would be more stable and constant.
Another observation that can be done is that oysters will settle more in the lower part of the intertidal areas, because all the oyster reefs are located also in these areas.
During the analysis of the height profiles it was noticed that the oyster reefs are usually located close to channels . The channels can be prior to the oyster reefs, Profile R-5420, or can be formed under the influence of the reefs, for which GP11 transect is an example. This relation is quite interesting because the future location of the artificial reef will be in the edge of the tidal flats, near the channels . This means that the place is not only good from the coastal defense point of view but also from a biological point of view as the oysters prefer and or create exactly this kind of locations and conditions.

4 CONCLUSIONS

From the analysis of the different cross sectional transects it is concluded that if nothing is done in order to protect the tidal flats, in a short period of time, these tidal flats will erode. The erosion of the tidal flats will cause a loss of valuable intertidal habitat, especially for many estuarine bird species that use these areas as foraging grounds. Due to erosion of the tidal flats the dikes will also become more exposed to wave action and therefore more exposed to ruptures and flooding during storm surges.

The long term trends showed that along transects with no oyster reefs present, erosion is the major process occurring on the tidal flat opposing to the sedimentation process occurring in the channels . Although sometimes it is possible to see sedimentation in some areas of the tidal flat, this fact can be explained by the shift of sediment from the erosion areas to the deposition areas, like the channels , and cannot be seen as a sedimentation process at least to the intended aim.

The analysis of the height profiles shows also that transects that cross oyster reefs usually show sedimentation or at least a decrease in the erosion rates on the reef area and also in some cases on its surroundings.

From the profiles it is also concluded that oysters preferentially settle low in the intertidal area. This fact is very interesting and important when constructing artificial reefs in the Oosterschelde. It demonstrates that artificial reefs should be constructed preferentially low in the intertidal, as here the chance of developing a living oyster reef will be the best. The fact of the oysters settle in the lower intertidal areas also make the use of these ecosystem engineers a suitable method due to the fact that the artificial reef will also be located in these areas in order to prevent the sediment from moving to the channels .

Finally as a conclusion it is possible to say that the results are encouraging for the point of view of using these ecosystem engineers as a short term solution to prevent the fast erosion of the tidal flats in the Oosterschelde.

5 RECOMMENDATIONS

5.1 RECOMMENDATIONS

During the transect analysis some difficulties were experienced due to the lack of data related to the presence of the oysters in the tidal flats. The exact time the reefs were formed is not well documented and the available oyster habitat maps span a too long period. Aerial photography from different years could be used to complement the available data and especially to identify the year(s) the oyster reefs were formed.

A detailed analysis of the same set of data is suggested but applying a different methodology. Instead of analyzing the whole transect, this should be divided in smaller sections comparable to the sections of the oyster reefs and then a comparison with a proper statistical analysis should be applied in order to evaluate if there is significant difference between the transects over oyster reefs and the transects on bare sediment.

6 REFERENCES

Drinkwaard AC (1999) Introductions and developments of oysters in the North Sea area: a review. Helgoländer Meeresuntersuchungen 52: 301-308

Jones CG, Lawton JH, Shachak M (1994) Organisms as ecosystem engineers. Oikos 69: 373-386

Mulder, J.P.M. & Louters, T. 1994. Changes in basin geomorphology after implementation of the Oosterschelde estuary project The Oosterschelde Estuary. Hydrobiologia. 282. 29-39.

Nienhuis PH, Smaal AC (1994) The Oosterschelde Estuary (The Netherlands): a case-study of a changing ecosystem. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp 597

Richard N. 2009. Pilot ecosystem engineers: Creation of shellfish beds using environmentally friendly techniques. Unpublished

Sibson, R., "A Brief Description of Natural Neighbor Interpolation," Chapter 2 in Interpolating multivariate data, John Wiley & Sons, New York, 1981, pp. 21-36.

SMAAL ,A.C., NIENHUIS ,P.H. 1992. The Eastern Scheldt (The Netherlands), from an estuary to a tidal bay, a review of responses at the ecosystem level. Communication nº611 of the NIE - Center for Estuarine and Coastal Ecology, Yerseke, the Netherlands

Smaal, A.C., Kater, B.J., and Wijsman, K. 2009. Introduction, establishment and expansion of the Pacific oyster Crassostrea gigas in the Oosterschelde (SW Netherlands). Helgol. Mar. Res. 63:75–83

Thorsten, B. 2009. Biogeomorphology of Spartina anglica tussocks - GIS based comparison of contrasting sites at the Westerschelde and Blackwater estuary. Hannover and Yerseke, in April 2009

Troost, K. 2009. Pacific oyster in Dutch estuaries. Causes of Success and Consequences for Native Bivalves. PhD thesis, University of Groningen, the Netherlands

Troost, K. 2010. Causes and effects of a highly successful marine invasion: Case-study of the introduced Pacific oyster Crassostrea gigas in continental NW European estuaries. Journal of Sea Research 64 (2010) 145–165

Van Hulsel, M.J. 2010. Constructing artificial shellfish reefs to save the tidal flats in a changed estuary

Van Zanten E, Adriaanse LA (2008) Verminderd getij. Verkenning naar mogelijke maatregelen om het verlies van platen, slikken en schorren in de Oosterschelde te beperken. Rijkswaterstaat Zeeland, Middelburg, The Netherlands.

Watson, D., “Contouring: A Guide to the Analysis and Display of Spatial Data”. Pergamon Press, London, 1992.

7 APPENDIX 1 – HEIGHT PROFILES AND EROSION/SEDIMENTATION RATES

7.1 TRANSECTS WITHOUT OYSTERS

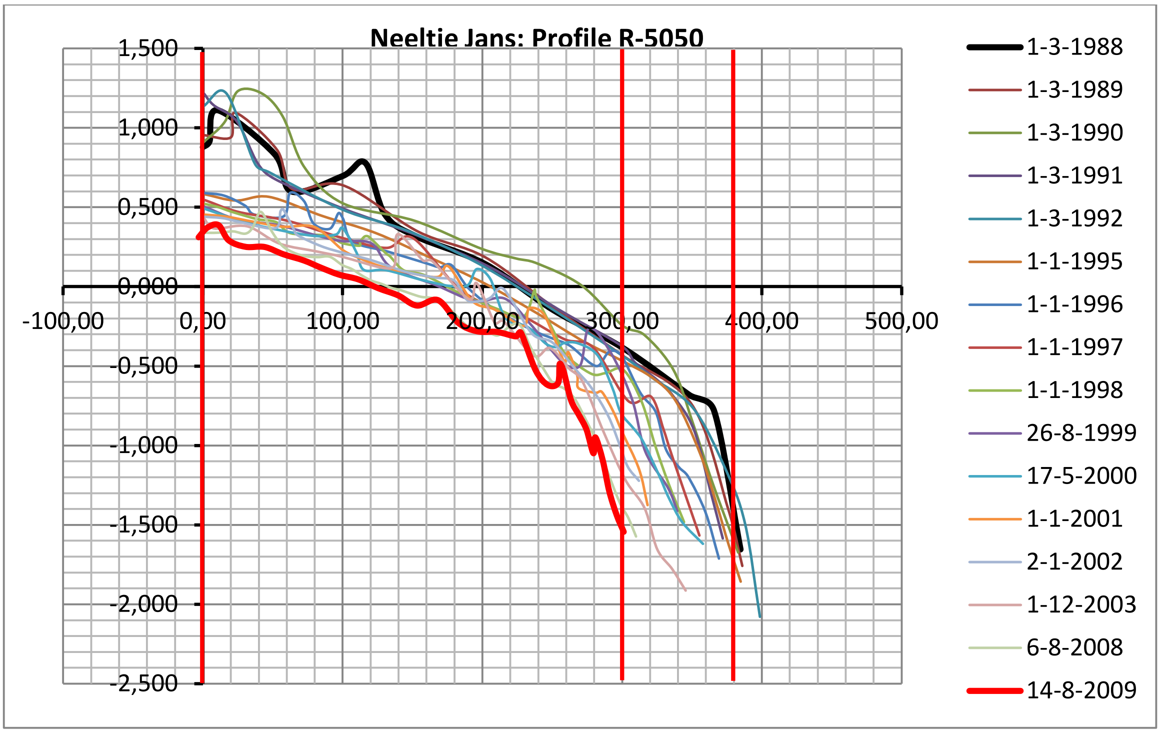

Fig. 1 Height profile of the transect R-5050 (Neeltje Jans)

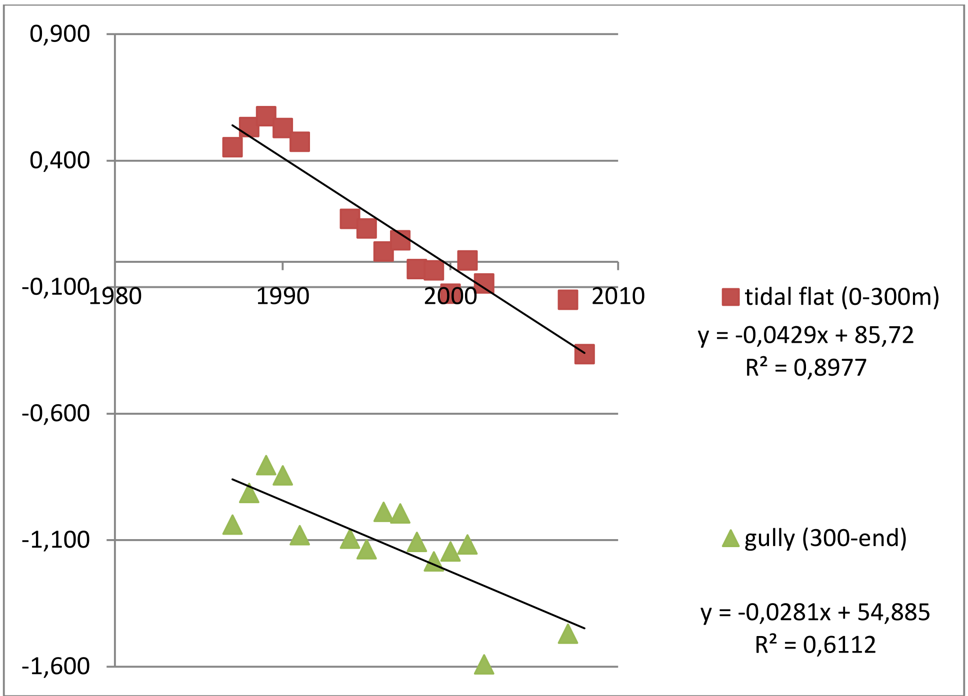

Fig. 2 Sediment height analysis of the transect R-5060 (Neeltje Jans)

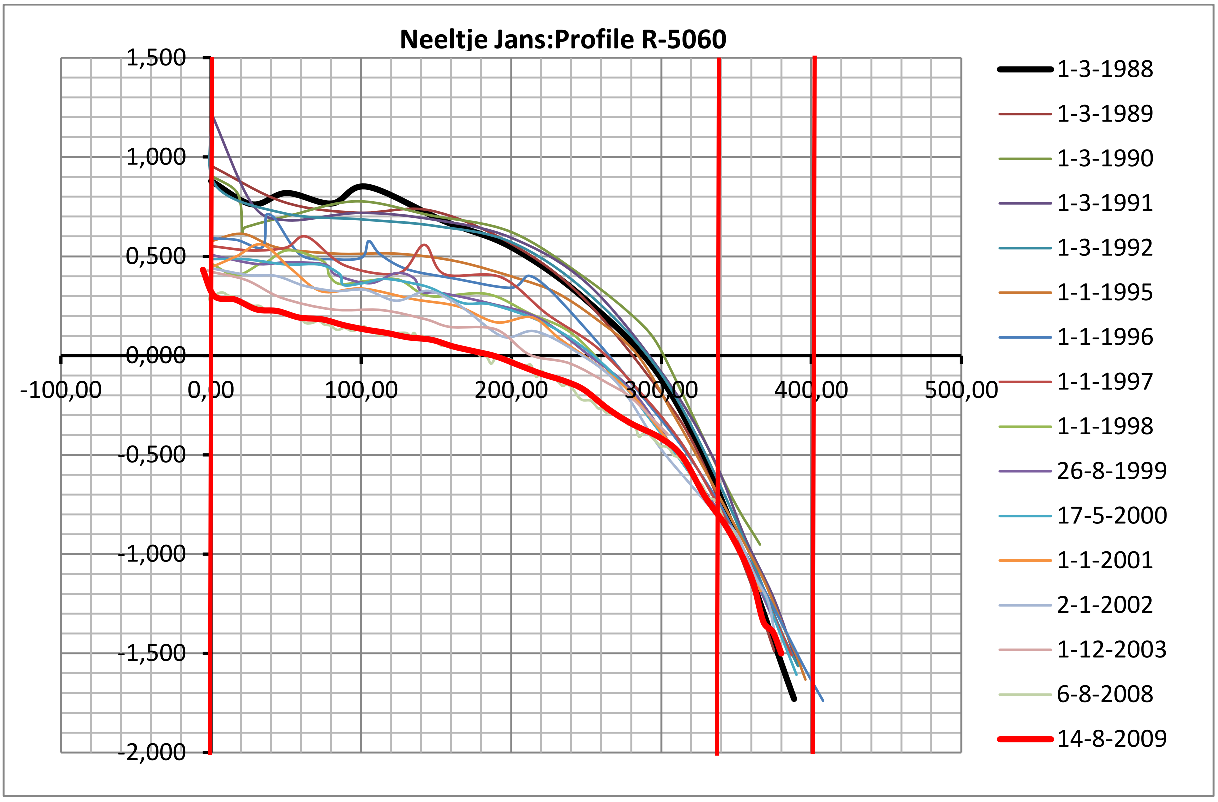

Fig. 3 Height profile of the transect R-5060 (Neeltje Jans)

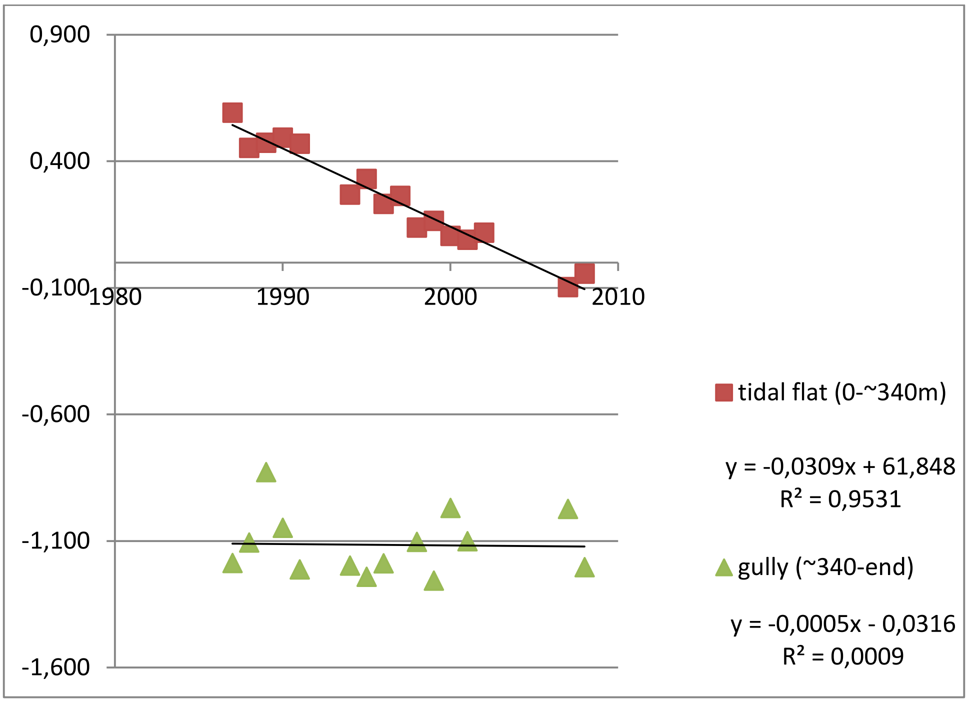

Fig. 4 Sediment height analysis of the transect R-5060 (Neeltje Jans)

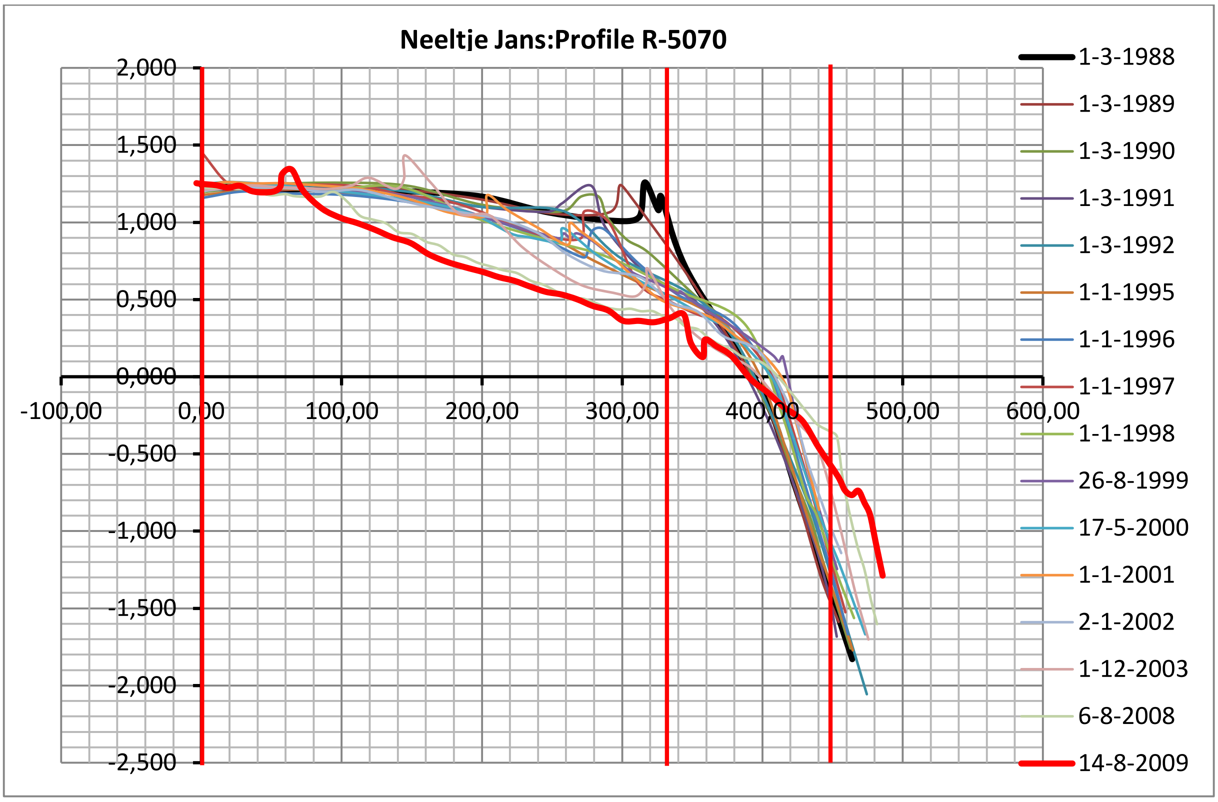

Fig. 5 Height profile of the transect R-5070 (Neeltje Jans)

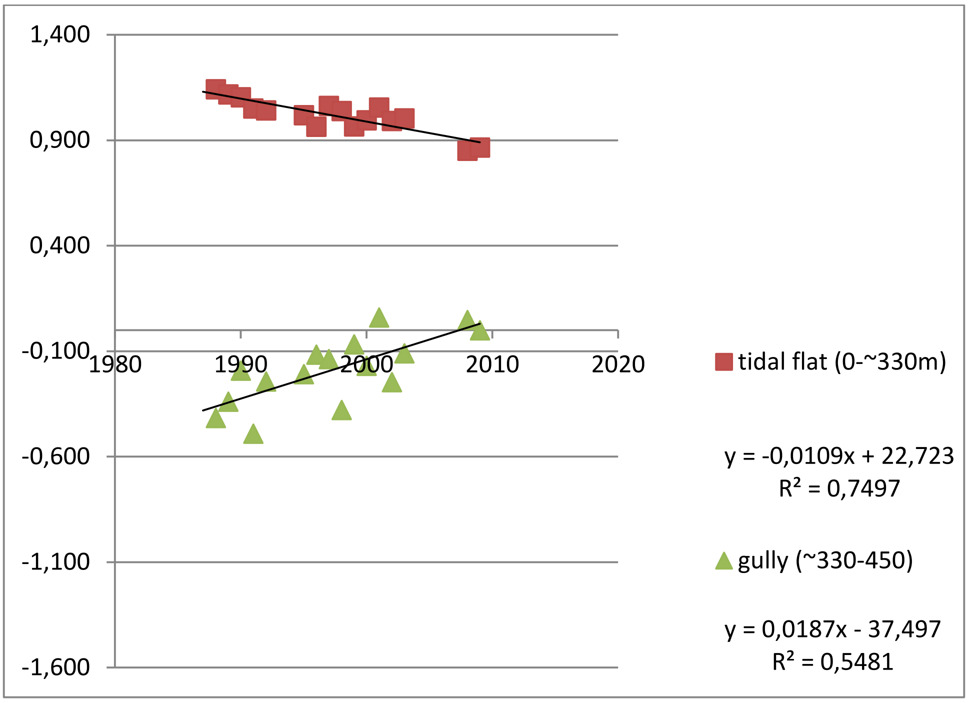

Fig. 6 Sediment height analysis of the transect R-5070 (Neeltje Jans)

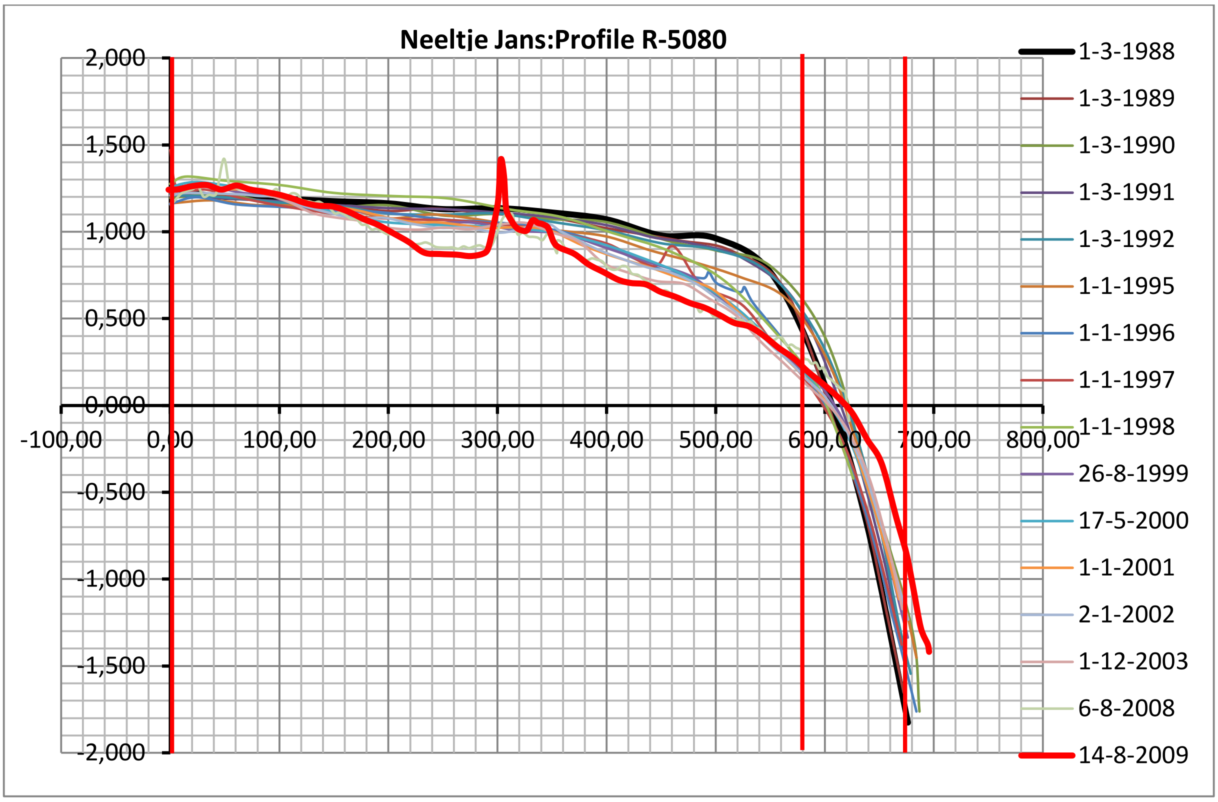

Fig. 7 Height profile of the transect R-5080 (Neeltje Jans)

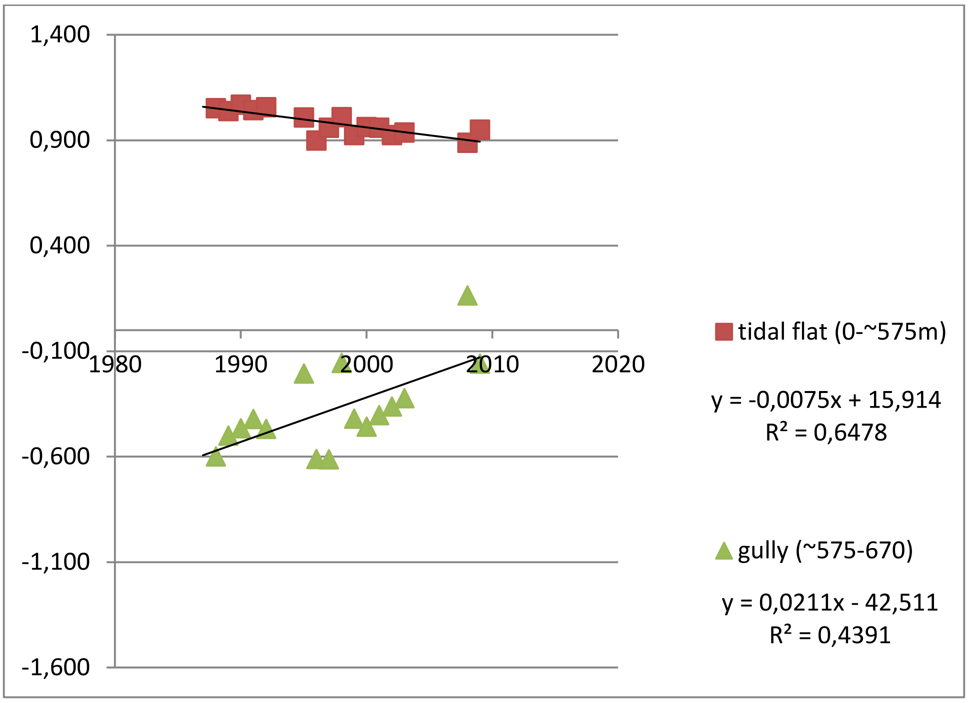

Fig. 8 Sediment height analysis of the transect R-5080 (Neeltje Jans)

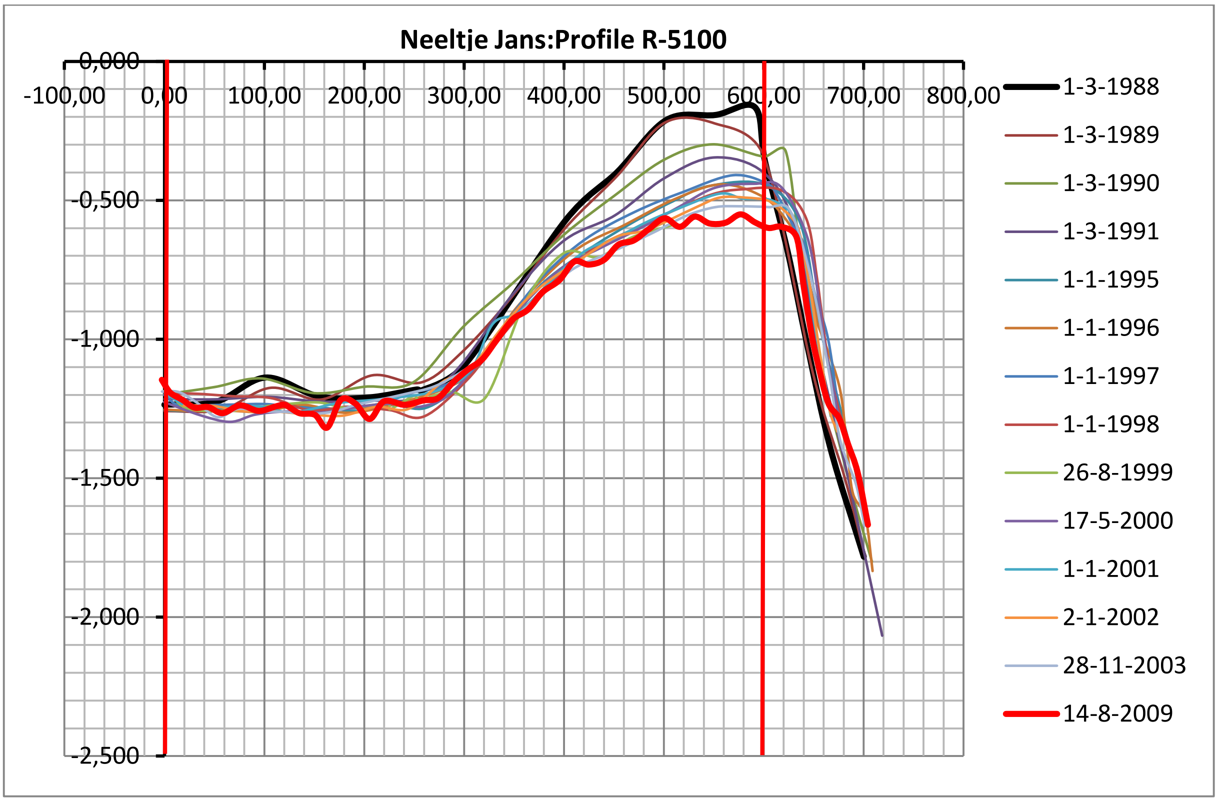

Fig. 9 Height profile of the transect R-5100 (Neeltje Jans)

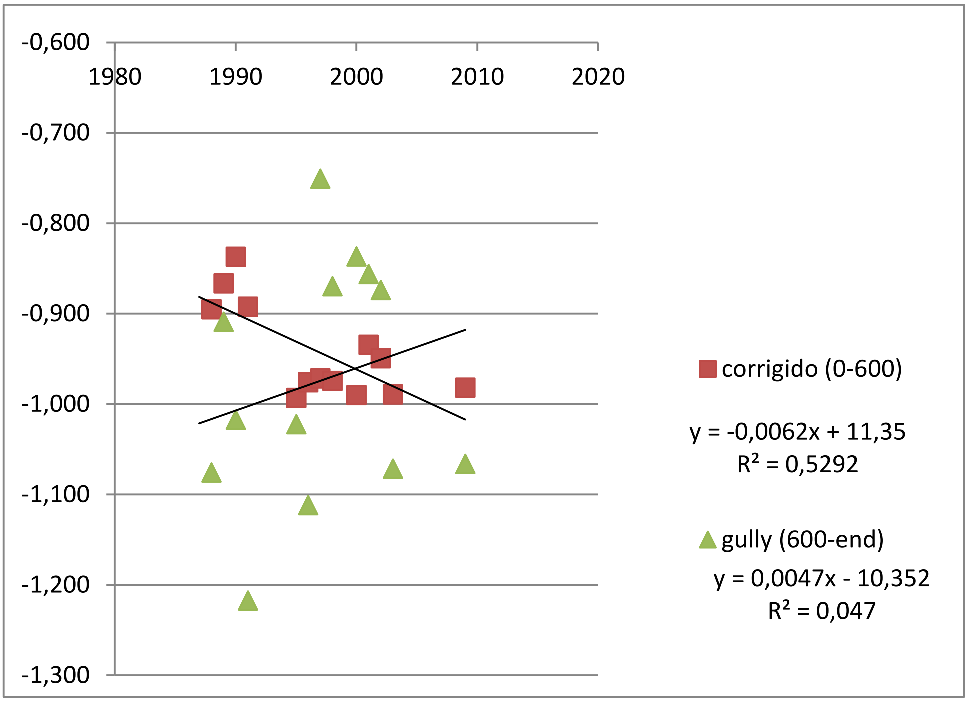

Fig. 10 Sediment height analysis of the transect R-5100 (Neeltje Jans)

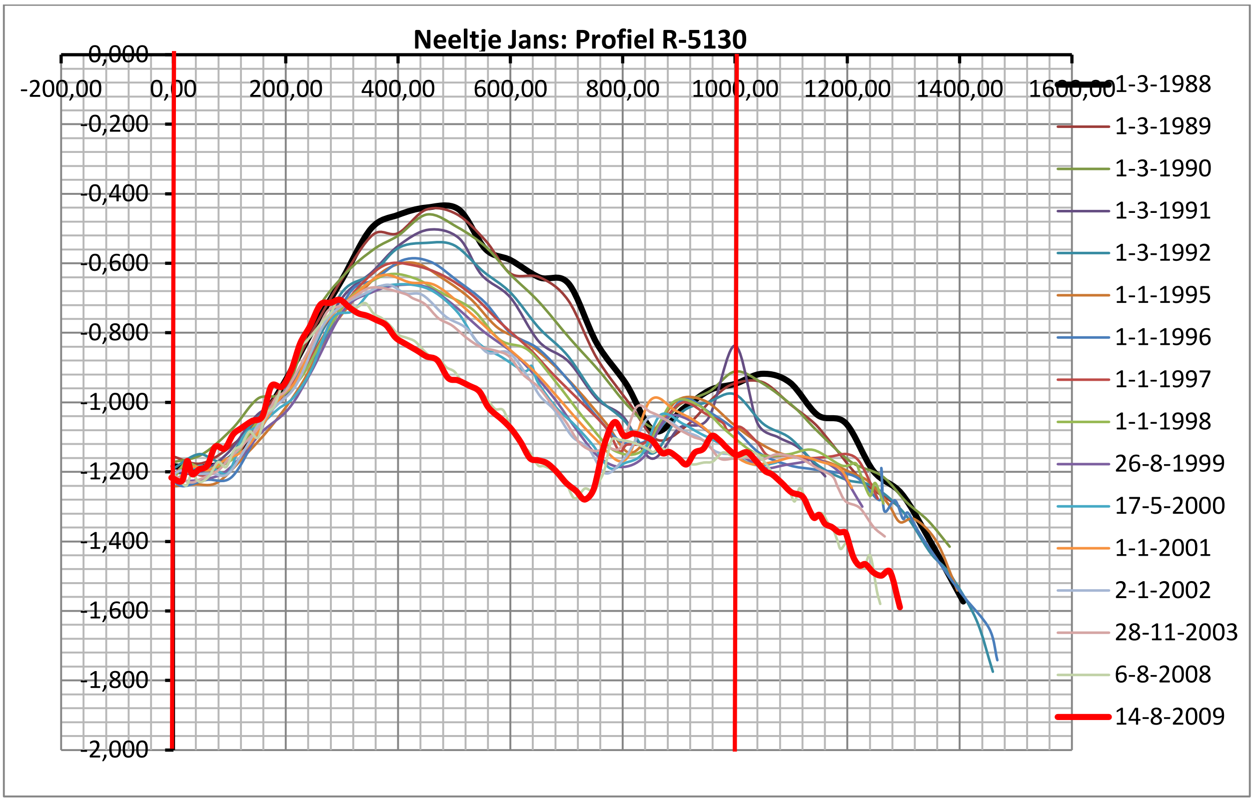

Fig. 11 Height profile of the transect R-5130 (Neeltje Jans)

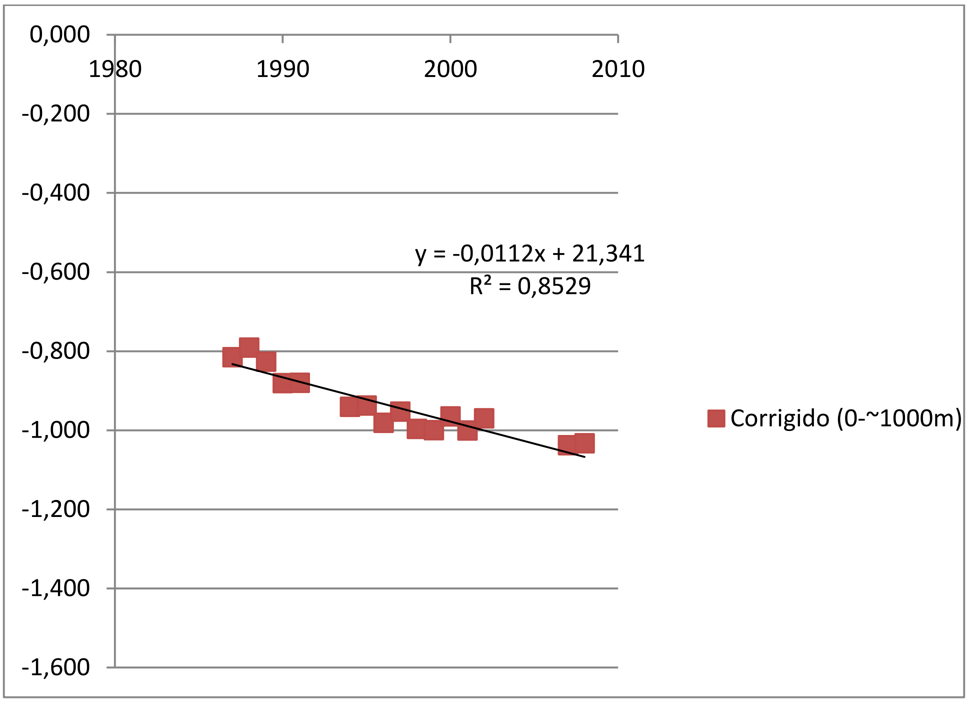

Fig. 12 Sediment height analysis of the transect R-5130 (Neeltje Jans)

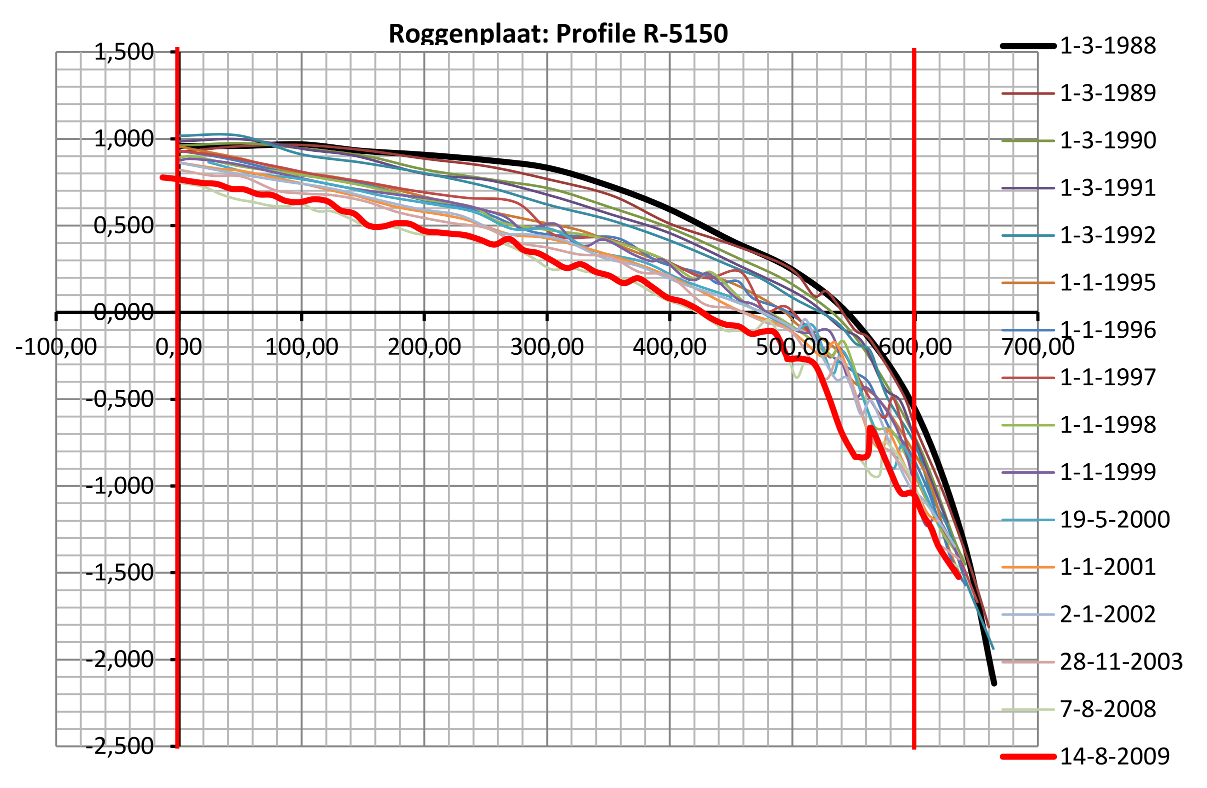

Fig. 13 Height profile of the transect R-5150 (Roggenplaat)

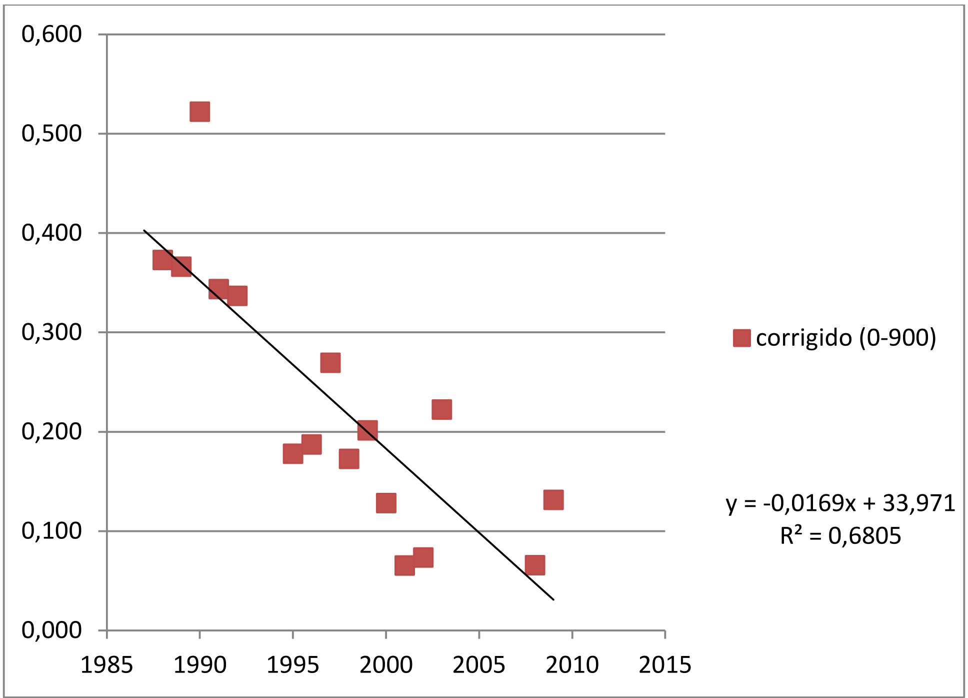

Fig. 14 Sediment height analysis of the transect R-5150 (Roggenplaat)

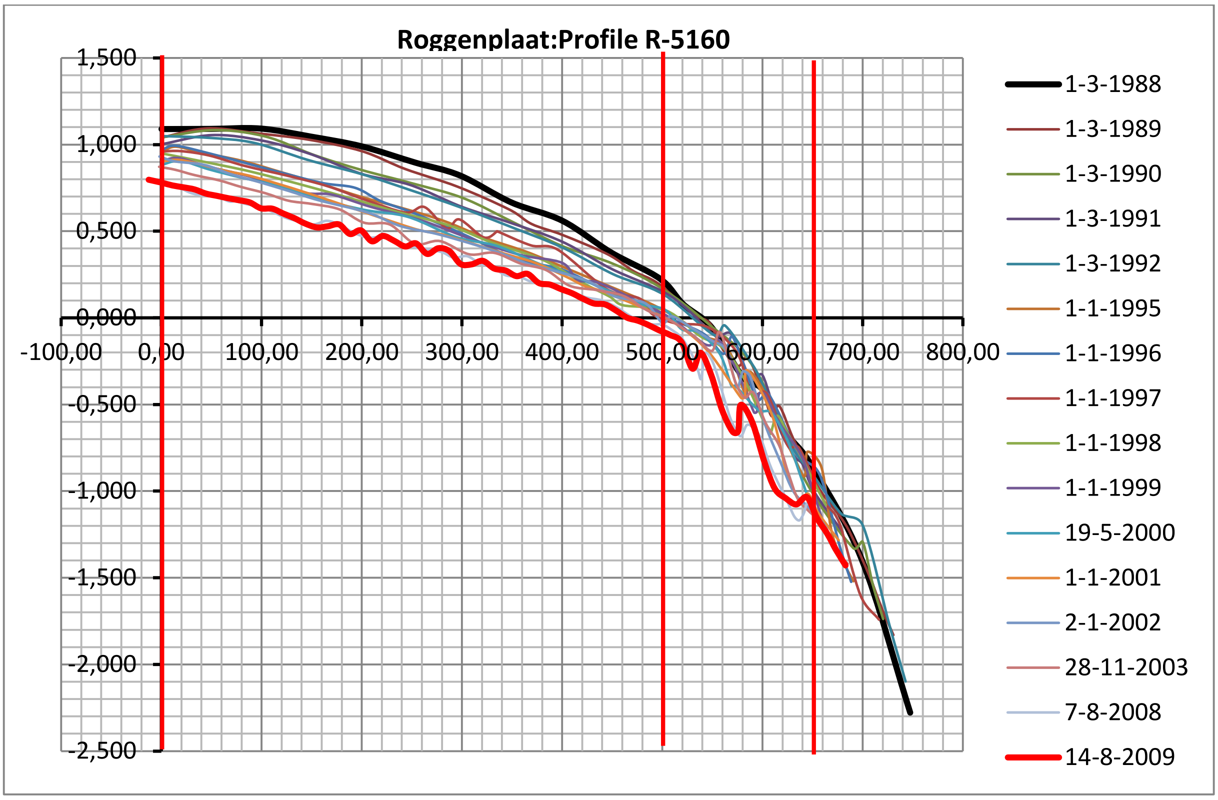

Fig. 15 Height profile of the transect R-5160 (Roggenplaat)

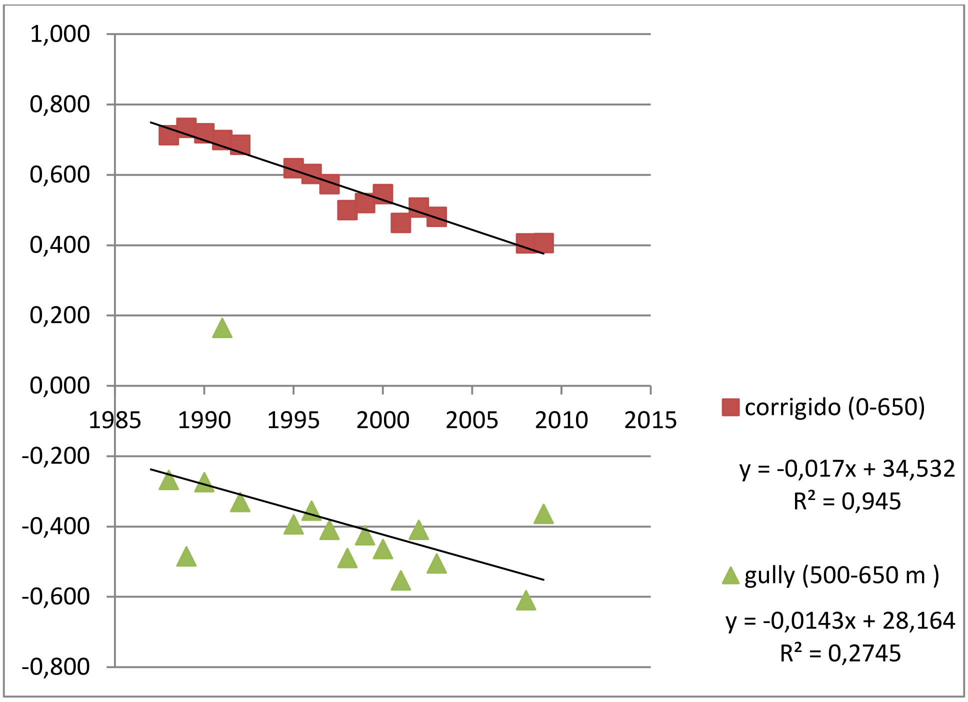

Fig. 16 Sediment height analysis of the transect R-5160 (Roggenplaat)

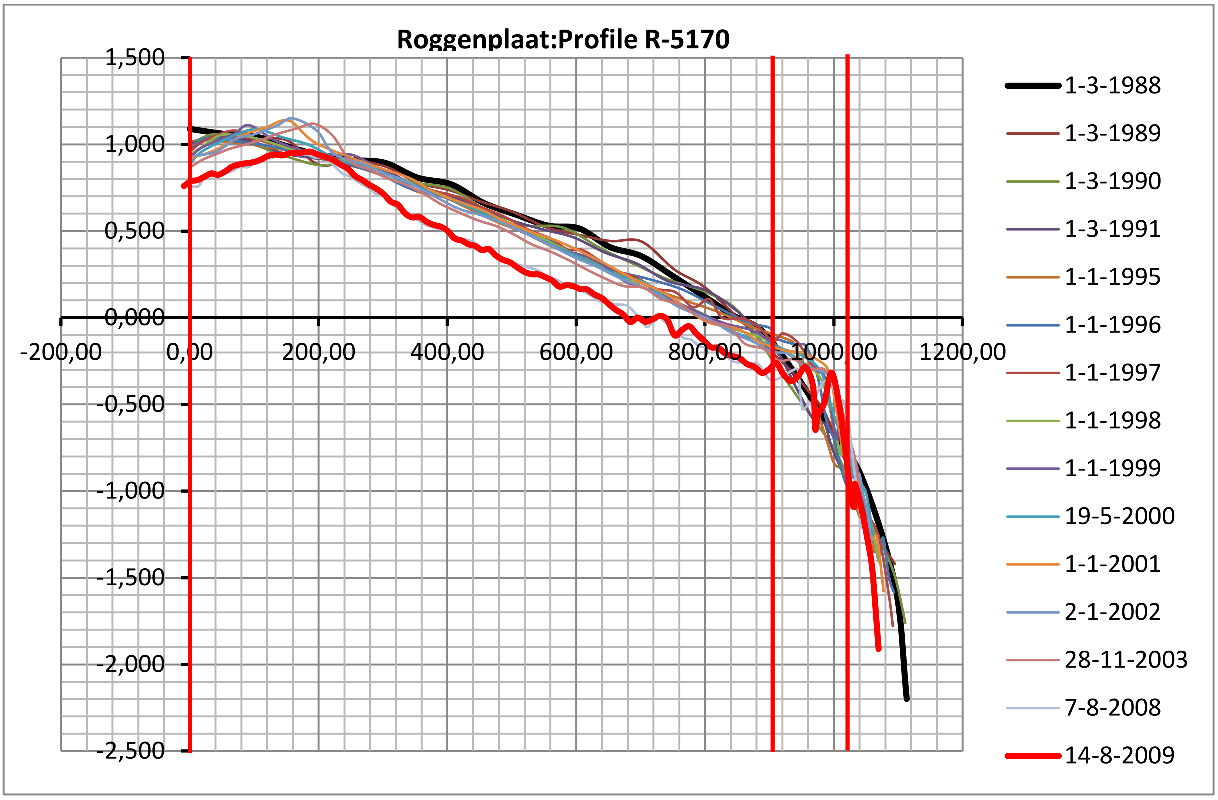

Fig. 17 Height profile of the transect R-5170 (Roggenplaat)

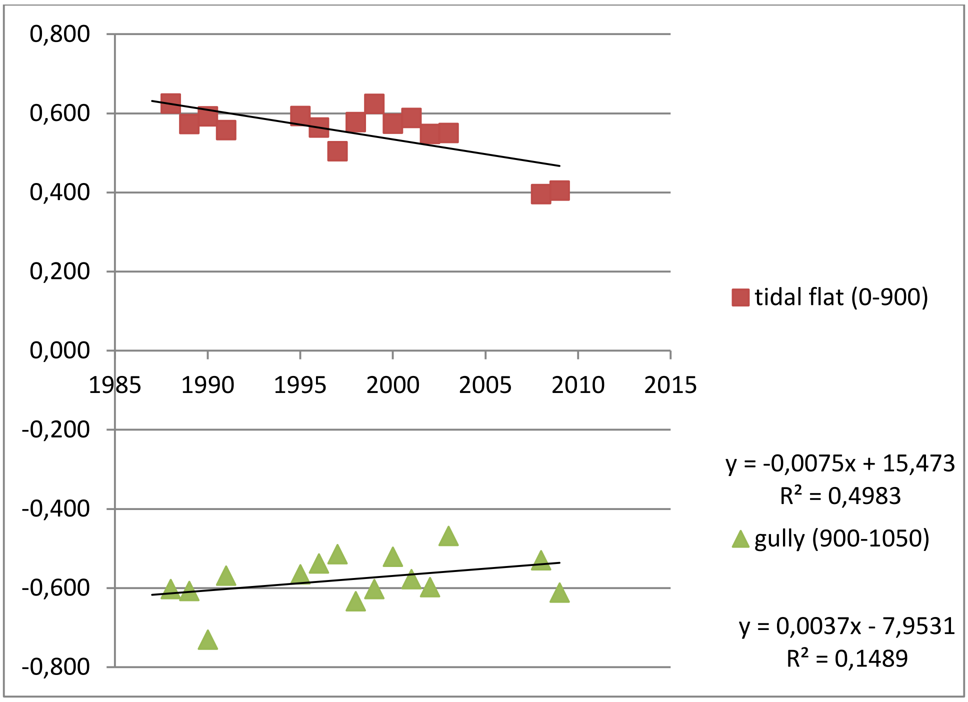

Fig. 18 Sediment height analysis of the transect R-5170 (Roggenplaat)

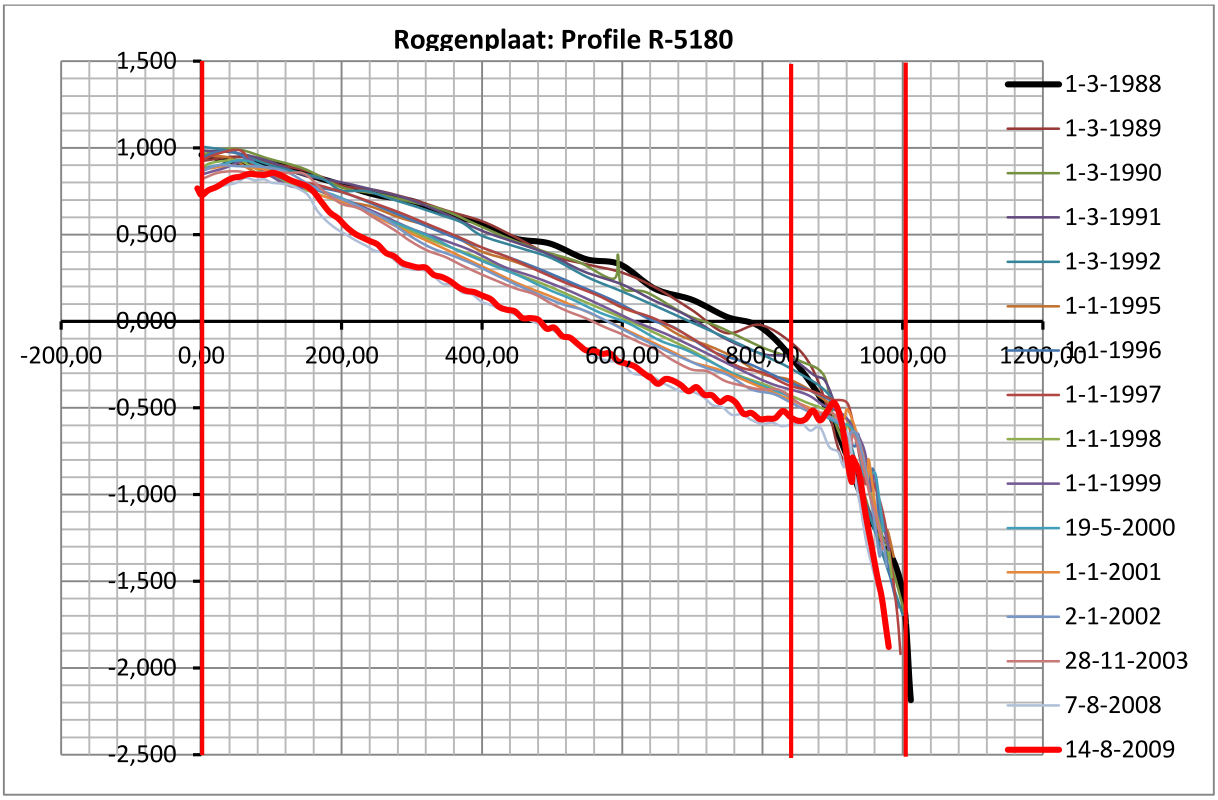

Fig. 19 Height profile of the transect R-5180 (Roggenplaat)

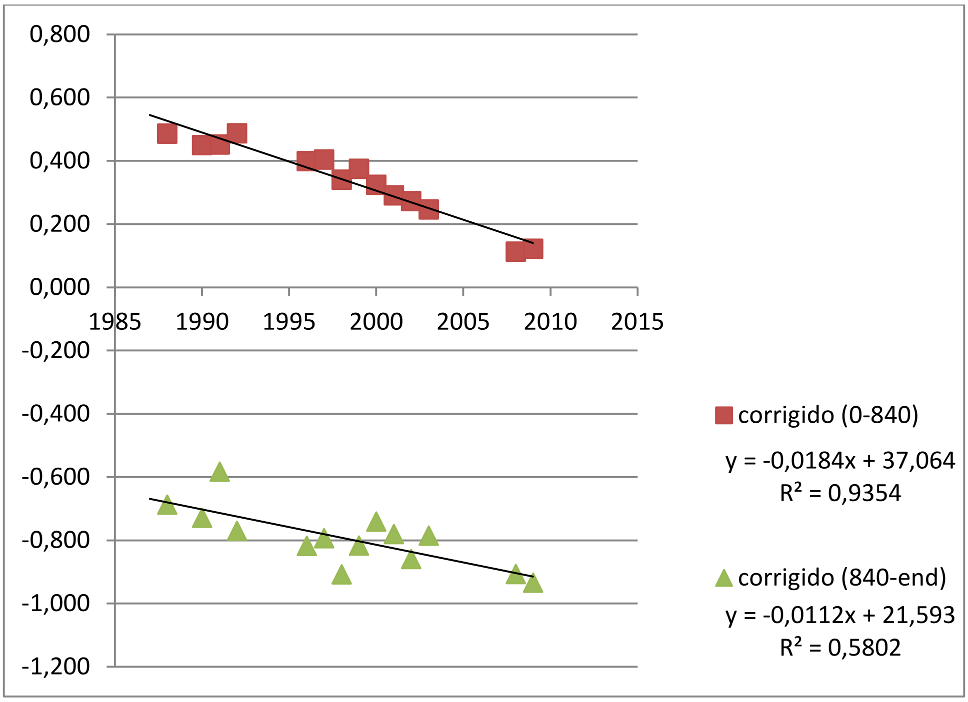

Fig. 20 Sediment height analysis of the transect R-5180 (Roggenplaat)

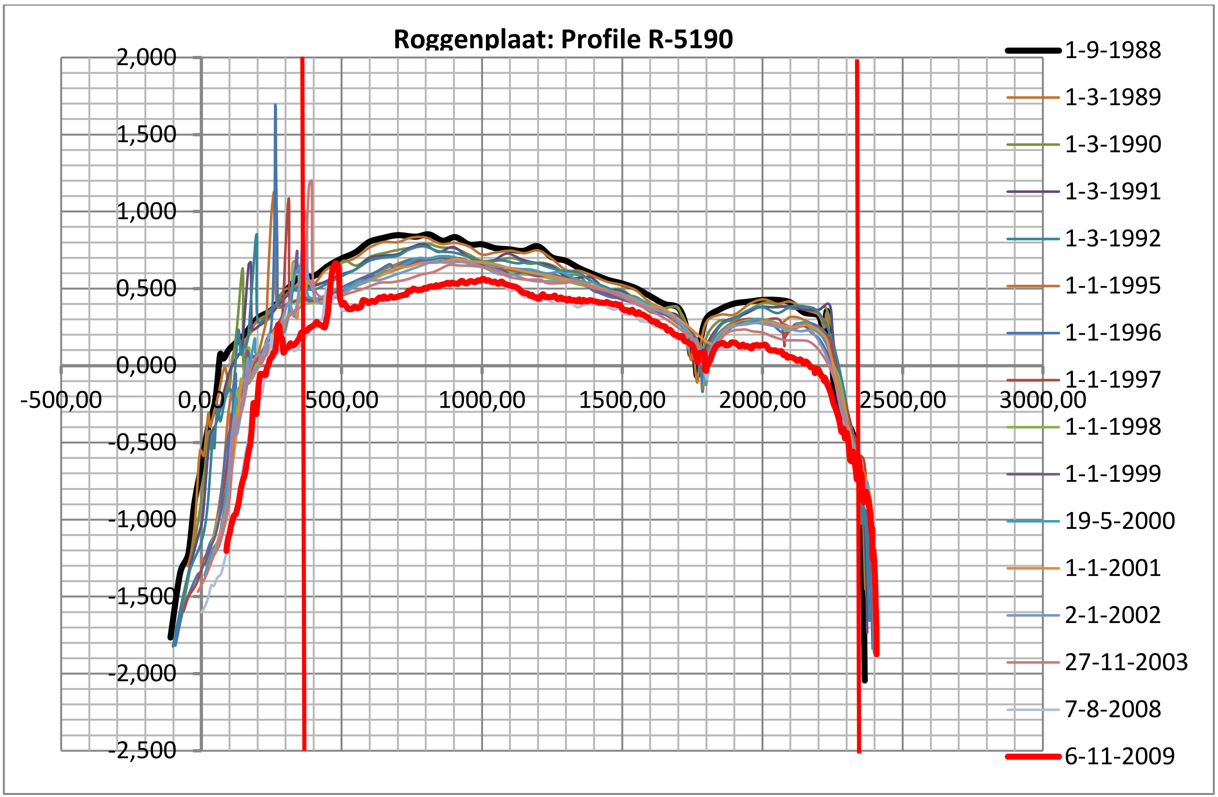

Fig. 21 Height profile of the transect R-5190 (Roggenplaat)

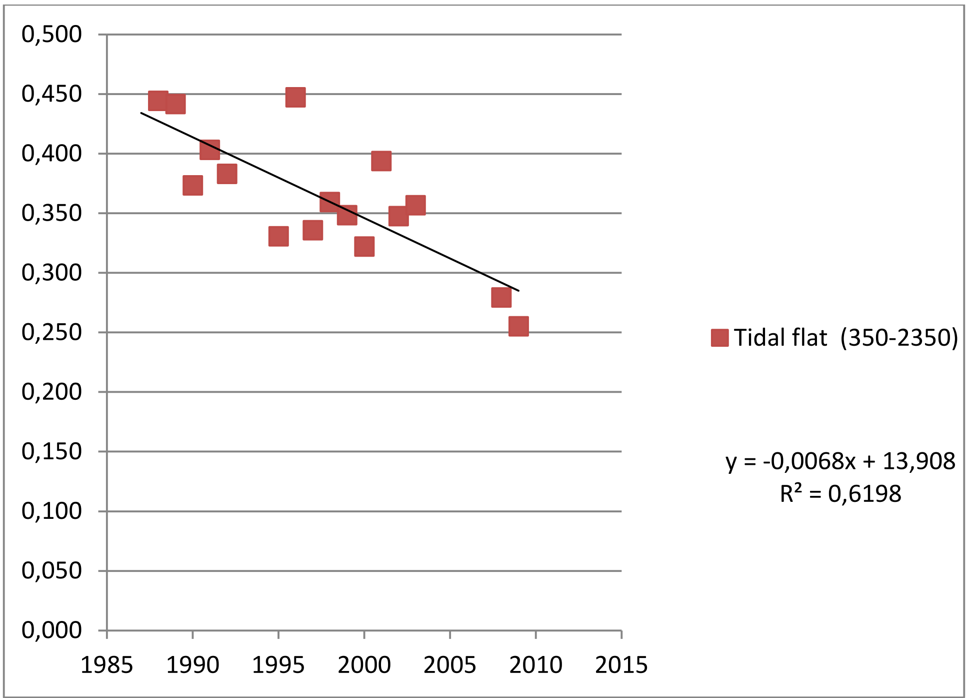

Fig. 22 Sediment height analysis of the transect R-5190 (Roggenplaat)

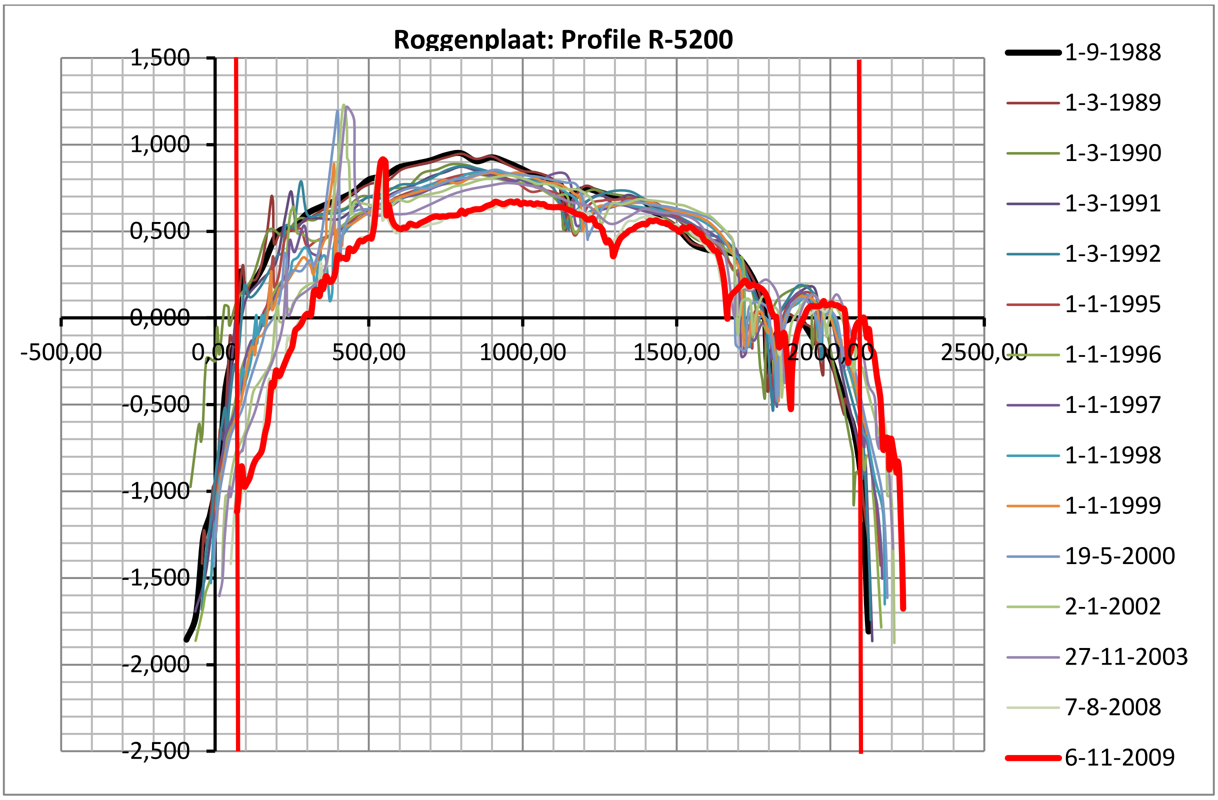

Fig. 23 Height profile of the transect R-5200 (Roggenplaat)

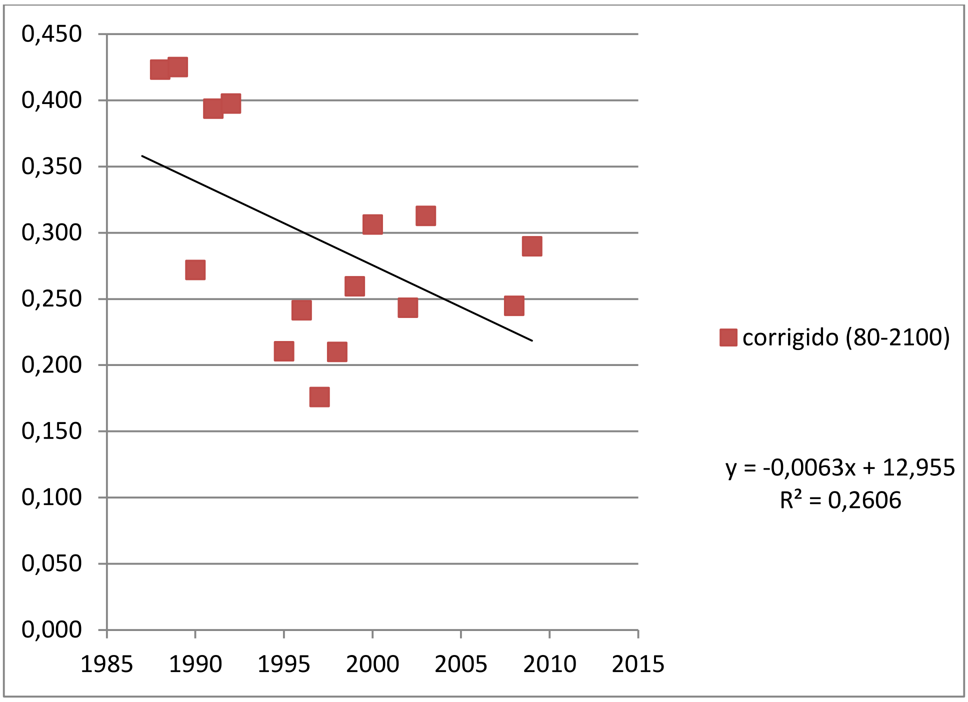

Fig. 24 Sediment height analysis of the transect R-5200 (Roggenplaat)

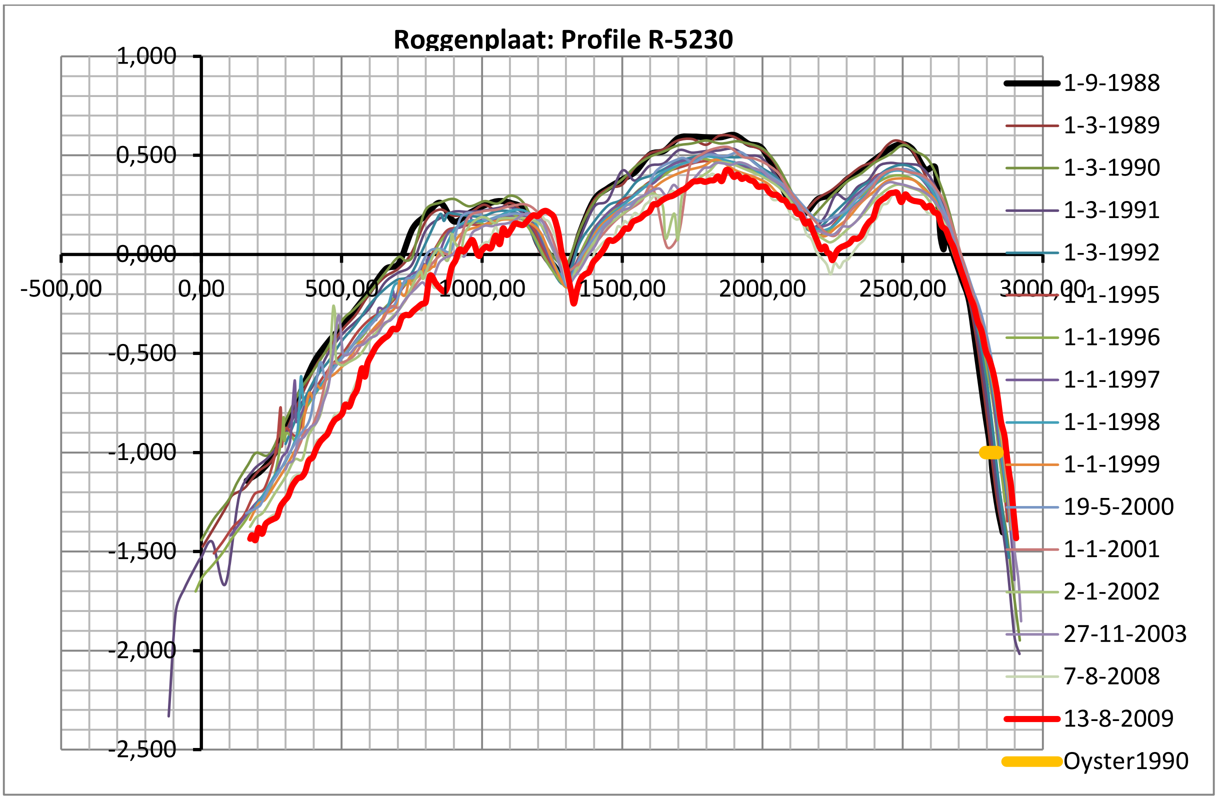

Fig. 25 Height profile of the transect R-5230 (Roggenplaat)

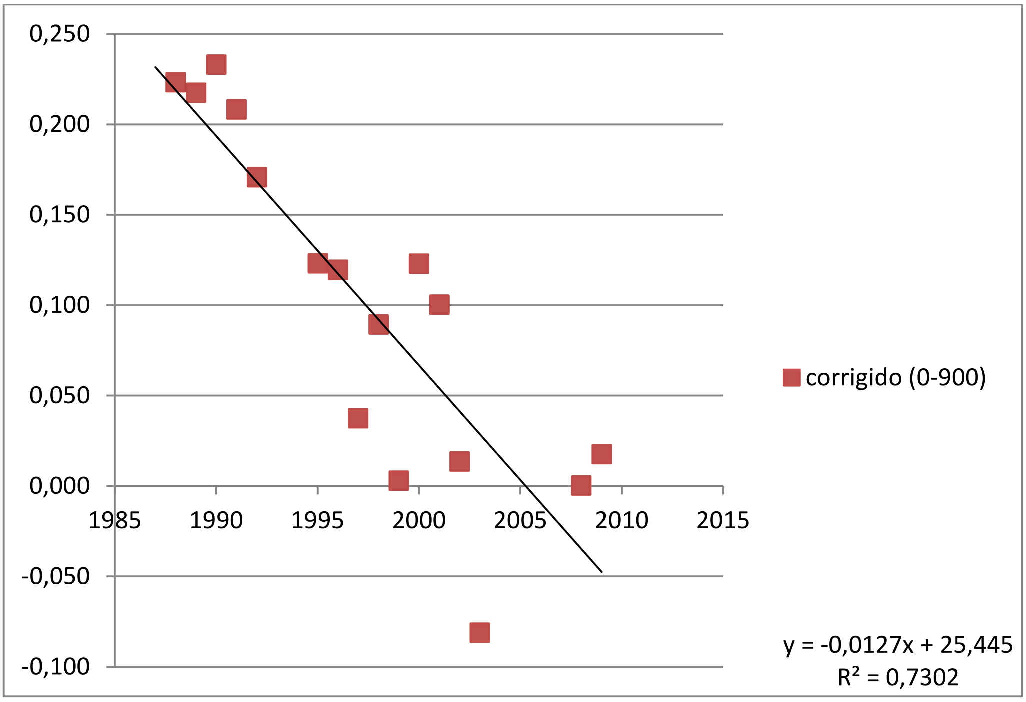

Fig. 26 Sediment height analysis of the transect R-5230 (Roggenplaat)

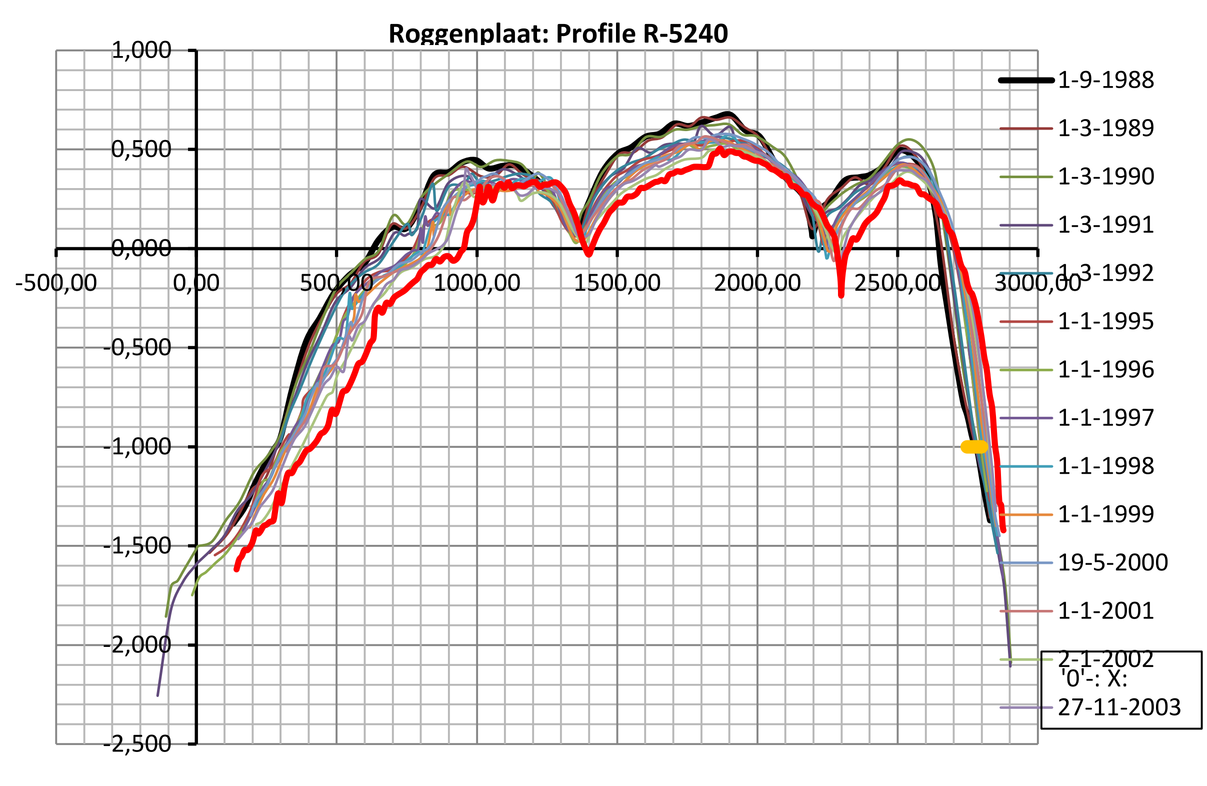

Fig. 27 Height profile of the transect R-5240 (Roggenplaat)

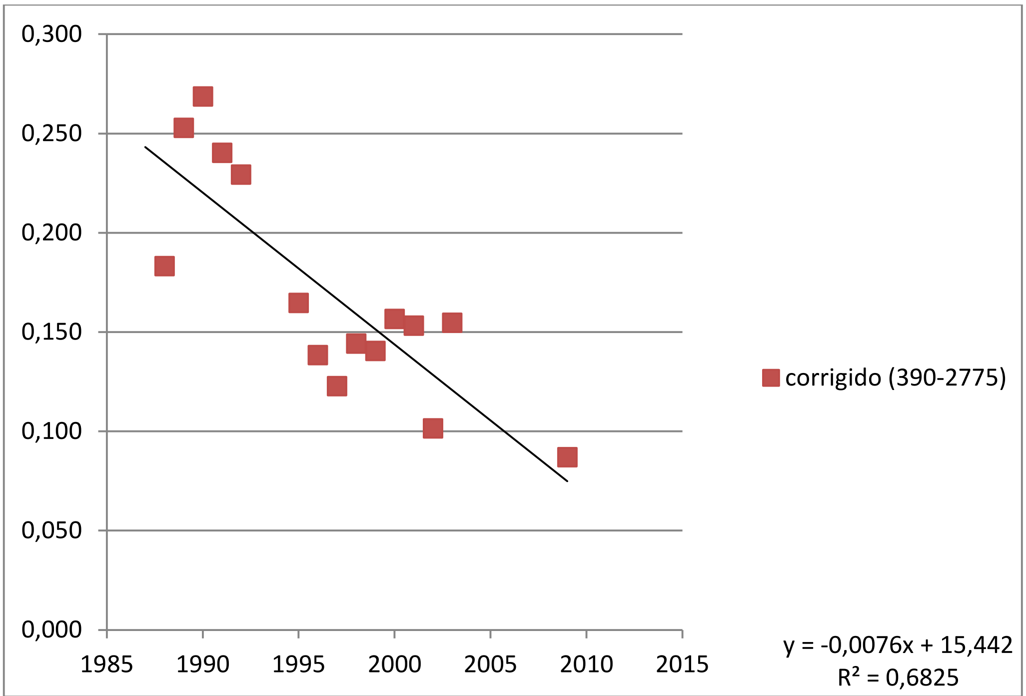

Fig. 28 Sediment height analysis of the transect R-5240 (Roggenplaat)

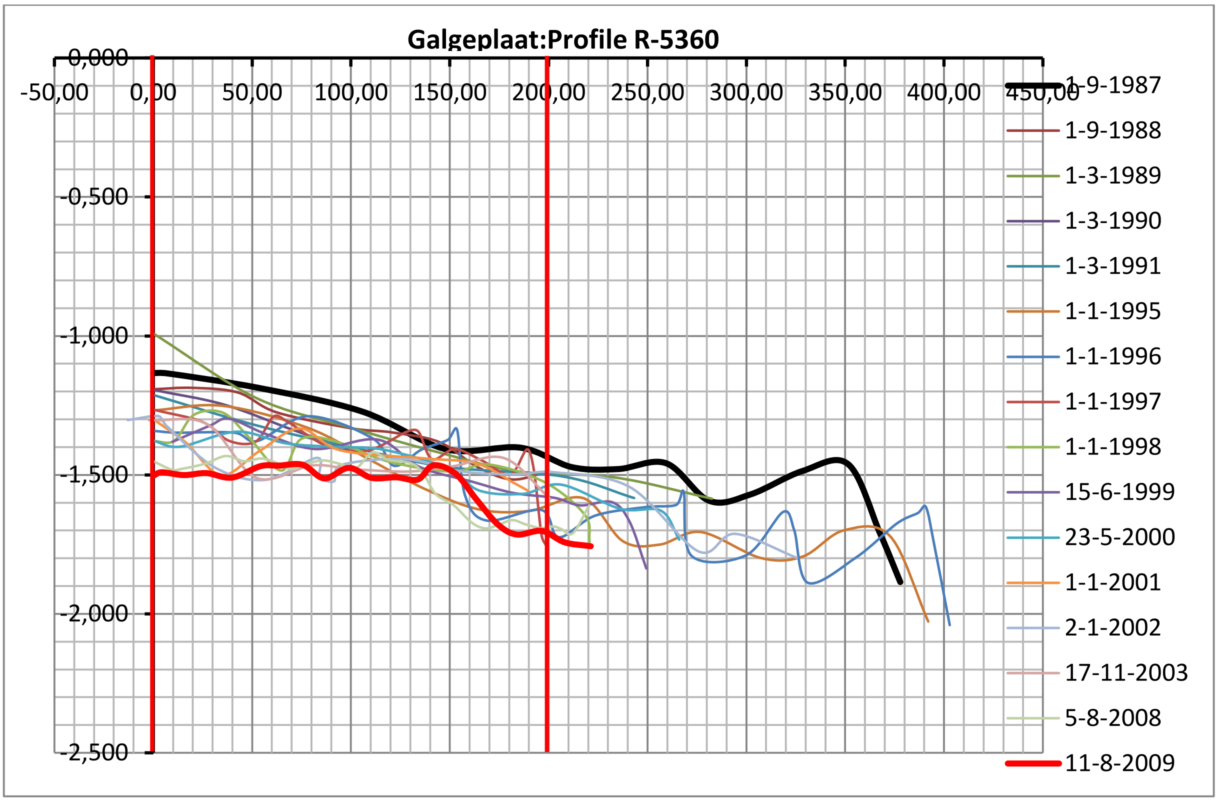

Fig. 29 Height profile of the transect R-5360 (Galgeplaat)

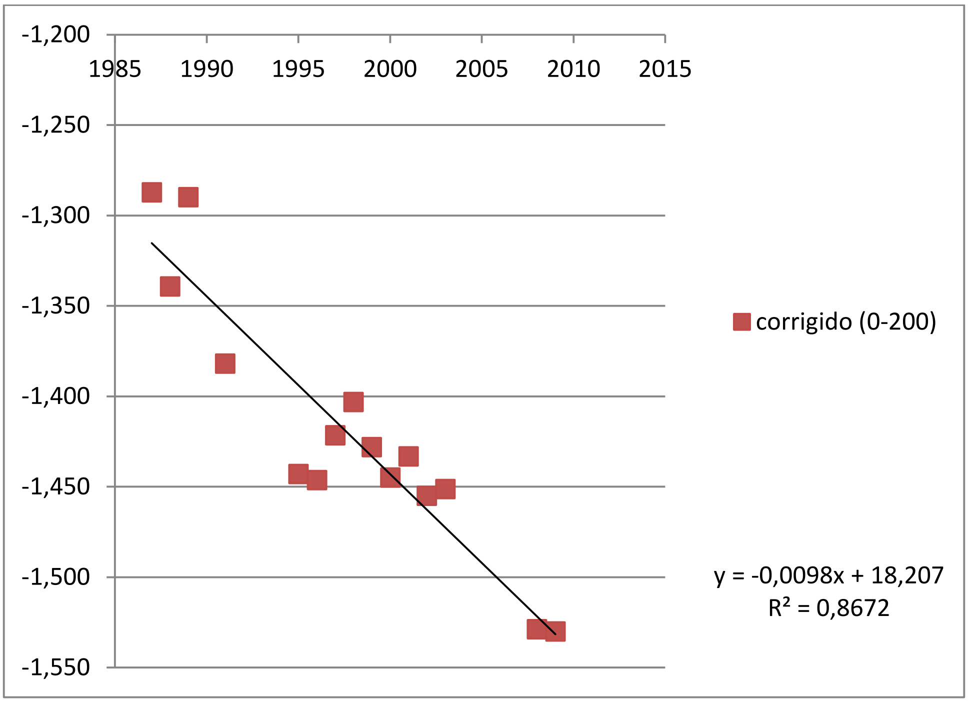

Fig. 30 Sediment height analysis of the transect R-5360 (Galgeplaat)

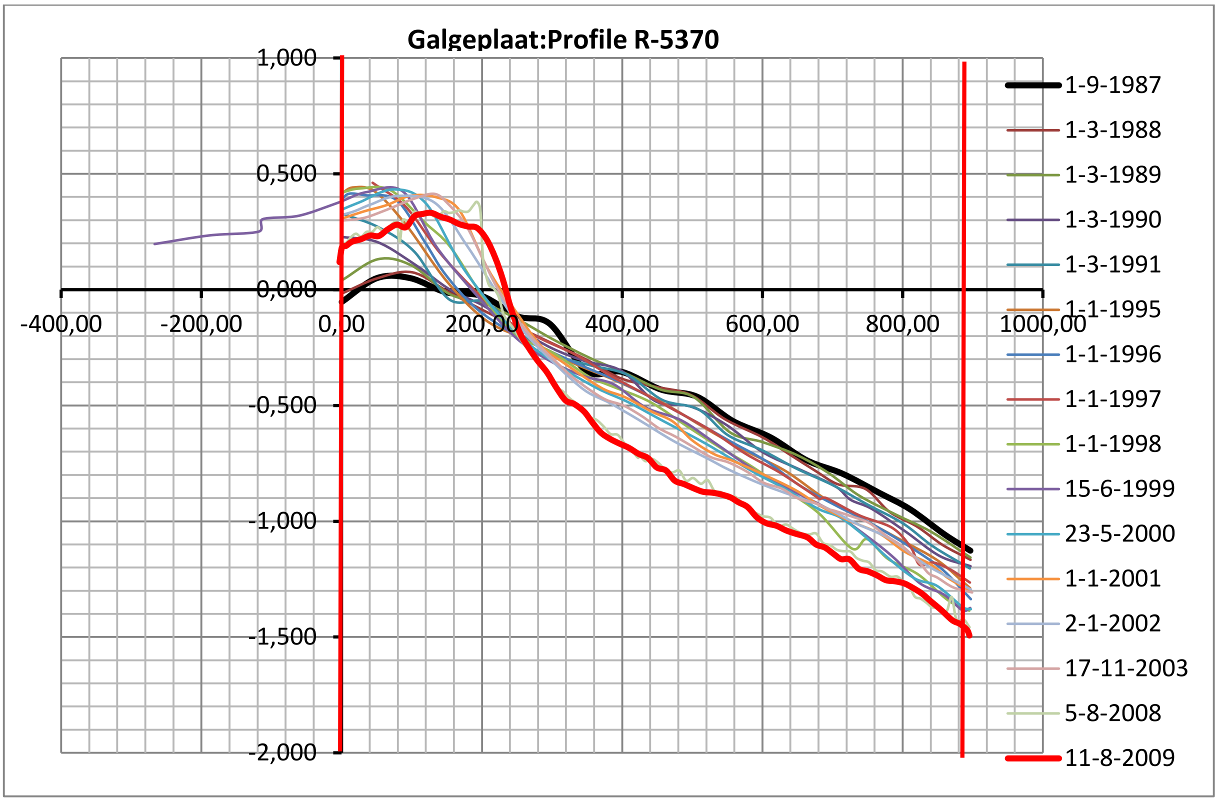

Fig. 31 Height profile of the transect R-5370 (Galgeplaat)

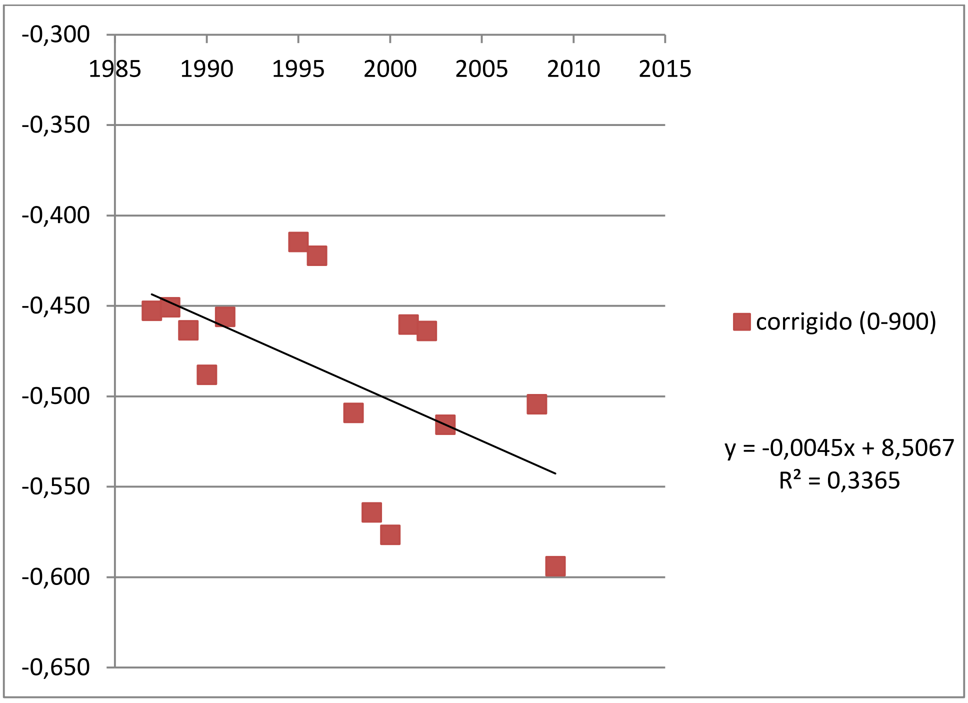

Fig. 32 Sediment height analysis of the transect R-5370 (Galgeplaat)

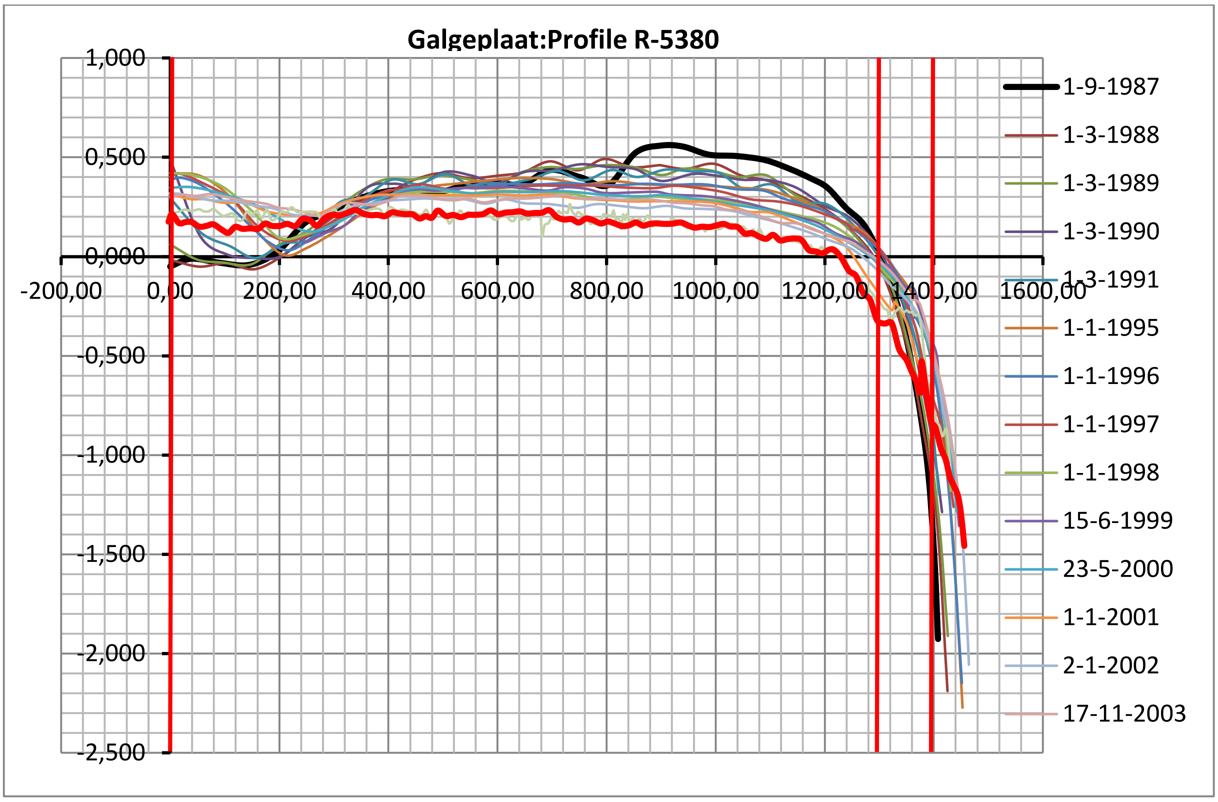

Fig. 33 Height profile of the transect R-5380 (Galgeplaat)

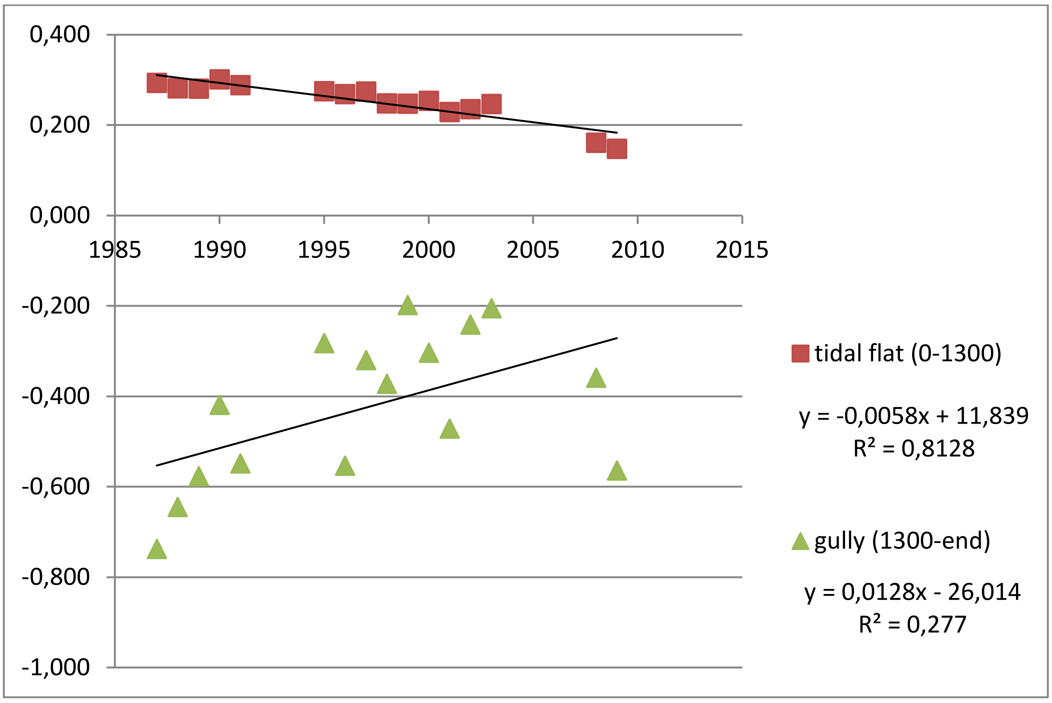

Fig. 34 Sediment height analysis of the transect R-5380 (Galgeplaat)

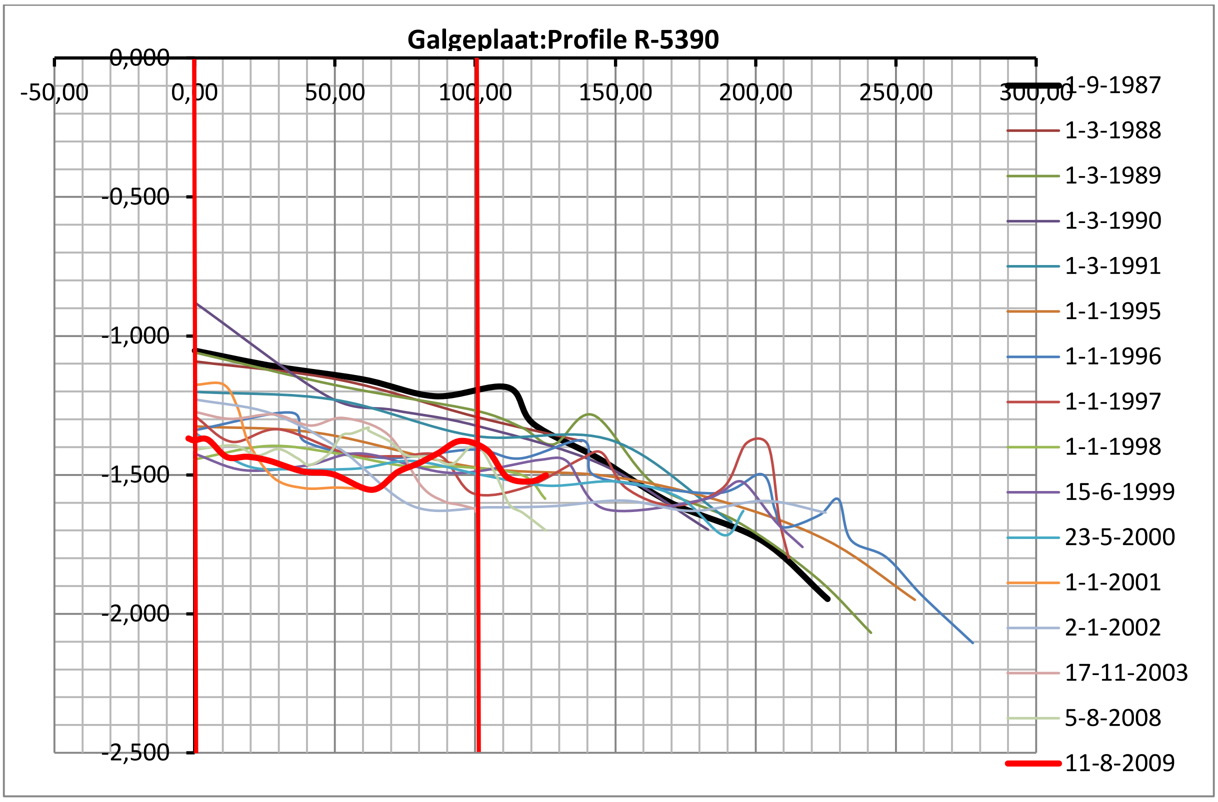

Fig. 35 Height profile of the transect R-5390 (Galgeplaat)

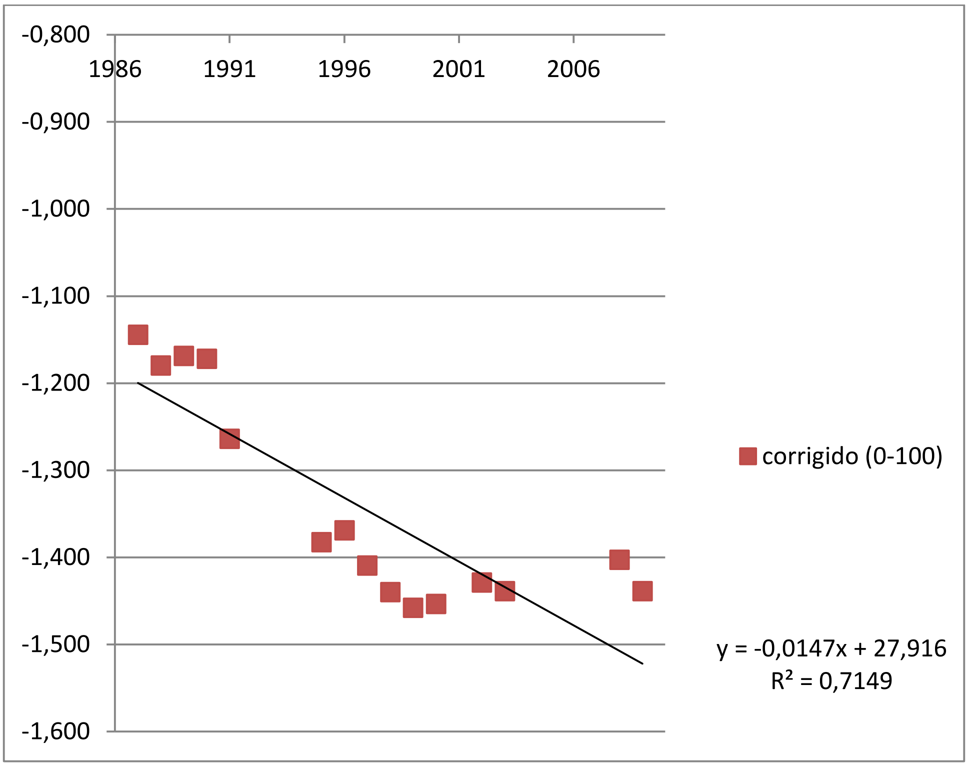

Fig. 36 Sediment height analysis of the transect R-5390 (Galgeplaat)

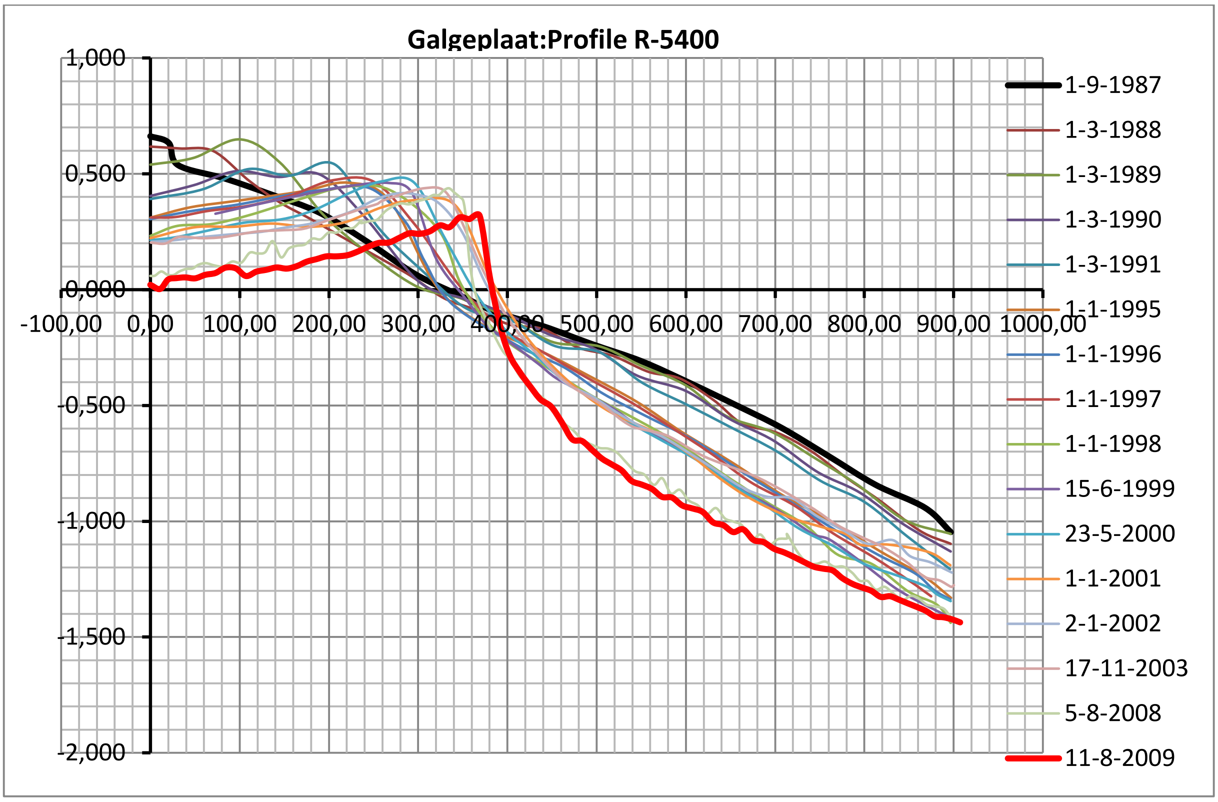

Fig. 37 Height profile of the transect R-5400 (Galgeplaat)

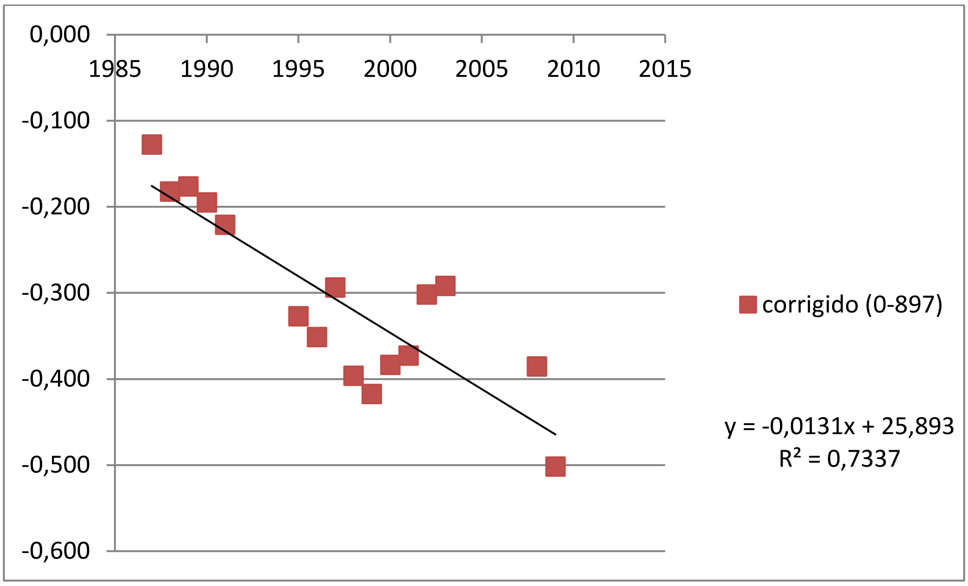

Fig. 38 Sediment height analysis of the transect R-5400 (Galgeplaat)

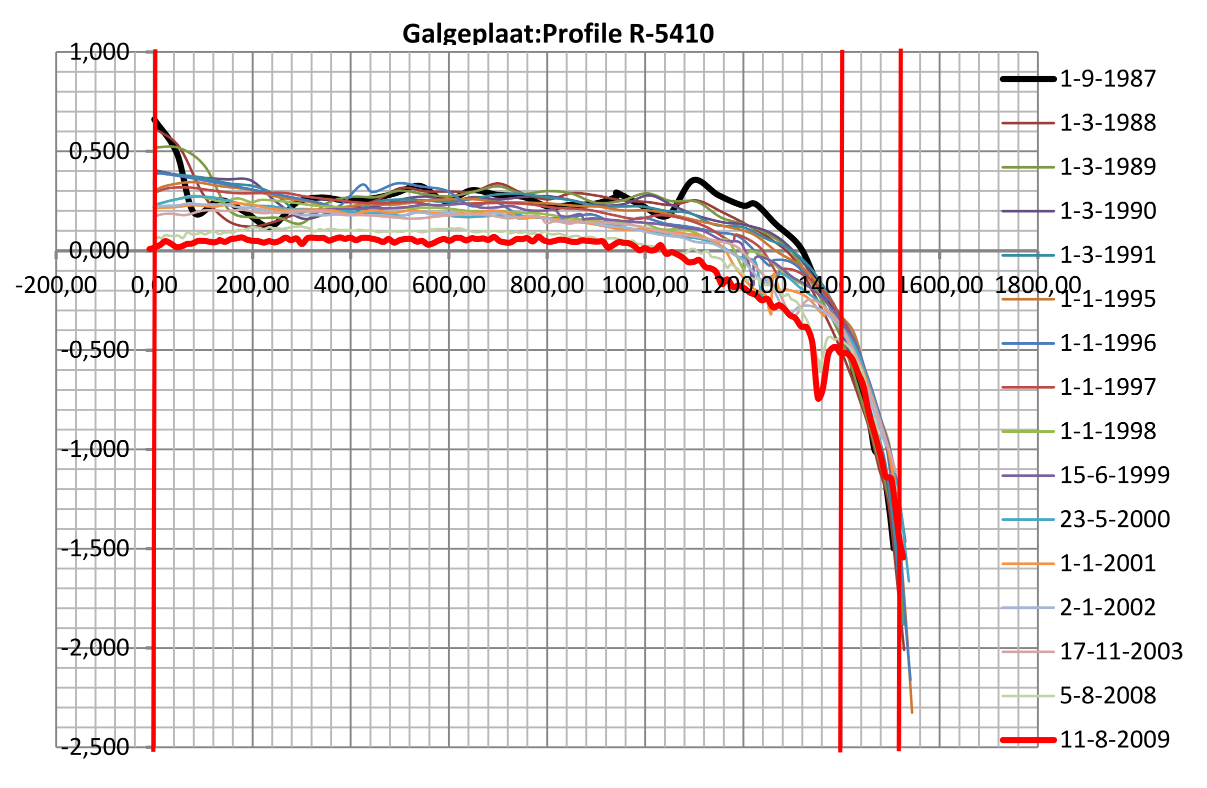

Fig. 39 Height profile of the transect R-5410 (Galgeplaat)

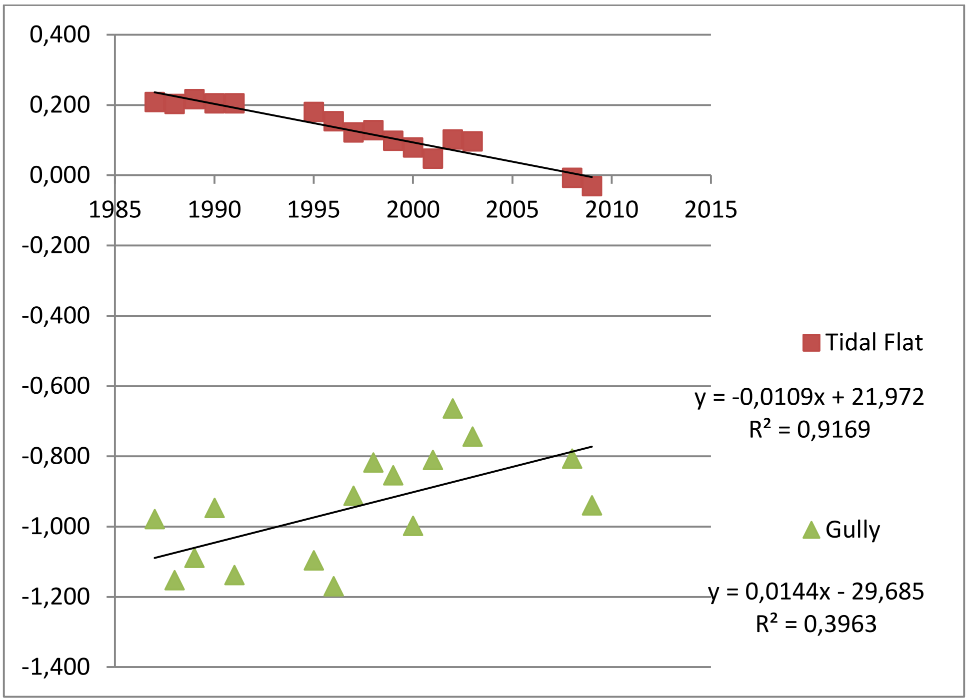

Fig. 40 Sediment height analysis of the transect R-5410 (Galgeplaat)

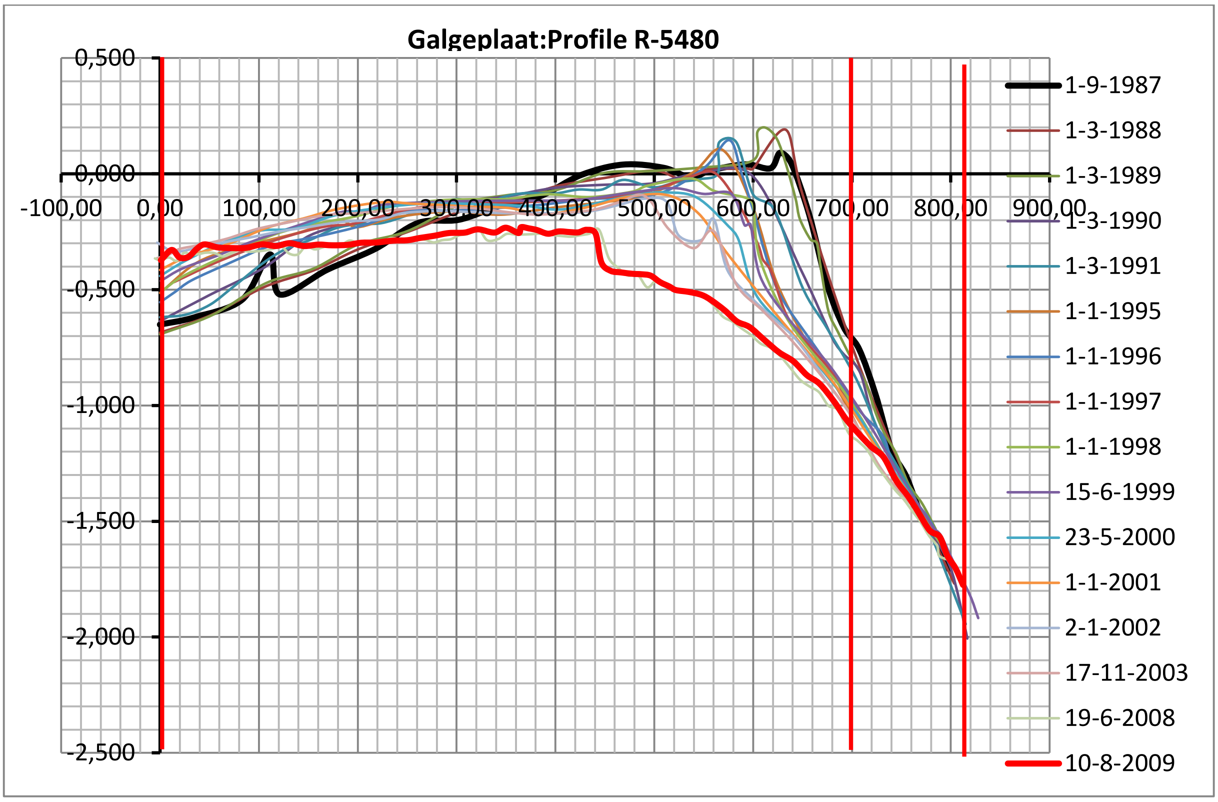

Fig. 41 Height profile of the transect R-5480 (Galgeplaat)

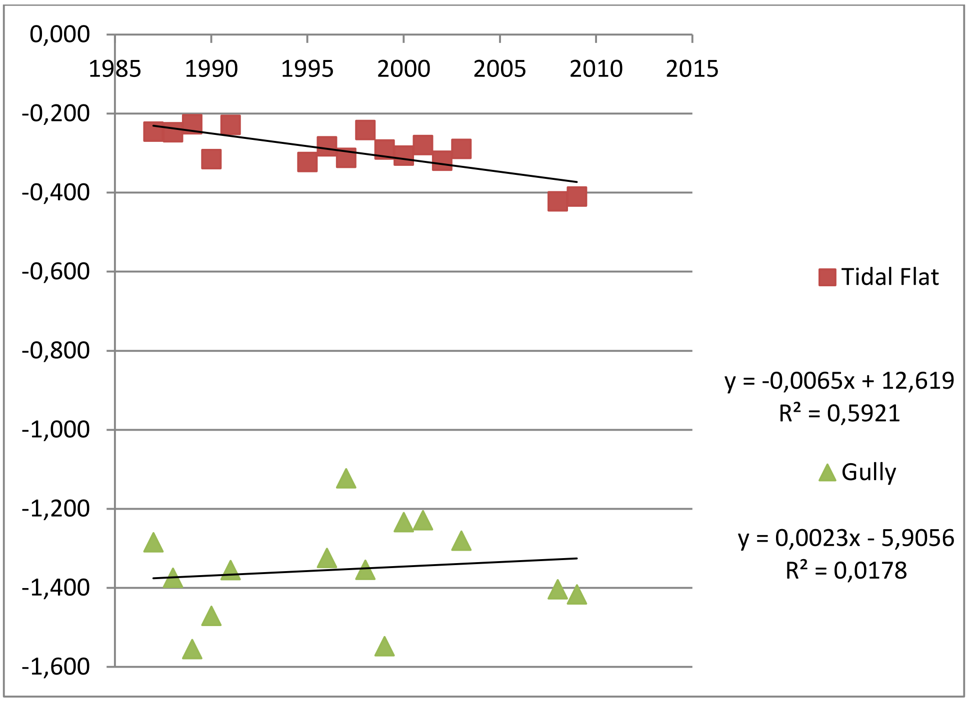

Fig. 42 Sediment height analysis of the transect R-5480 (Galgeplaat)

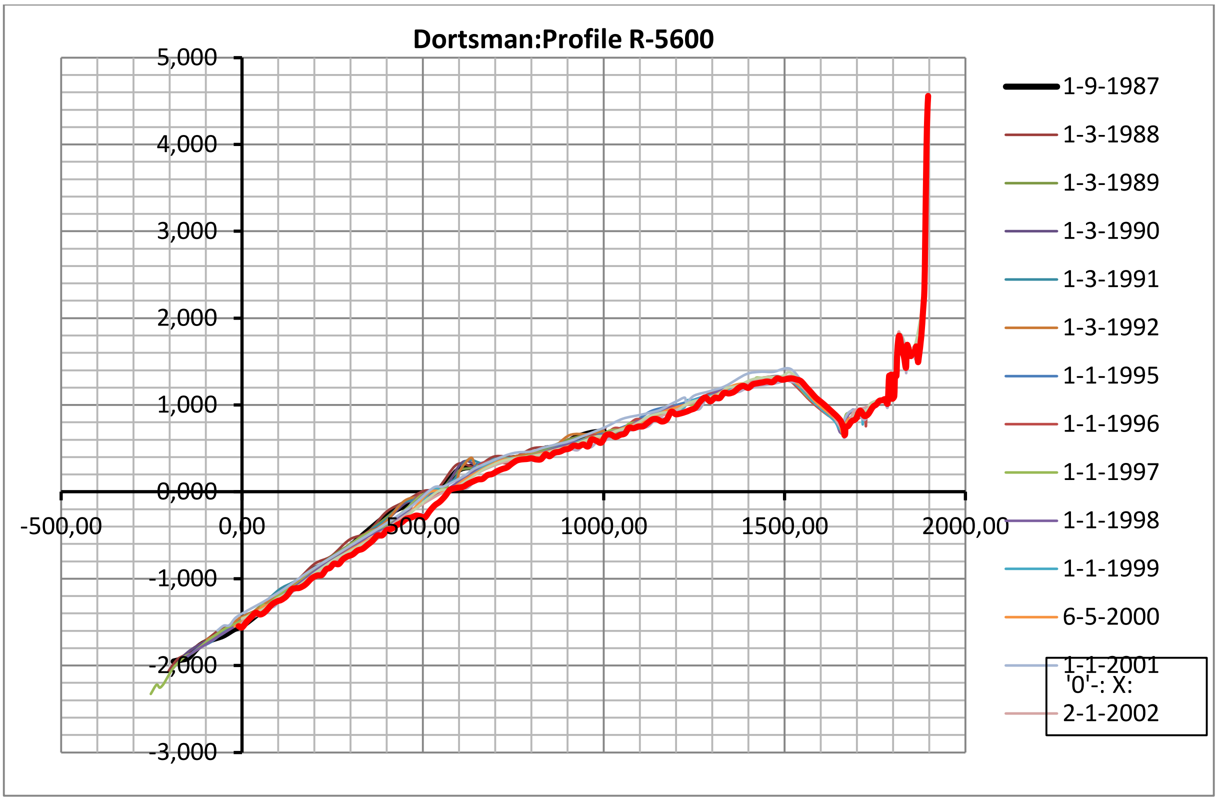

Fig. 43 Height profile of the transect R-5600 (Dortsman)

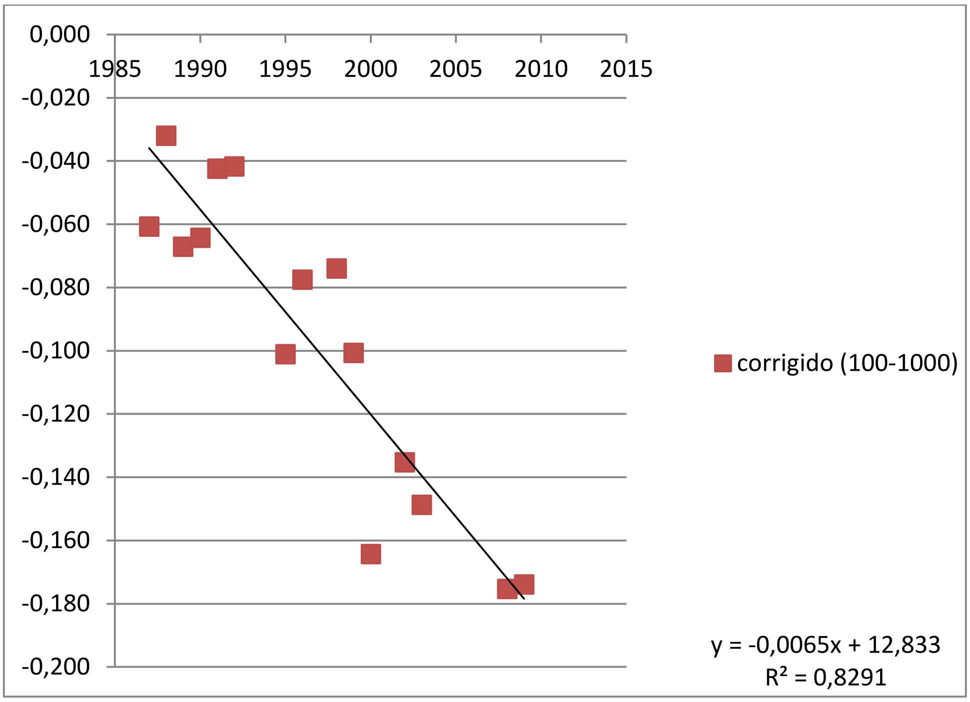

Fig. 44 Sediment height analysis of the transect R-5600 (Dortsman)

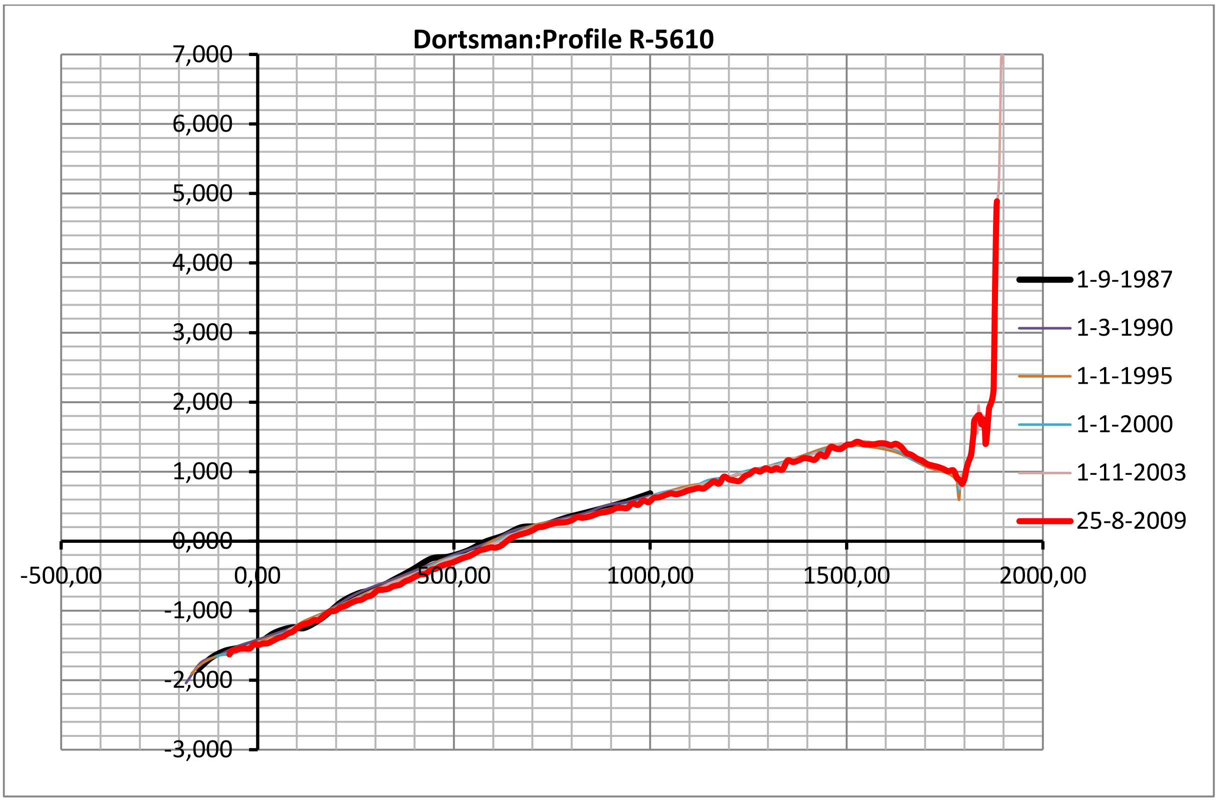

Fig. 45 Height profile of the transect R-5610 (Dortsman)

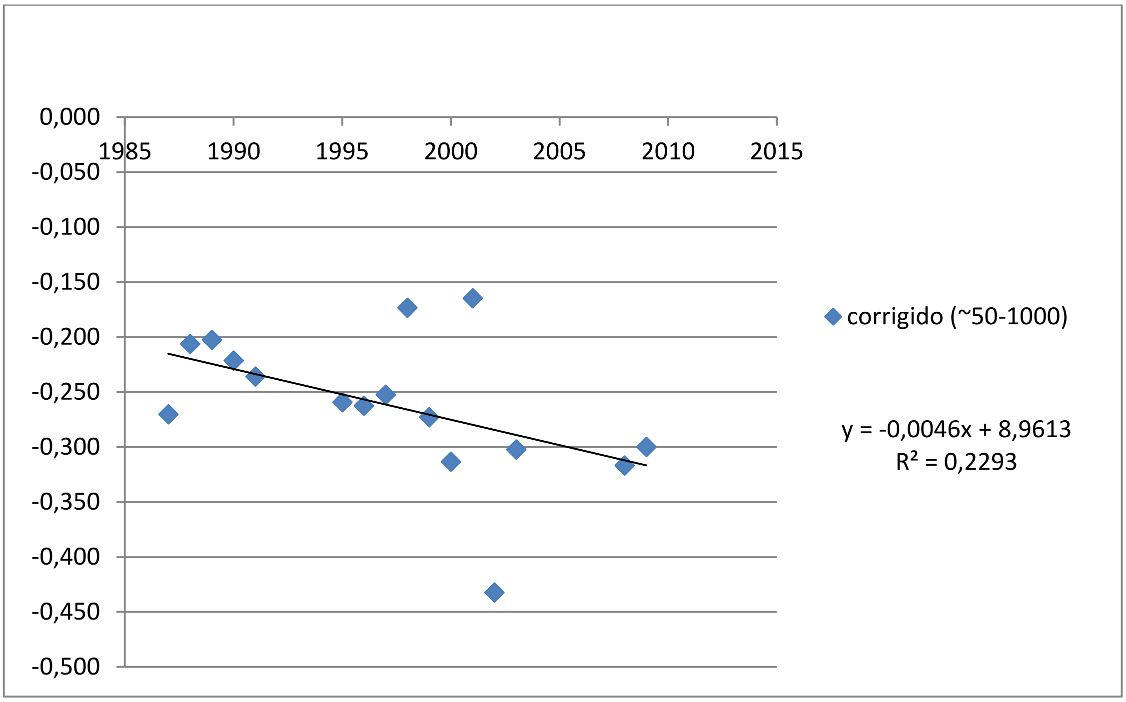

Fig. 46 Sediment height analysis of the transect R-5610 (Dortsman)

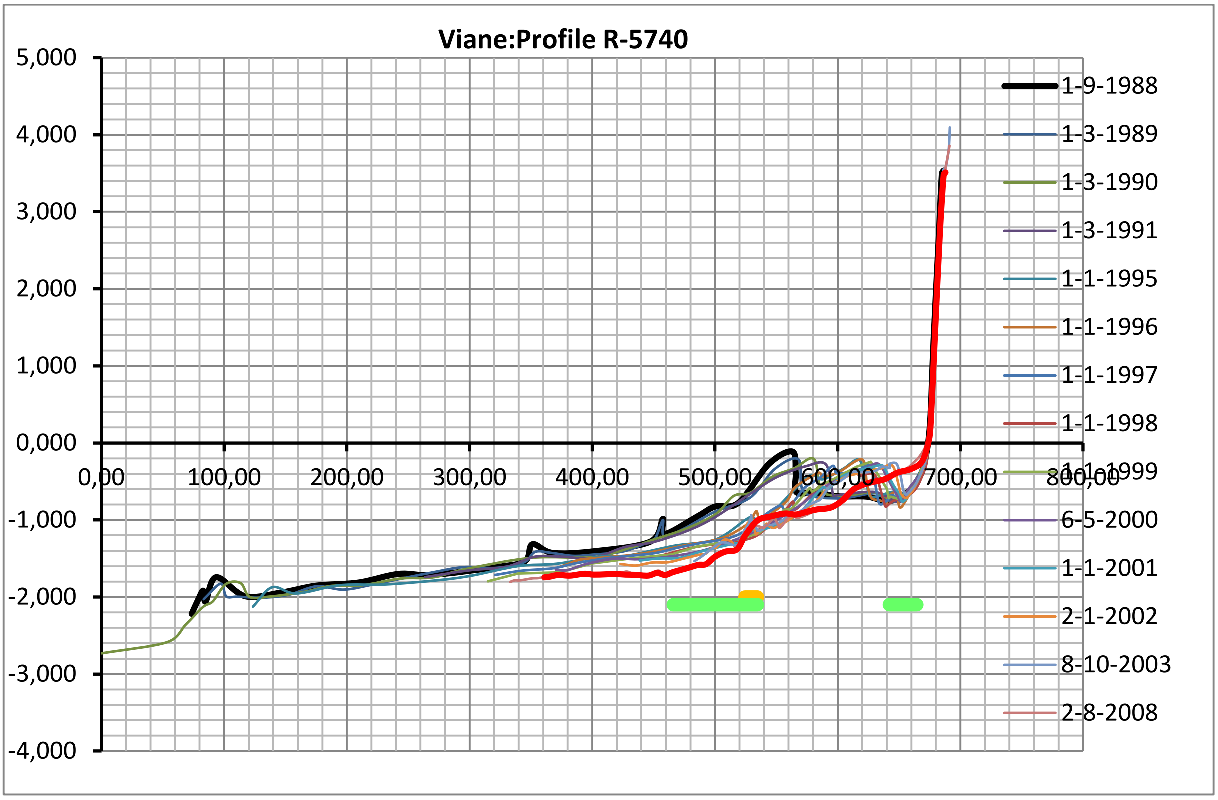

Fig. 47 Height profile of the transect R-5740 (Viane)

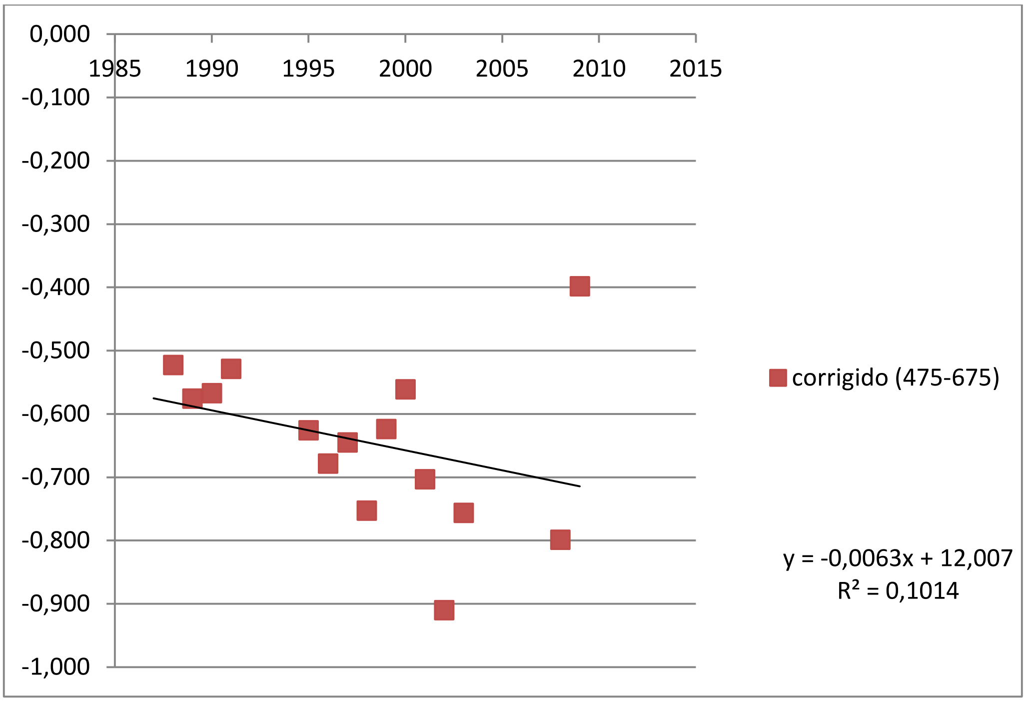

Fig. 48 Sediment height analysis of the transect R5740 (Viane)

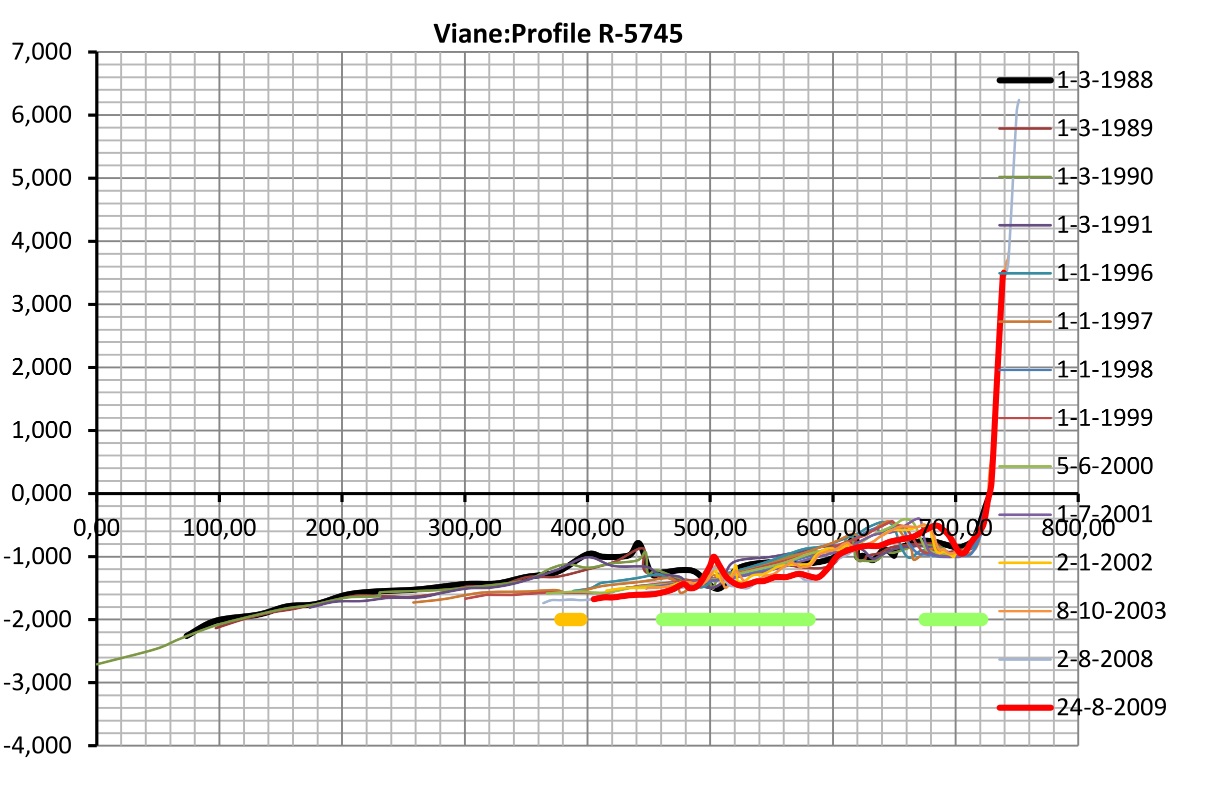

Fig. 49 Height profile of the transect R-5745 (Viane)

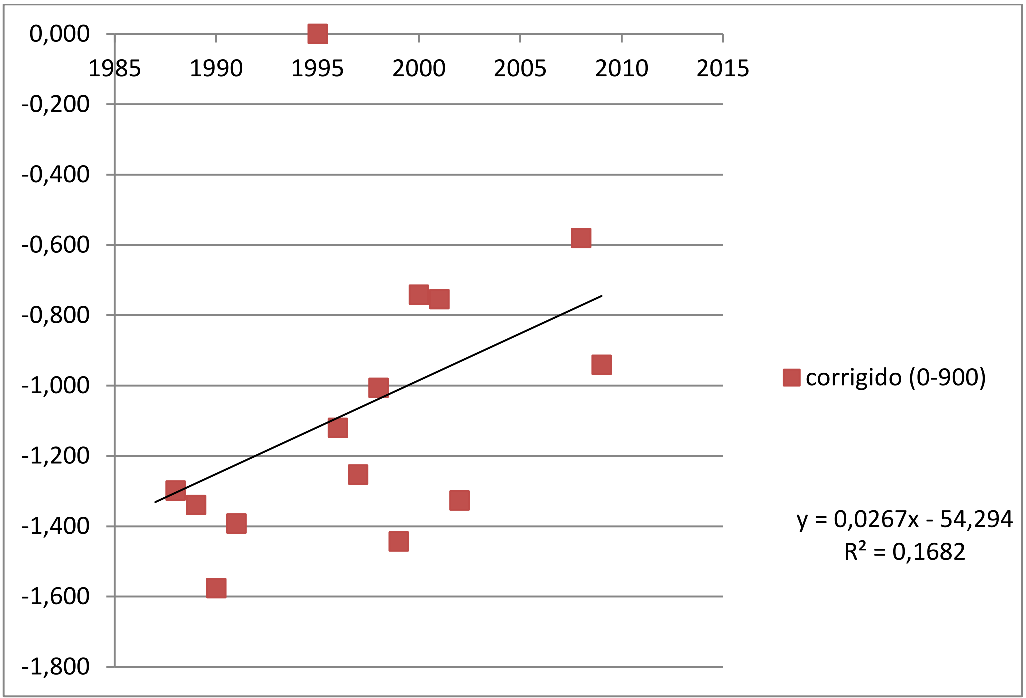

Fig. 50 Sediment height analysis of the transect R-5745 (Viane)

7.2 TRANSECTS CROSSING OYSTER REEFS

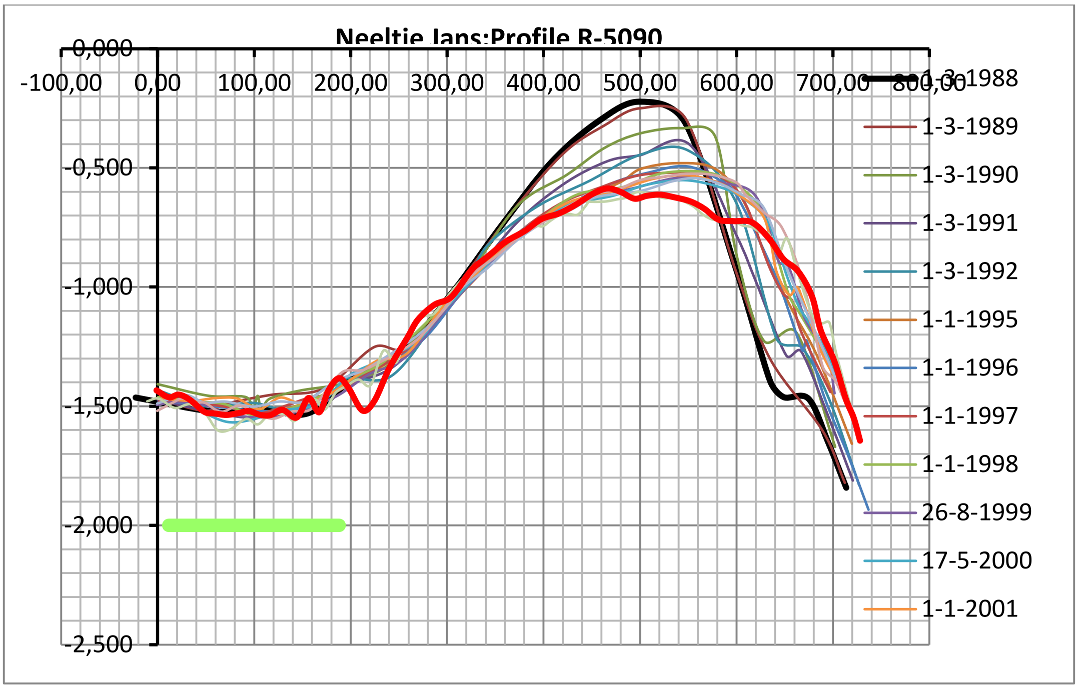

Fig. 51 Height profile of the transect R-5090 (Neeltje Jans)

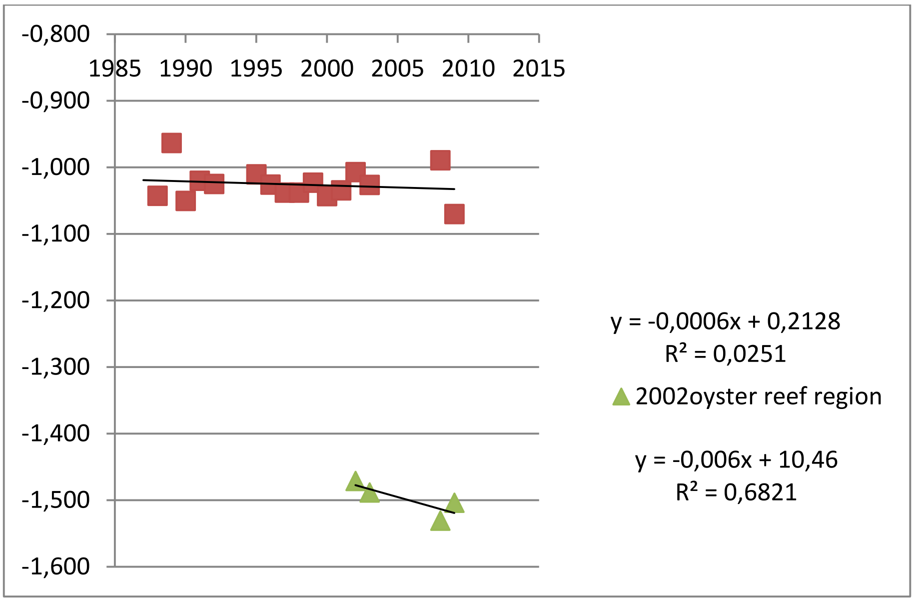

Fig. 52 Sediment height analysis of the transect R-5090 (Neeltje Jans)

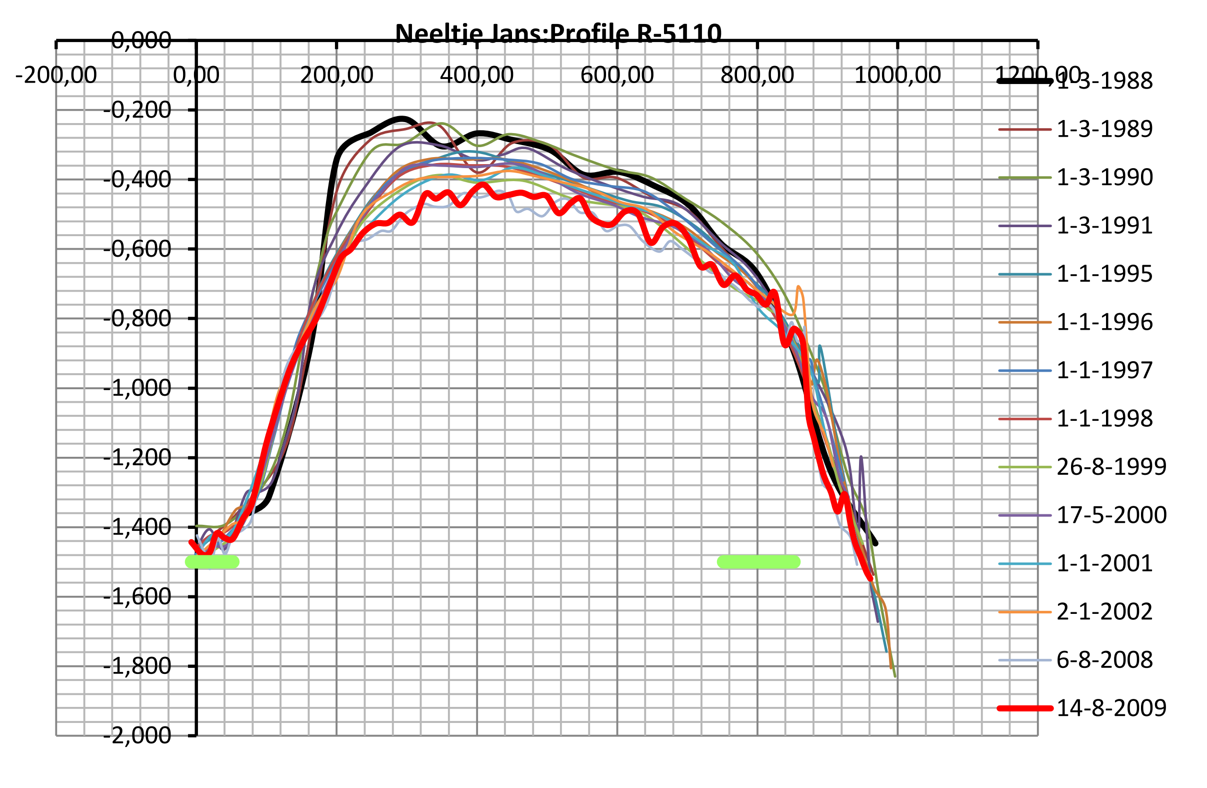

Fig. 53 Height profile of the transect R-5110 (Neeltje Jans)

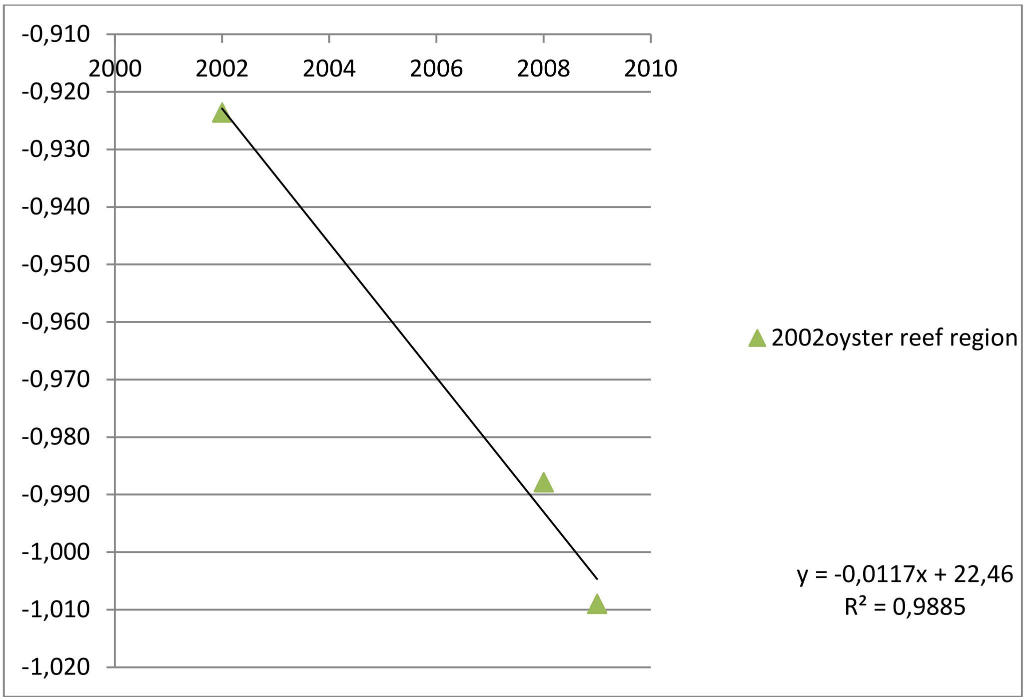

Fig. 54 Sediment height analysis of the transect R-5110 (Neeltje Jans)

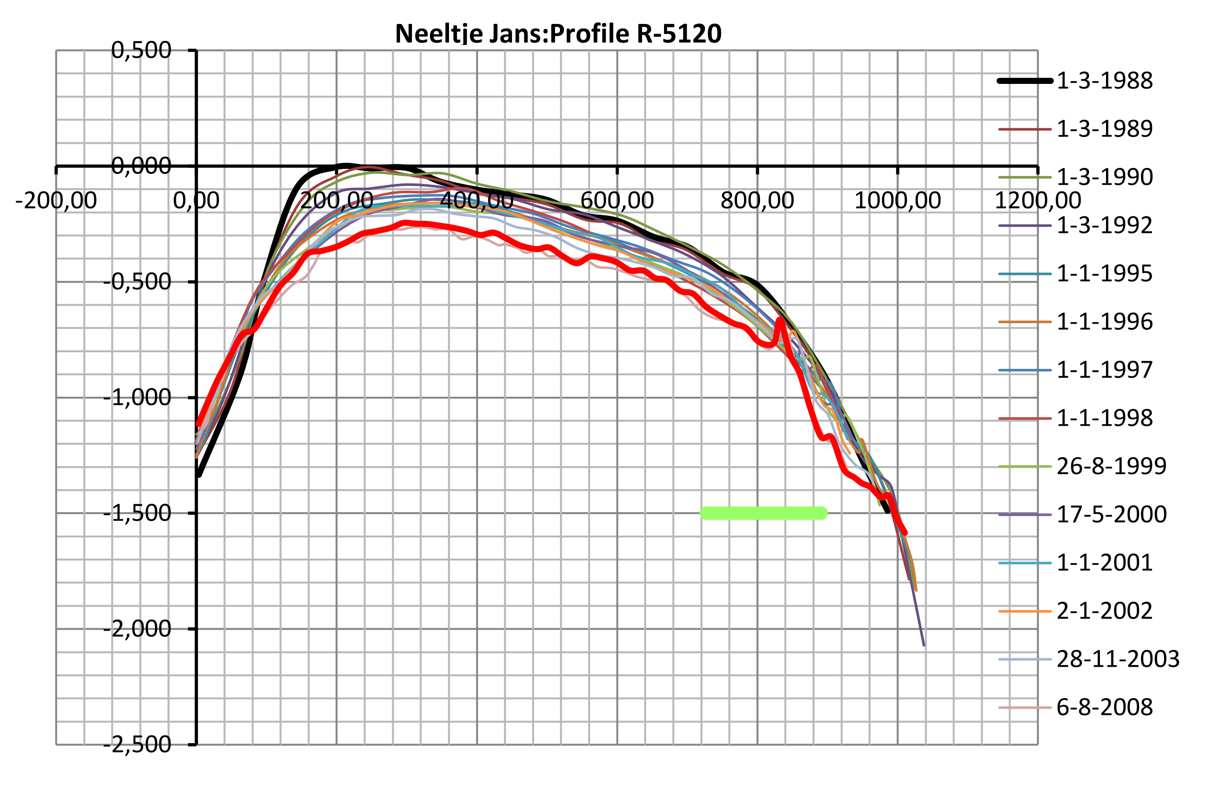

Fig. 55 Height profile of the transect R-5120 (Neeltje Jans)

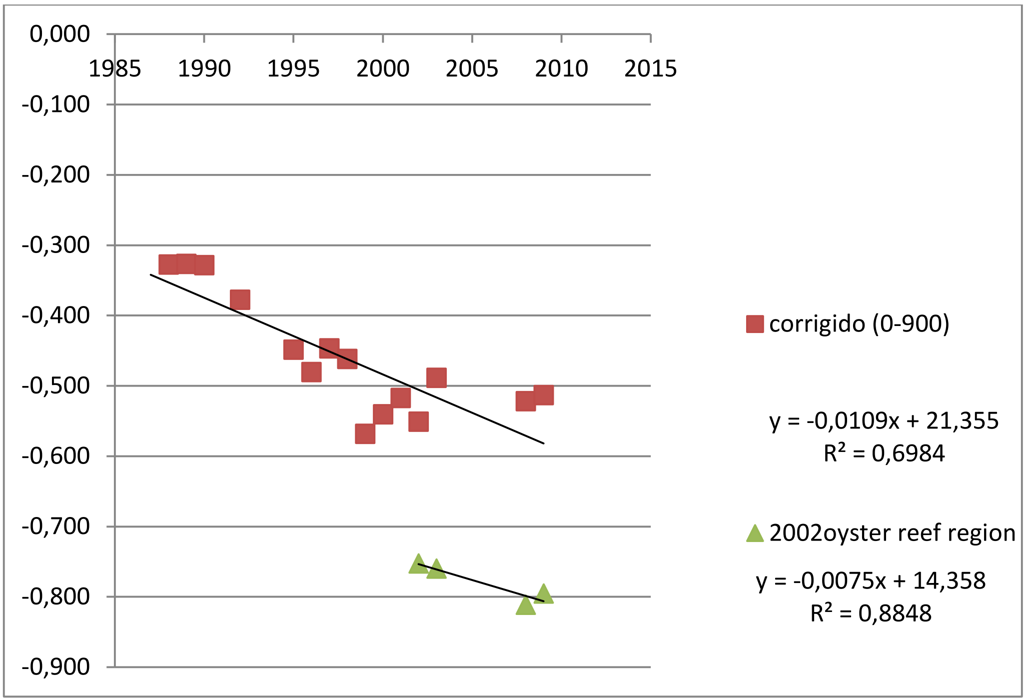

Fig. 56 Sediment height analysis of the transect R-5120 (Neeltje Jans)

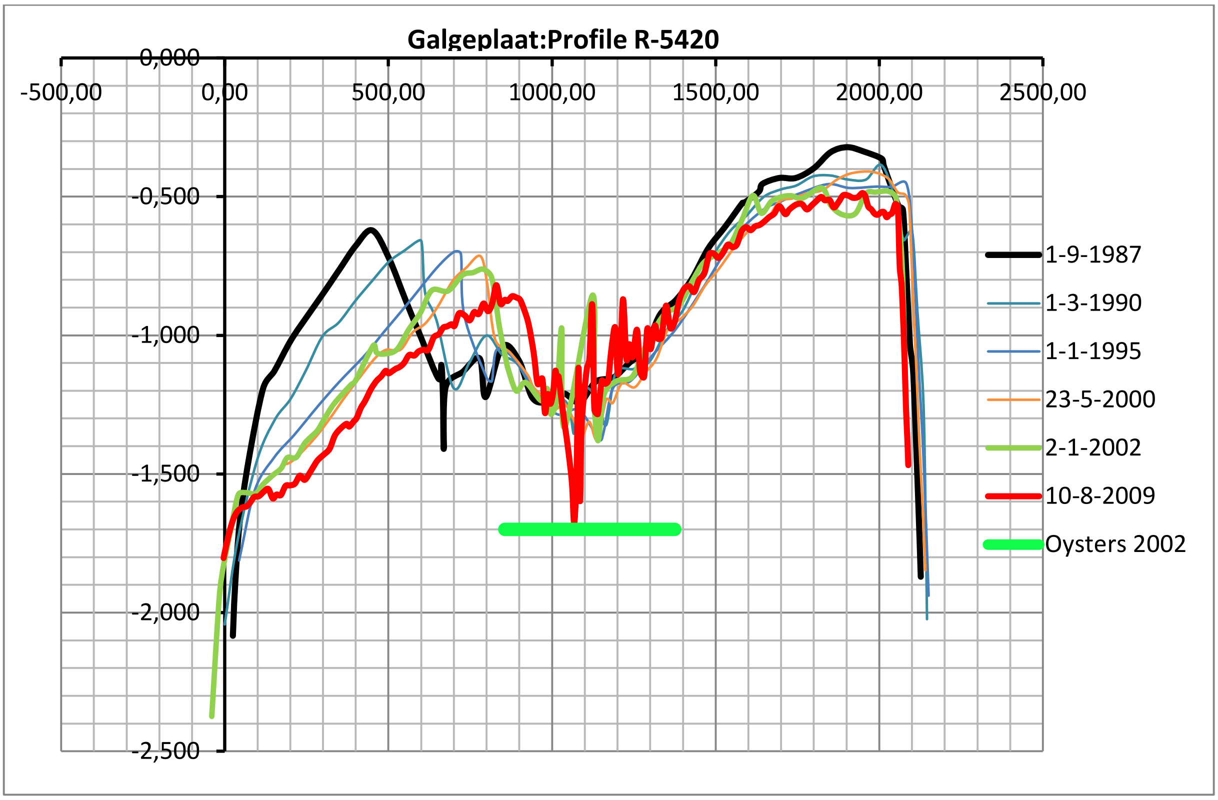

Fig. 57 Height profile of the transect R-5420 (Galgeplaat)

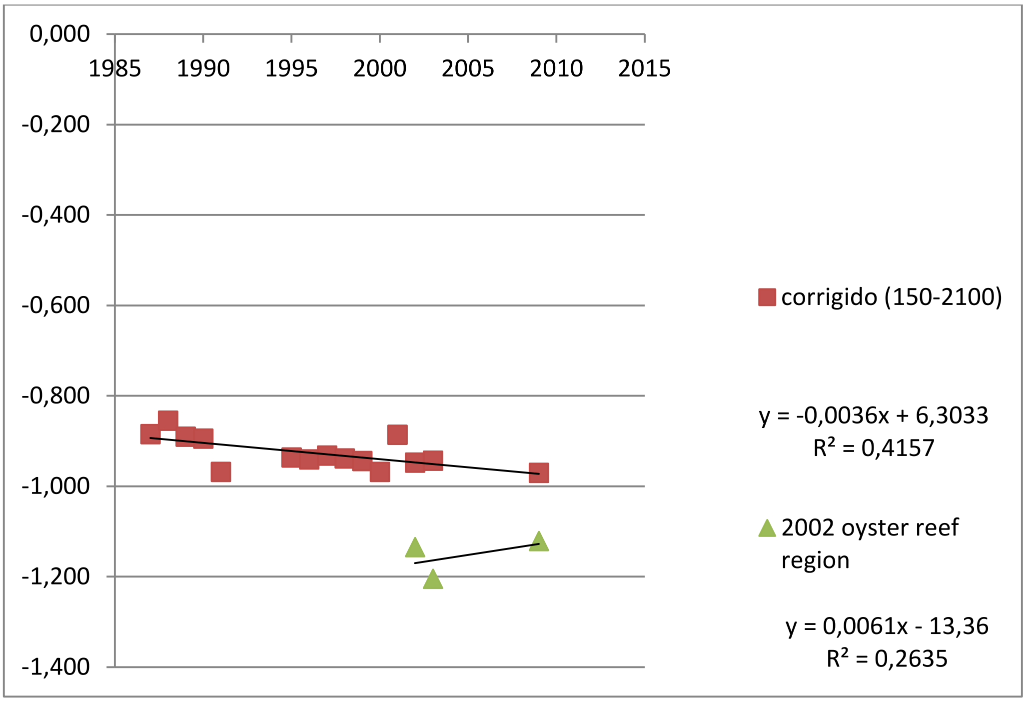

Fig. 58 Sediment height analysis of the transect R-5420 (Galgeplaat)

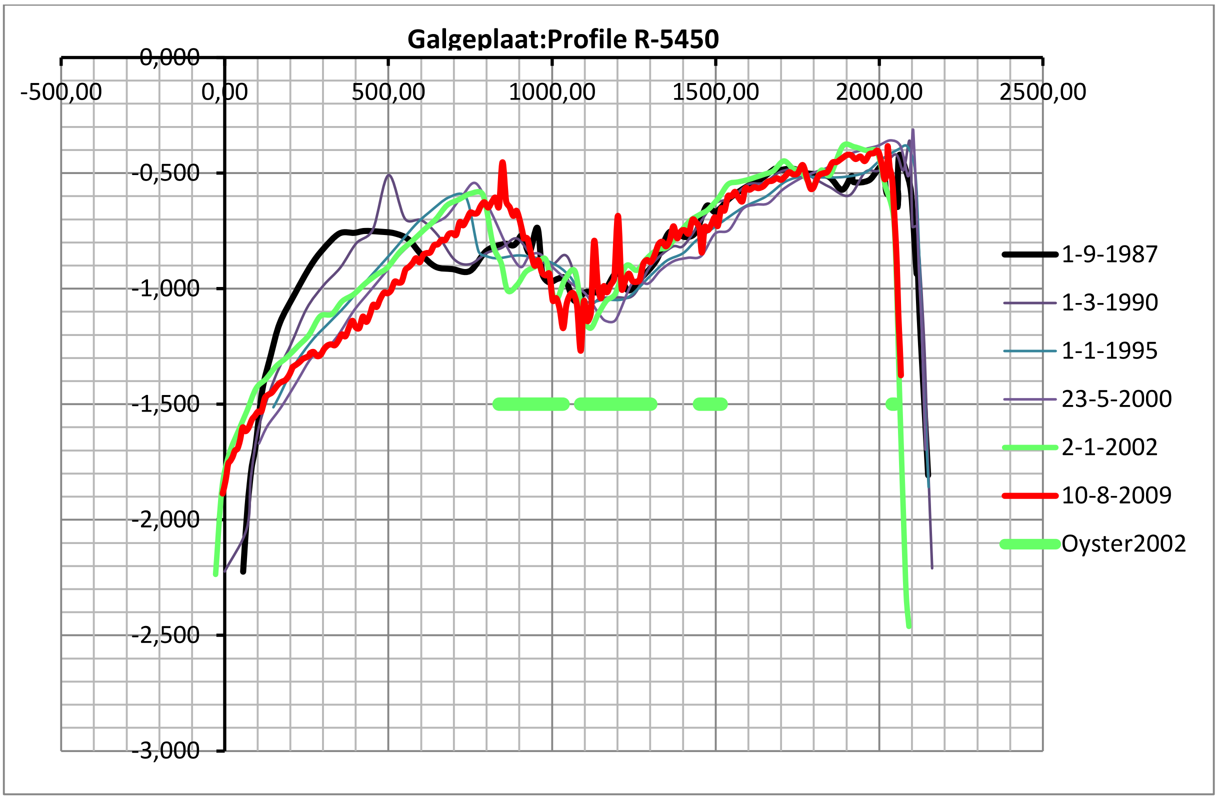

Fig. 59 Height profile of the transect R-5450 (Galgeplaat)

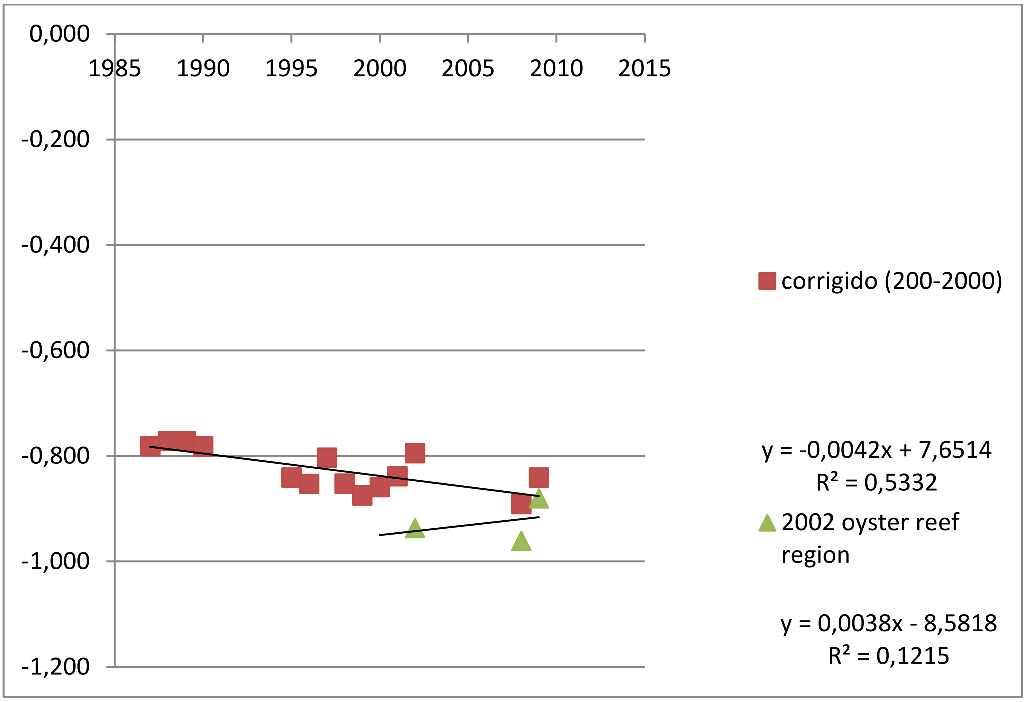

Fig. 60 Sediment height analysis of the transect R-5450 (Galgeplaat)

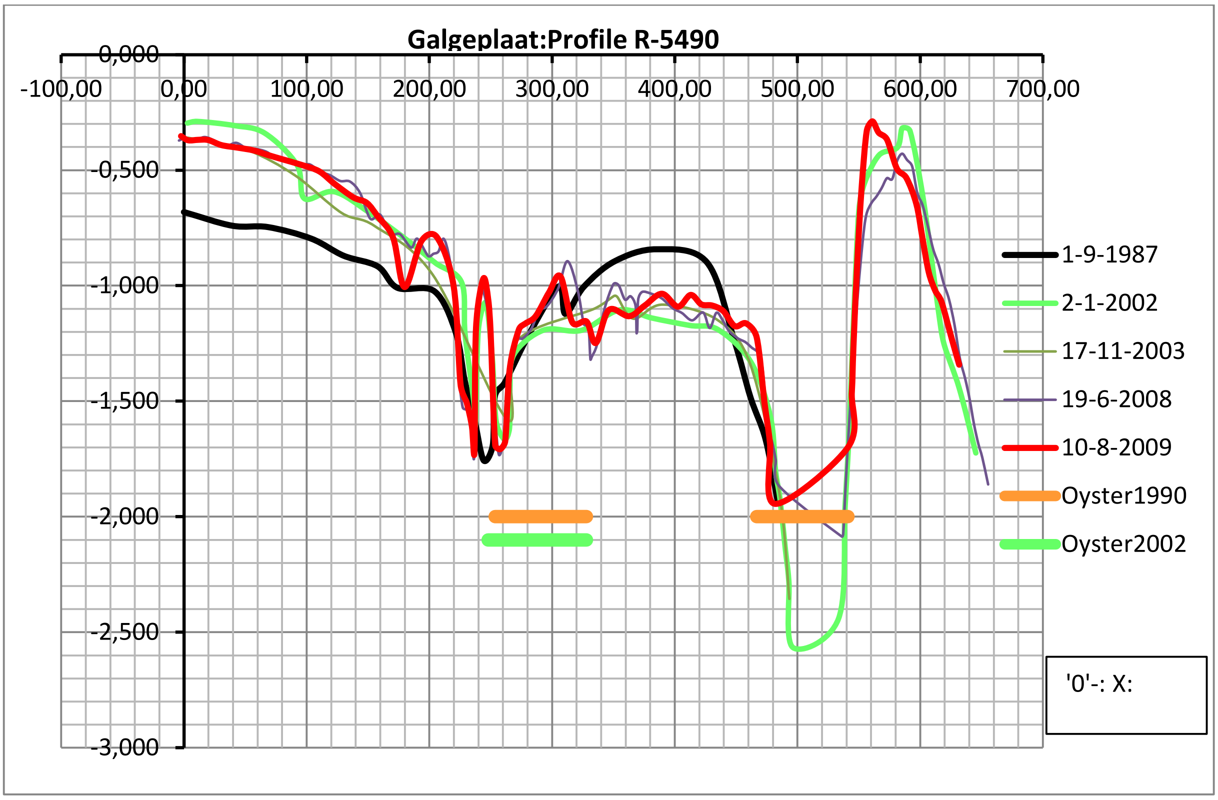

Fig. 61 Height profile of the transect R-5490 (Galgeplaat)

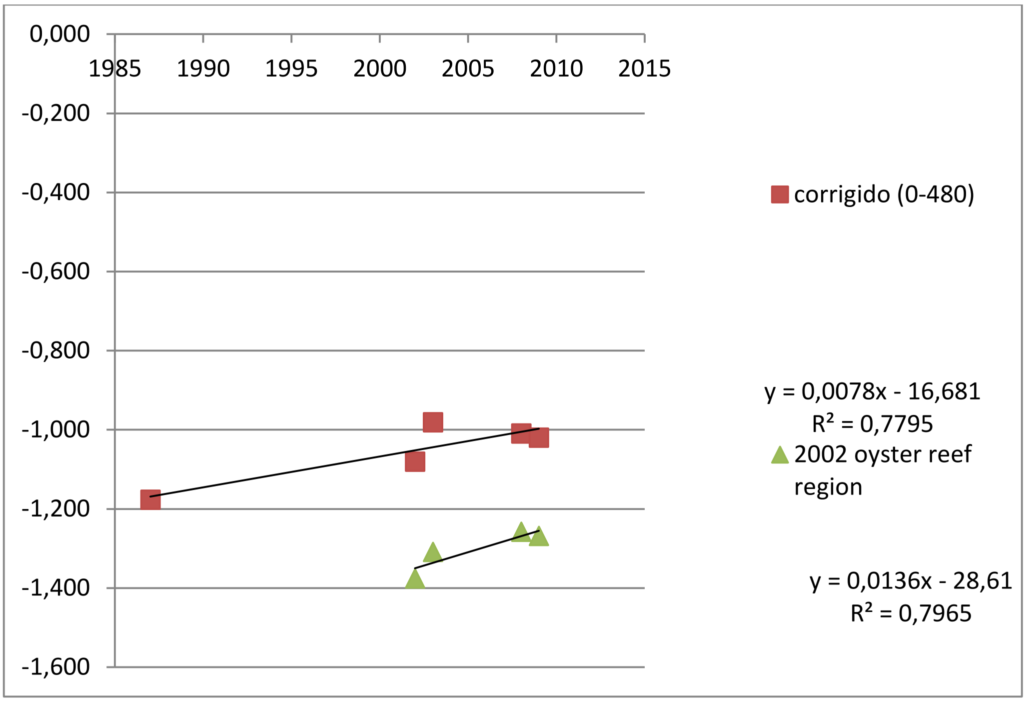

Fig. 62 Sediment height analysis of the transect R-5490 (Galgeplaat)

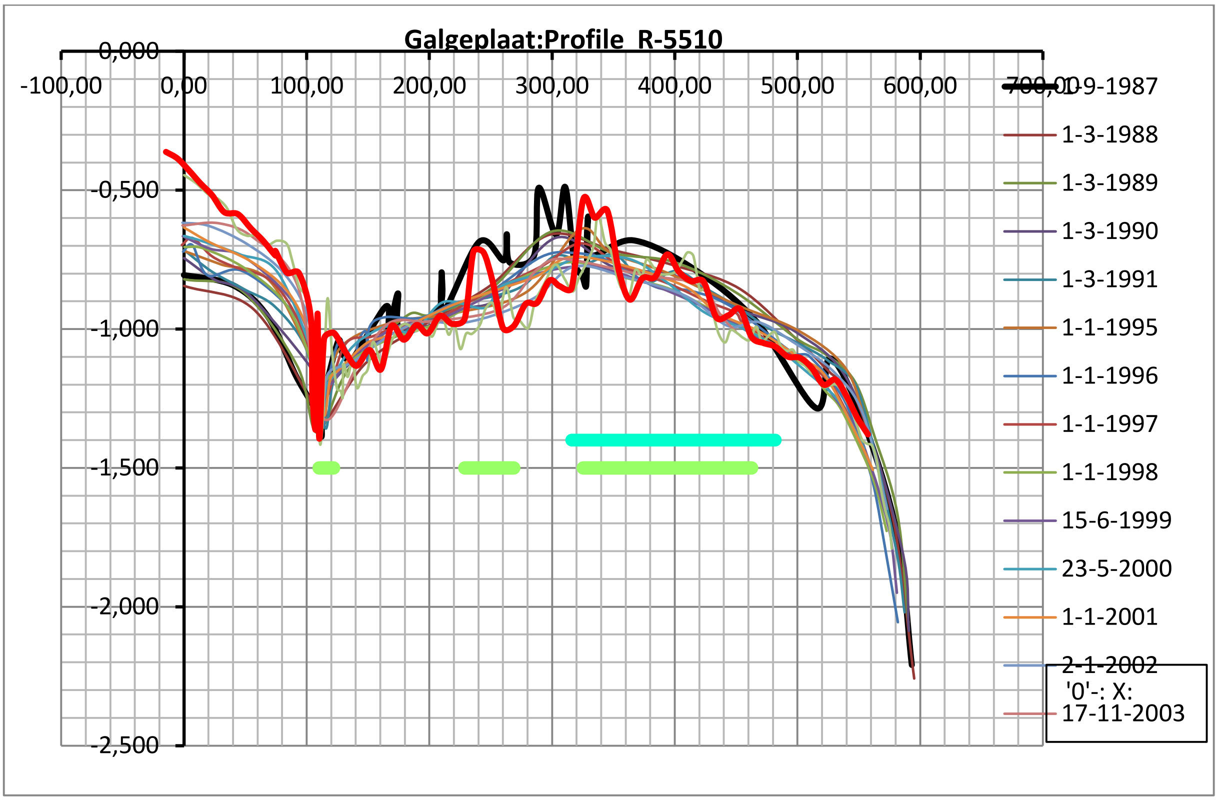

Fig. 63 Height profile of the transect R-5510 (Galgeplaat)

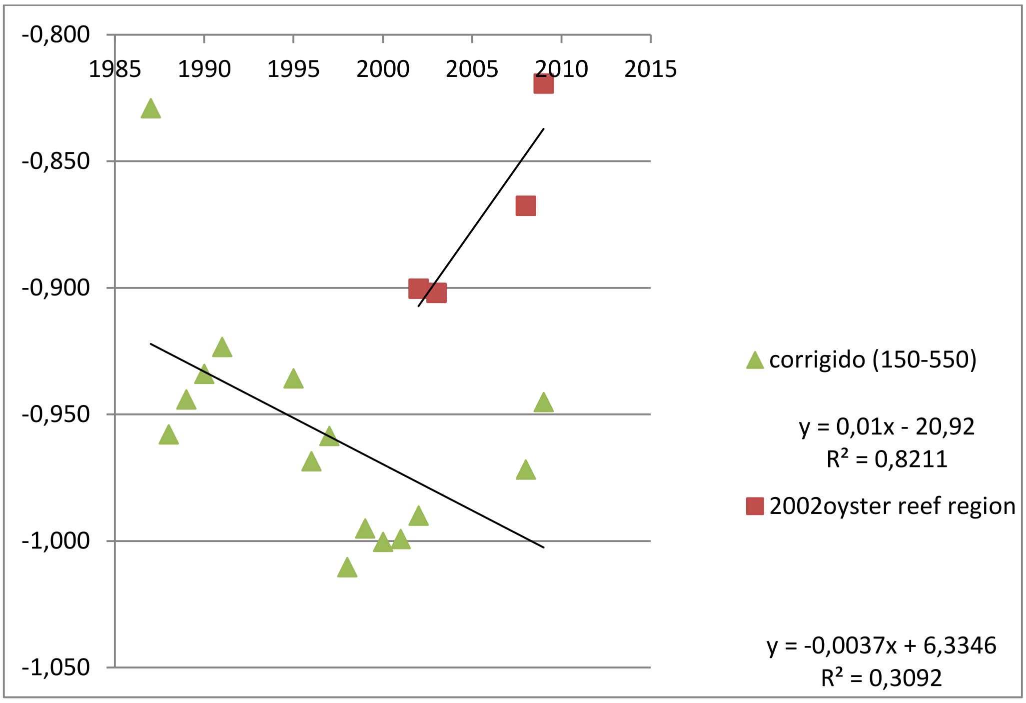

Fig. 64 Sediment height analysis of the transect R-5510 (Galgeplaat)

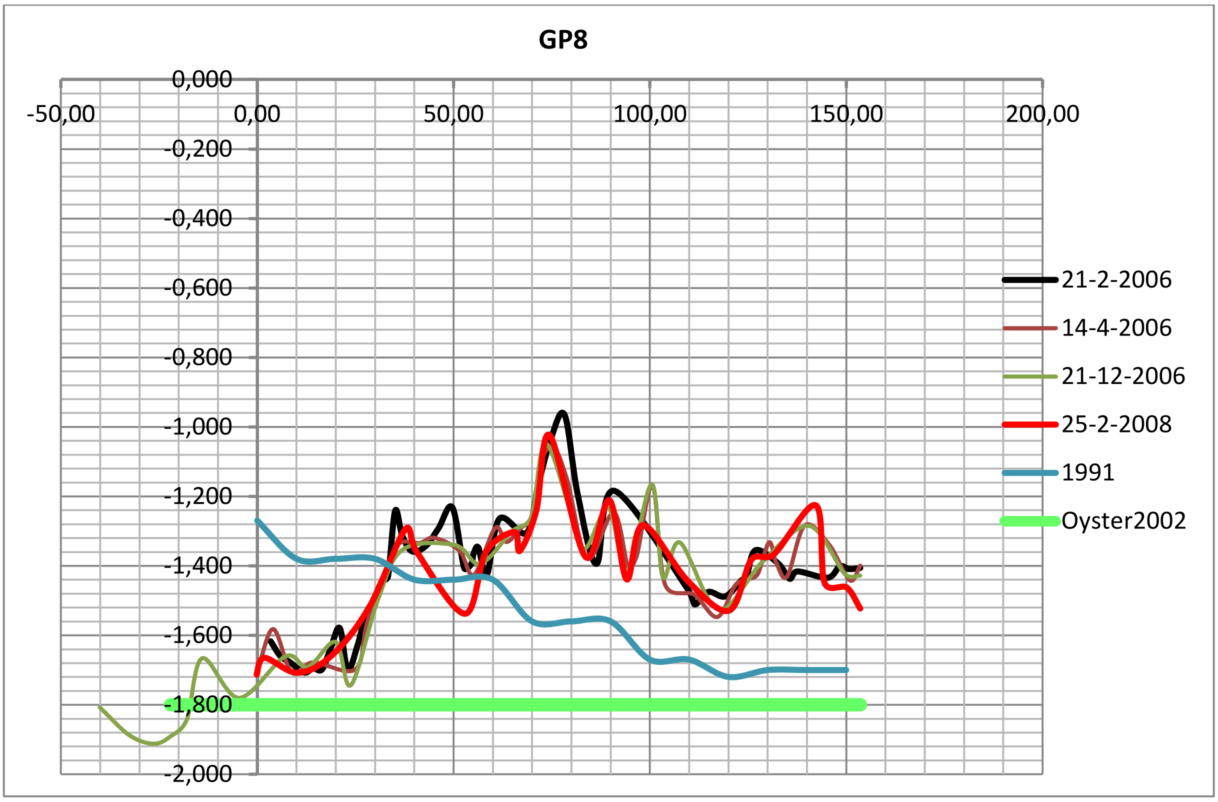

Fig. 65 Height profile of the transect GP8 (Galgeplaat)

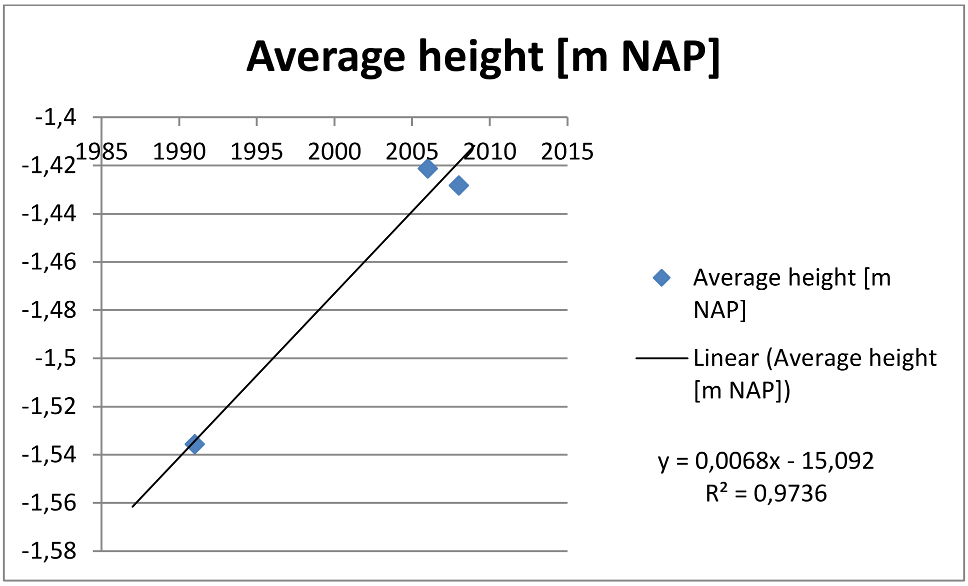

Fig. 66 Sediment height analysis of the transect GP8 (Galgeplaat)

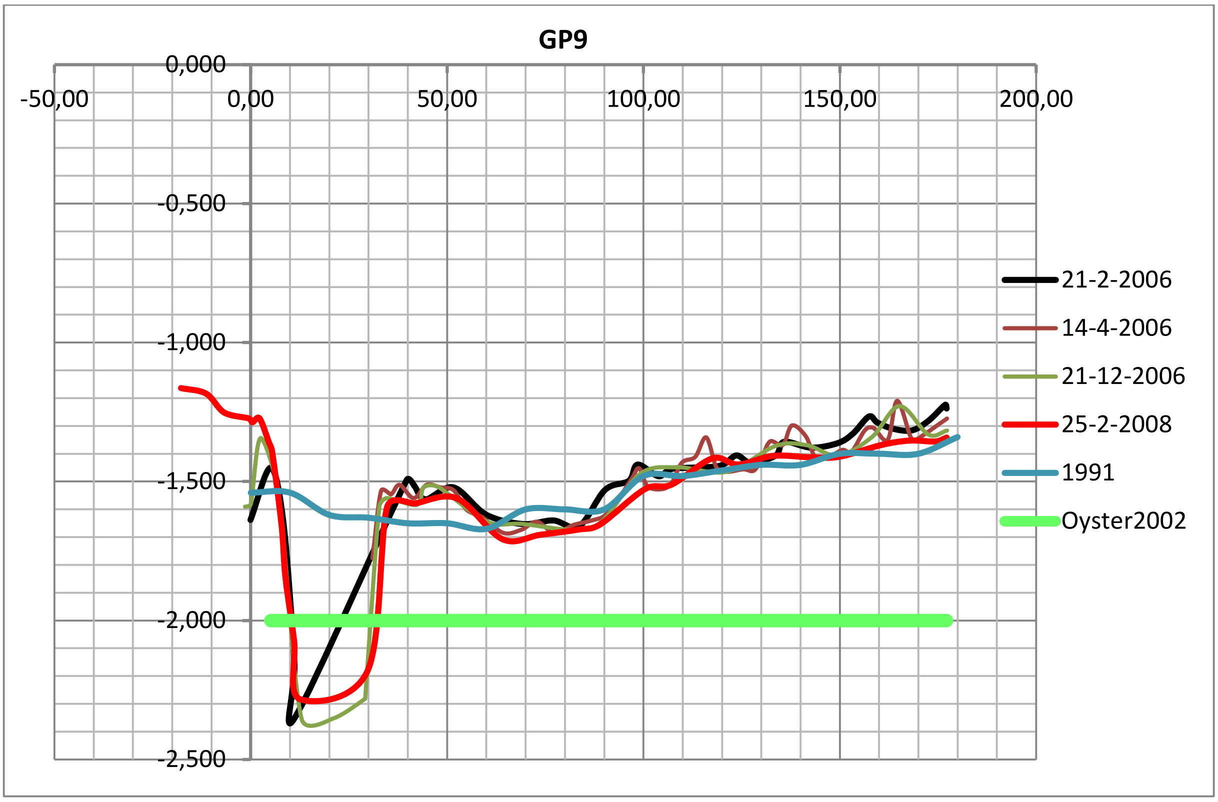

Fig. 67 Height profile of the transect GP9 (Galgeplaat)

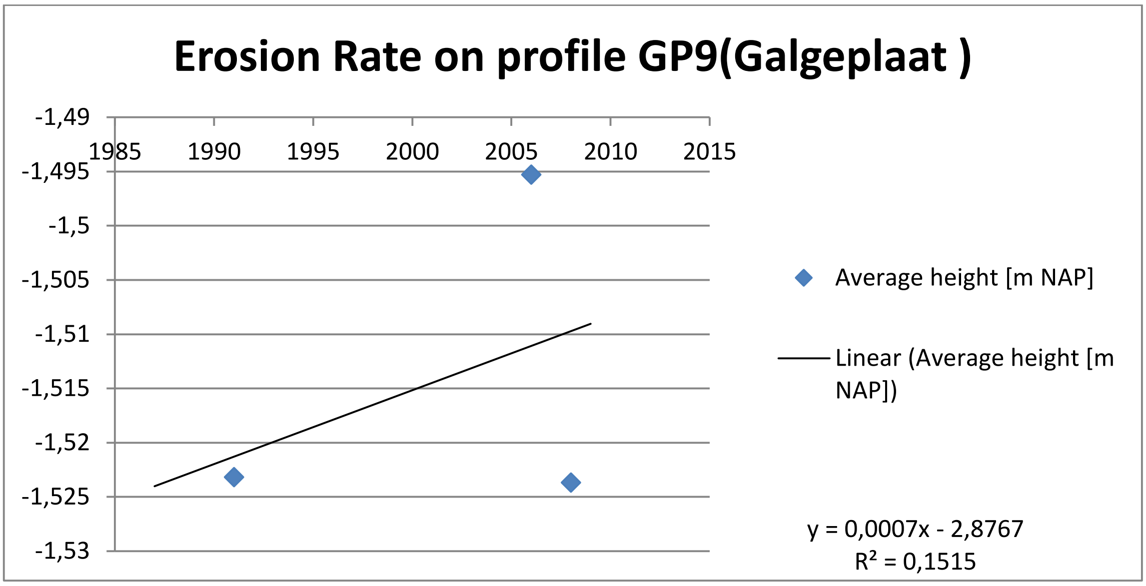

Fig. 68 Sediment height analysis of the transect GP9 (Galgeplaat)

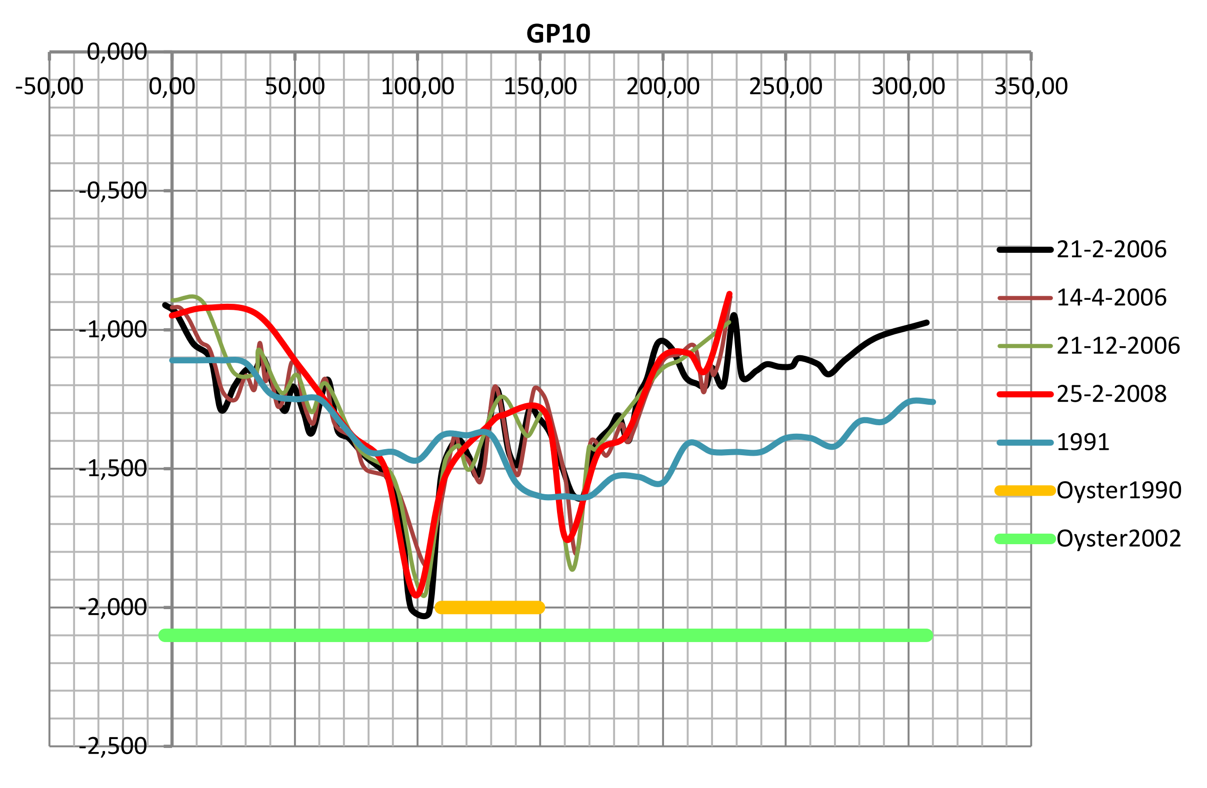

Fig. 69 Height profile of the transect GP10 (Galgeplaat)

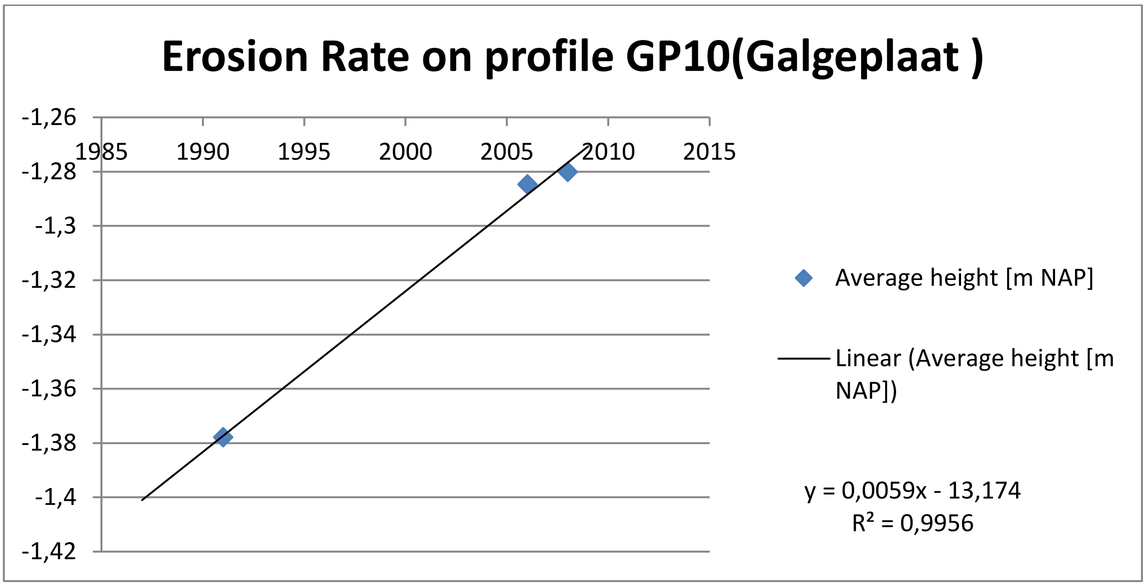

Fig. 70 Sediment height analysis of the transect GP10 (Galgeplaat)

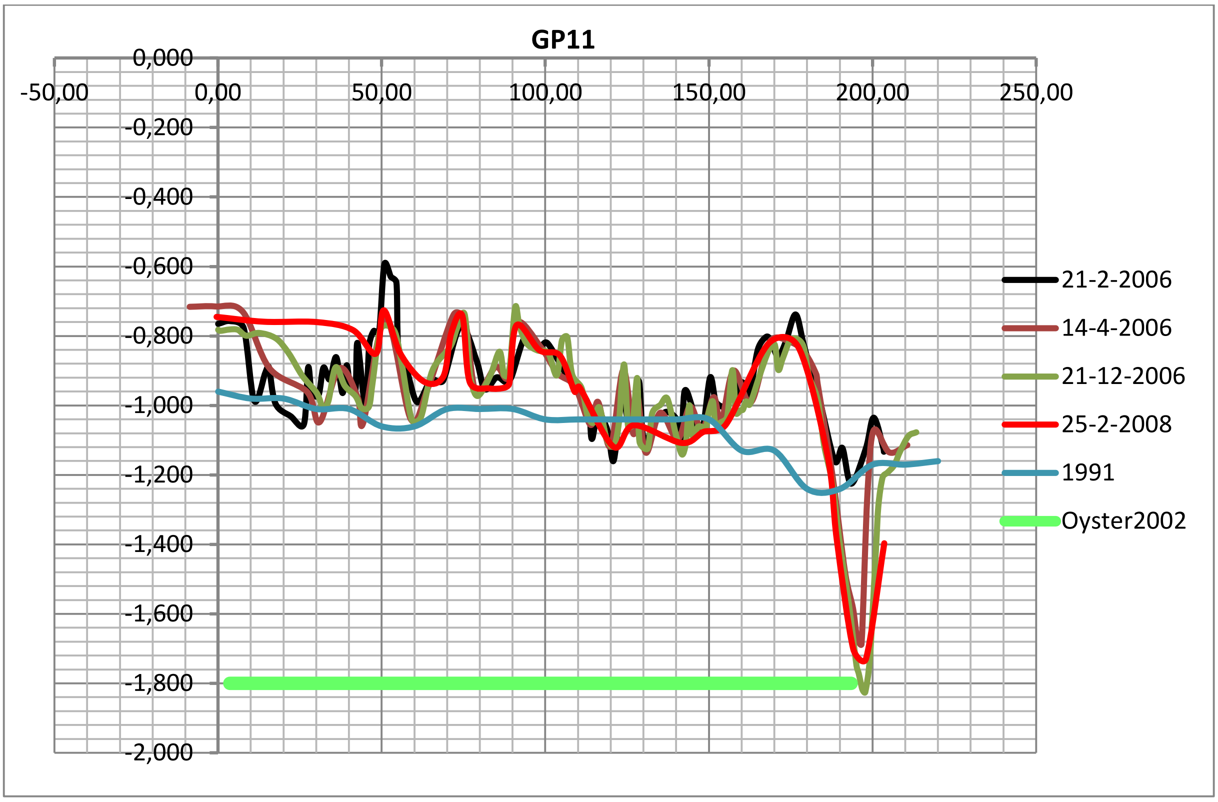

Fig. 71 Height profile of the transect GP11 (Galgeplaat)

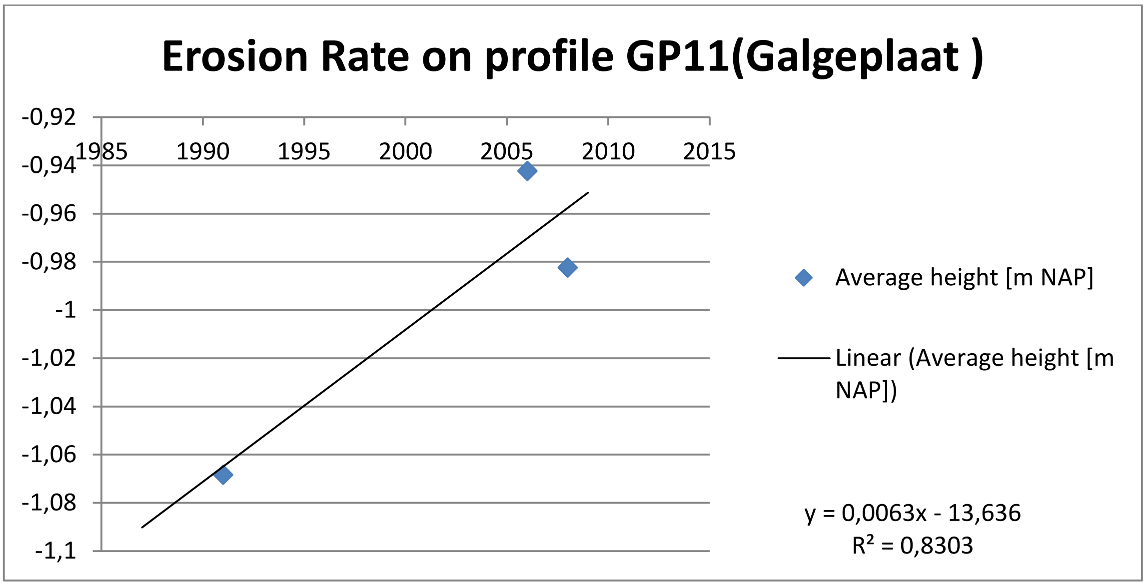

Fig. 72 Sediment height analysis of the transect GP11 (Galgeplaat)

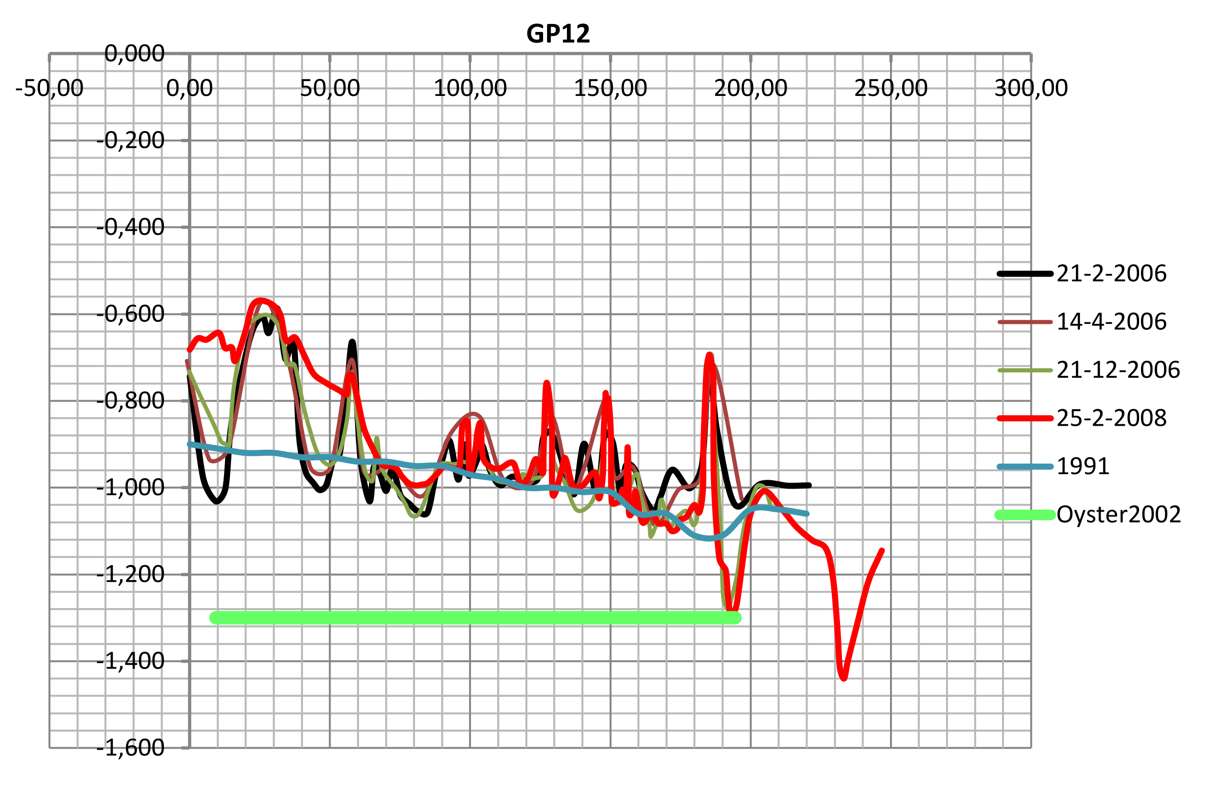

Fig. 73 Height profile of the transect GP12 (Galgeplaat)

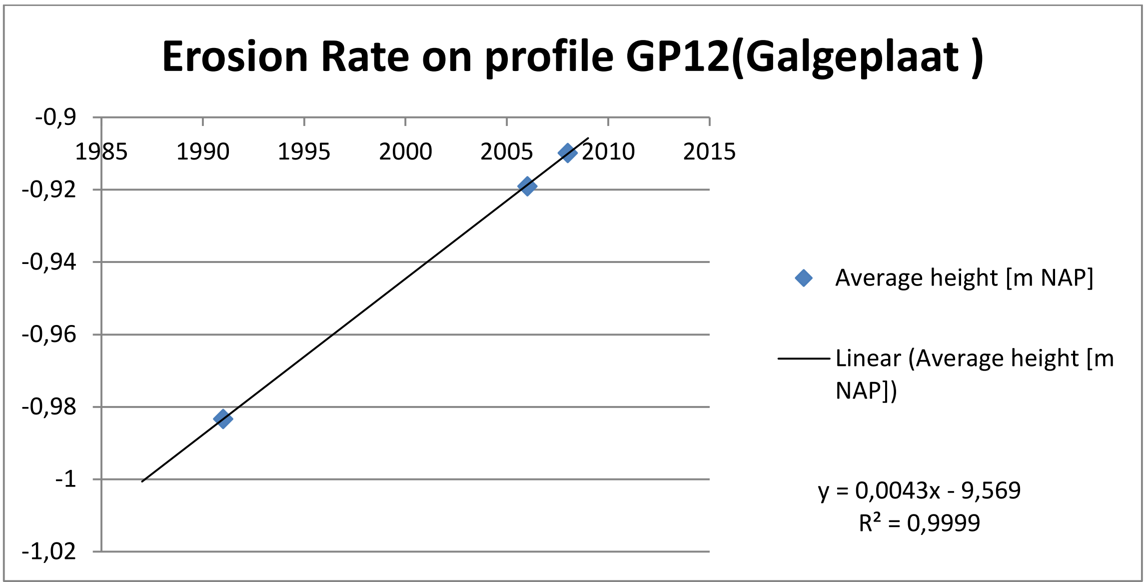

Fig. 74 Sediment height analysis of the transect GP12 (Galgeplaat)

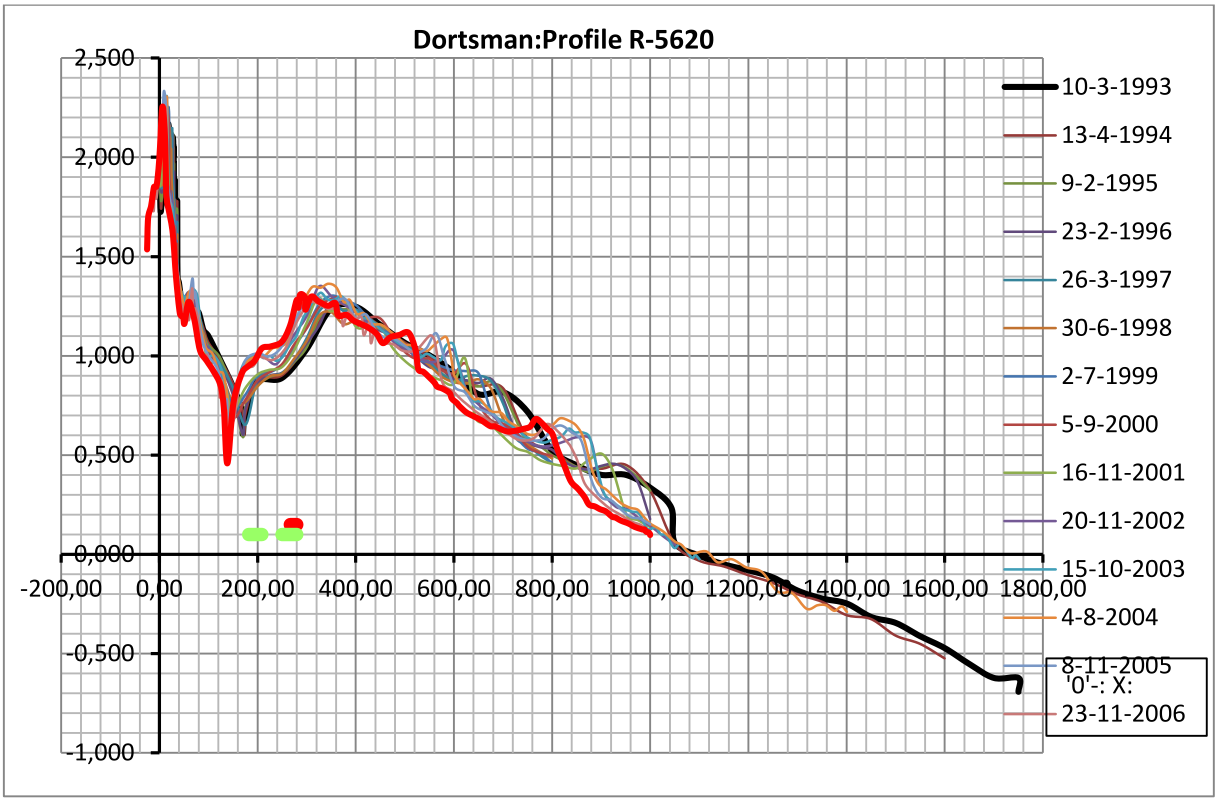

Fig. 75 Height profile of the transect R-5620 (Dortsman)

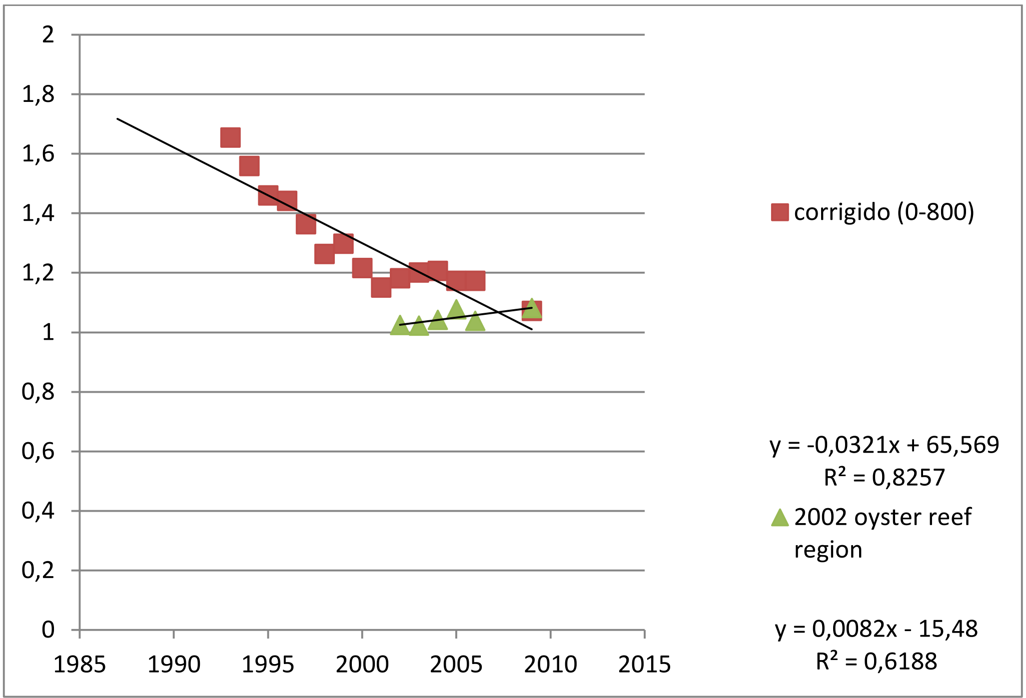

Fig. 76 Sediment height analysis of the transect R-5620 (Dortsman)

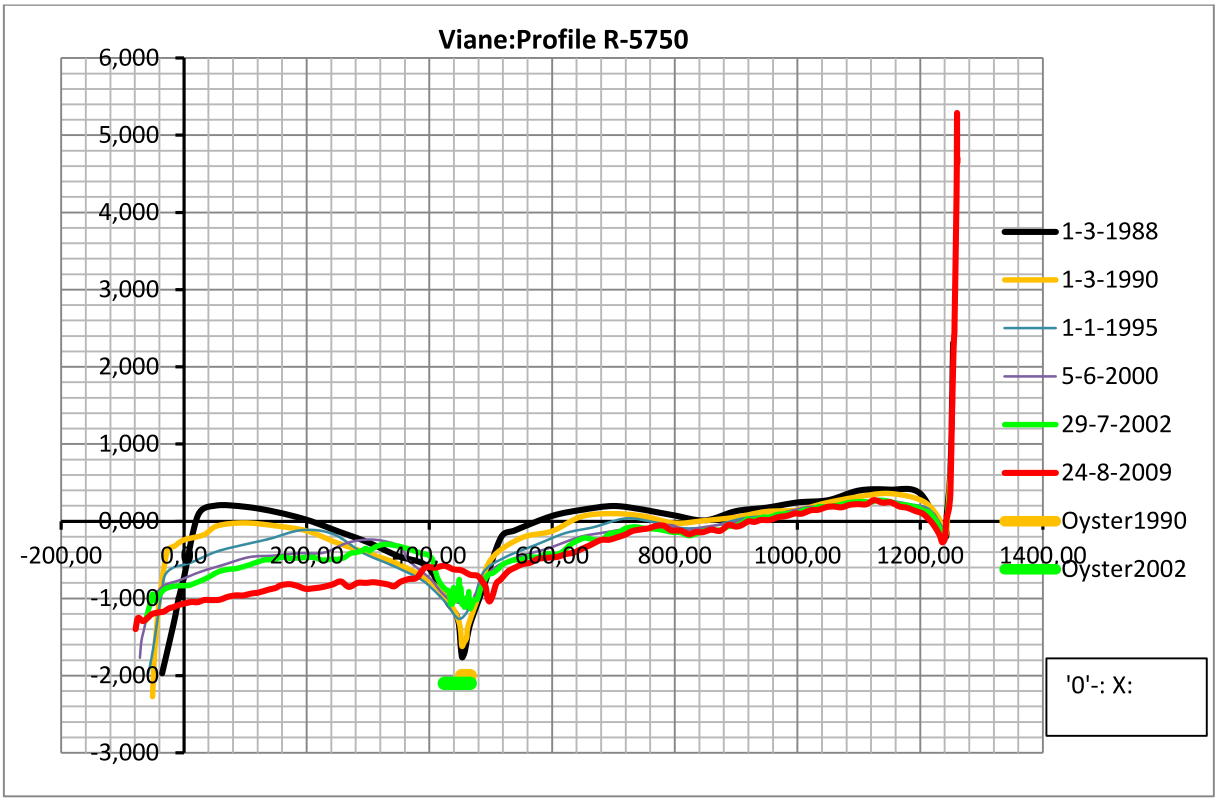

Fig. 77 Height profile of the transect R-5750 (Viane)

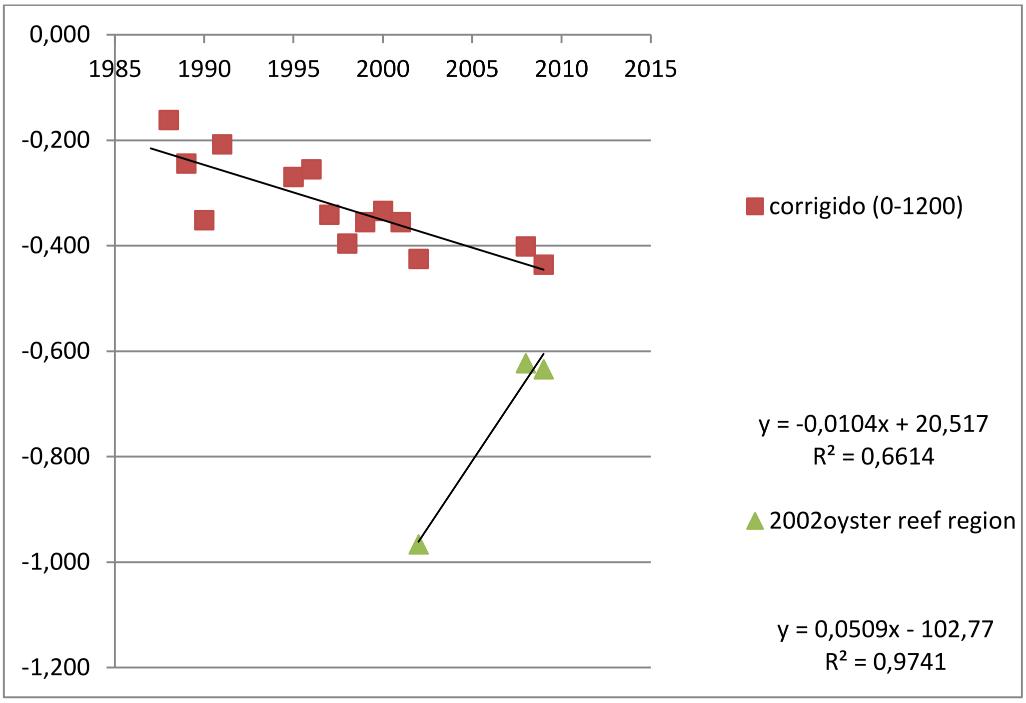

Fig. 78 Sediment height analysis of the transect R-5750 (Viane)

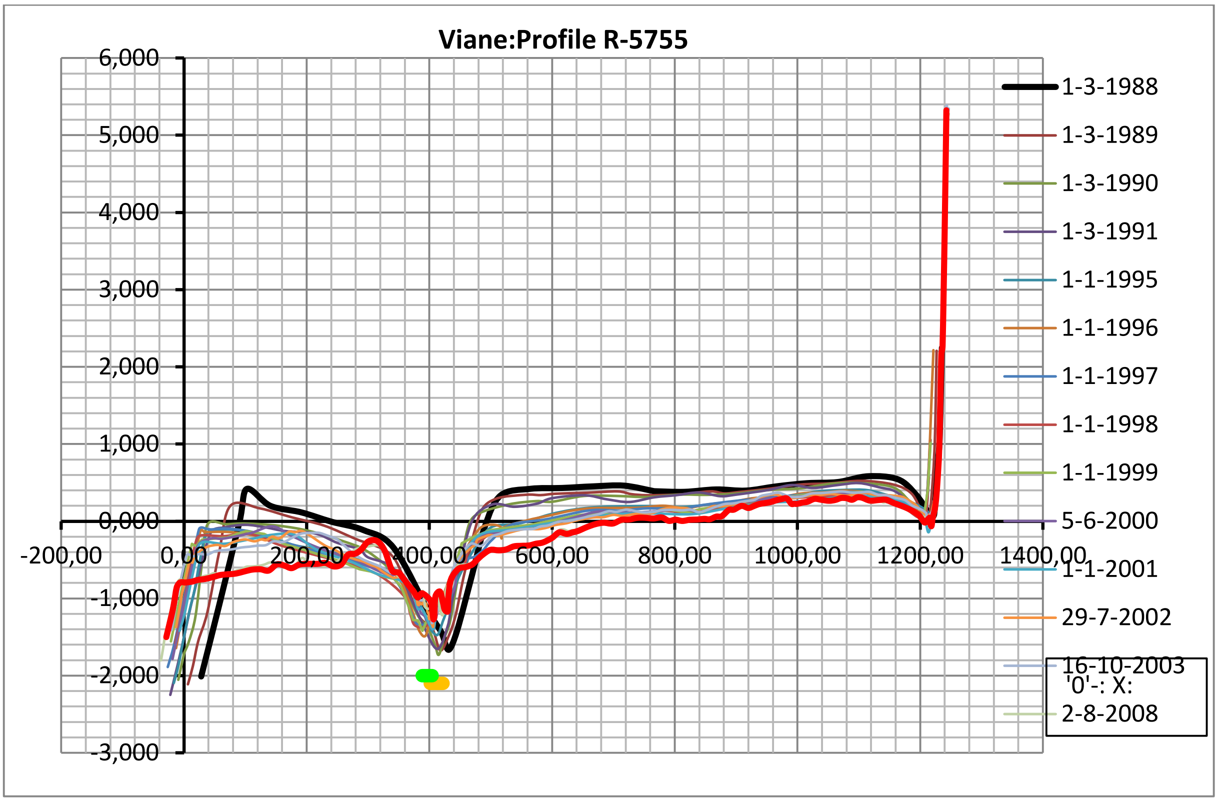

Fig. 79Height profile of the transect R-5755 (Viane)

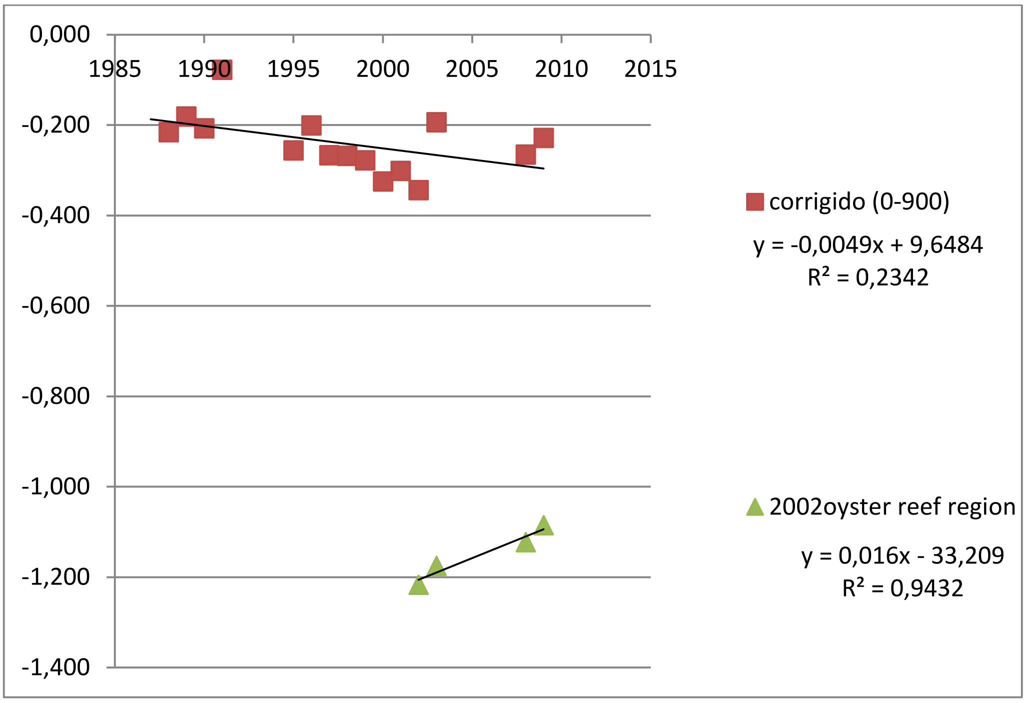

Fig. 80 Sediment height analysis of the transect R-5755 (Viane)

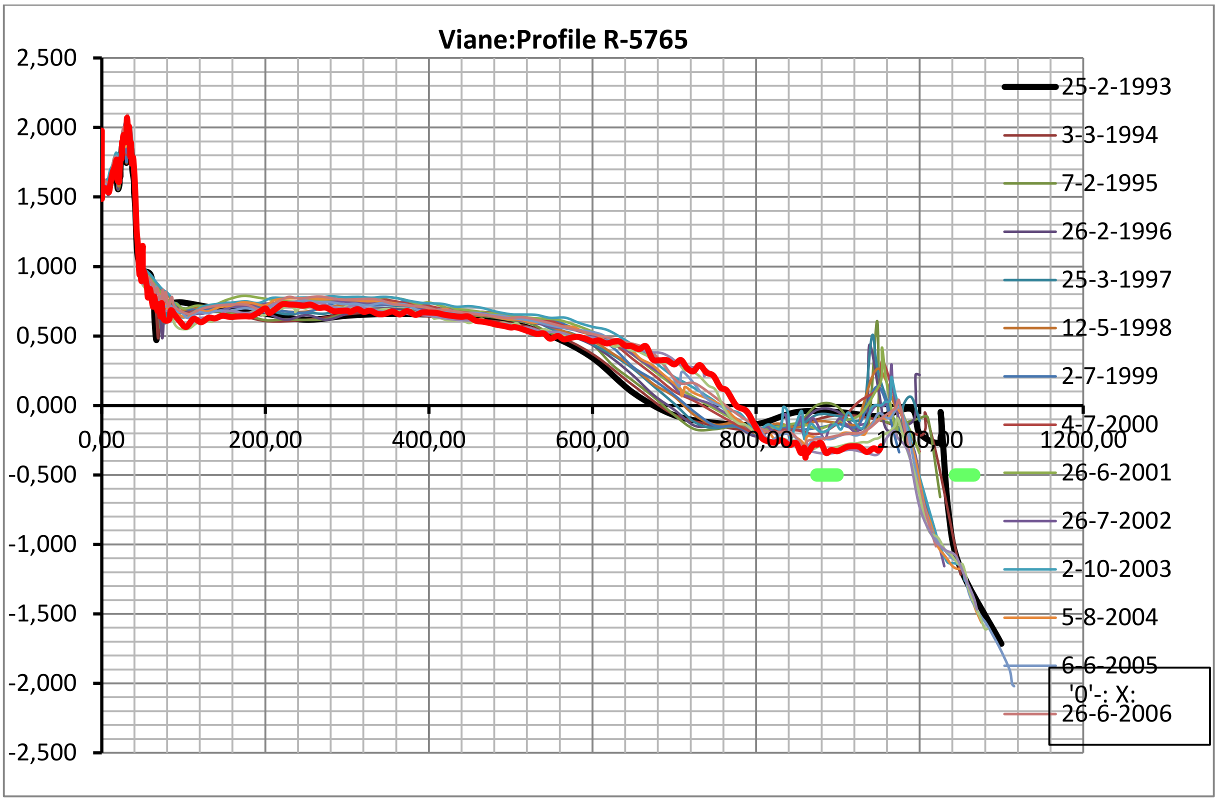

Fig. 81 Height profile of the transect R-5765 (Viane)

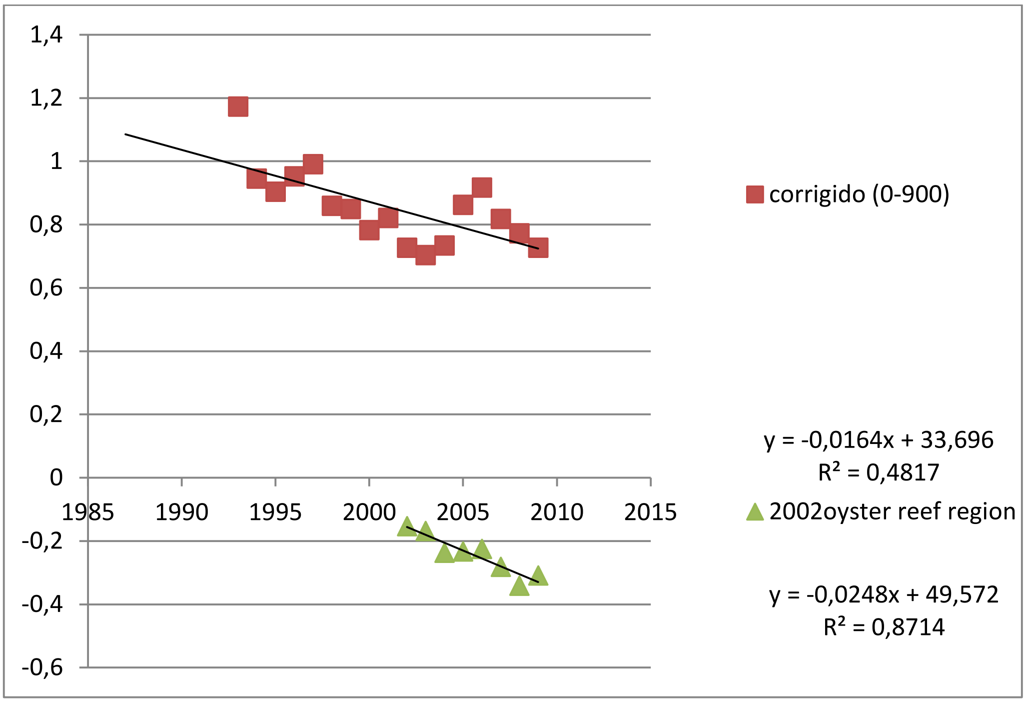

Fig. 82 Sediment height analysis of the transect R-5765 (Viane)

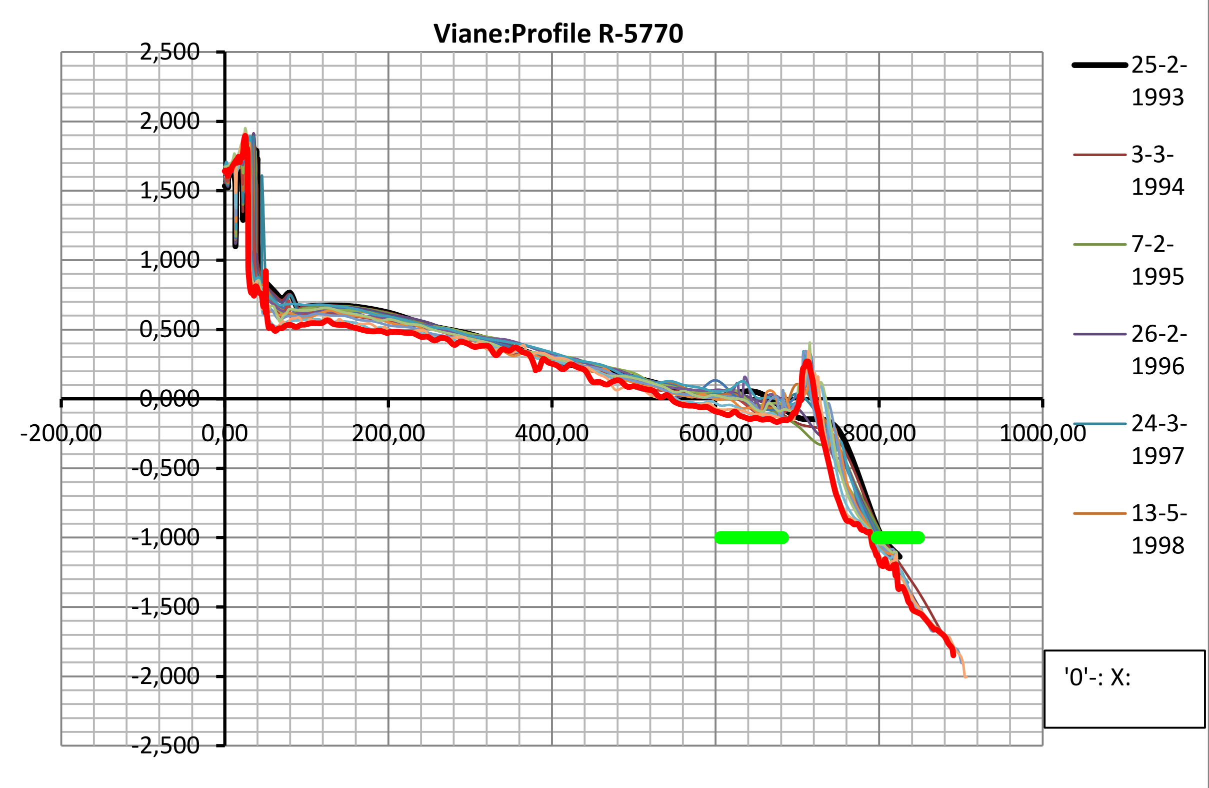

Fig. 83 Height profile of the transect R-5770 (viane)

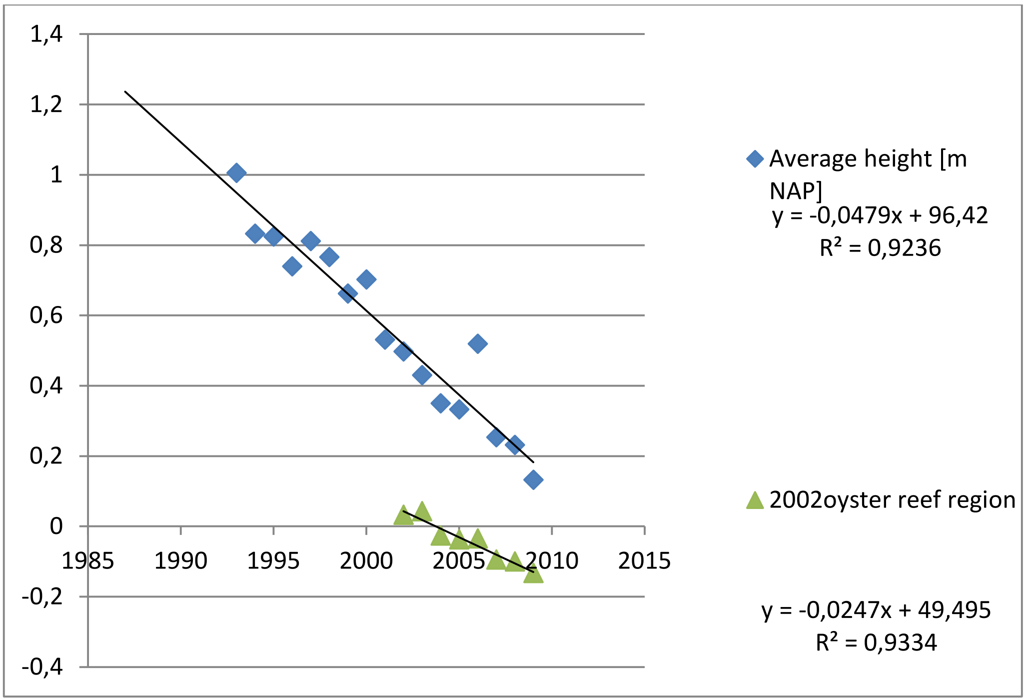

Fig. 84 Sediment height analysis of the transect R-5770 (Viane)