

FAIRWAY MAINTENANCE OF THE LOWER IJssel

FINAL REPORT

Master Thesis:



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“No servira
como poema, pero
seguro que nunca se
ha escrito uno mas
largo. Muchas
felicidades”

Summary

“Fairway Maintenance of the river IJssel”

The inland trade is a very important economical activity in The Netherland. Therefore to maintain and improve waterways is a common activity.

The main problems that threaten the safety in the shipping are the erosion and sedimentation on the banks, especially in the bend banks. So some studies are necessary to know the best method to avoid the sedimentation and erosion in these places.

This study is focused in the effect of a sand trap in the River IJssel over the sedimentation and to try to answer questions about its effectiveness and if it is possible to find a better layout for the sand trap.

To carry out this research is necessary to set-up a mathematical model which can reproduce the behaviour of the river and the sand trap. So a mathematical model has been built using the Delft3D software.

So, the effectiveness of the original sand trap has been studied and three possible alternatives have been studied too. The alternatives are:

- Two different sand traps with same volume of the original one, but shallower, longer than the original one and nearest to the sedimentation zone (alternatives A.1 and A.2).
- Sand trap with more volume than the original one and nearest to the sedimentation zone (alternative B).

The results of this study show that the effect of the sand trap over the sedimentation in a bend located 2 km downstream of the sand trap is non-existent. Also the results show that the alternatives A.1, A.2 and A.3 are more efficient, it means that they catches more sediments, but they don't produce any effect over the sedimentation zone.

To study the effect of a bigger sand trap and nearest to the sedimentation zone is necessary. Also it is recommended to improve the data about sediment transport, bed levels and discharges in the lower stretch of IJssel. These data will be necessary to carry out a better mathematical model.

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1. Introduction

Because of the special location of The Netherlands, the inland trade is a very important activity in the country. Through the channels a lot of commercial ships arrive to different countries in Europe and deliver to them their commodities.

So a lot of transport companies use the fairways in The Netherlands to deliver their products. These companies choose this mean of transporting because is cheap and safe. But to guarantee this safety is necessary to maintain an enough depth for shipping and navigation.

The main problem that threatens the shipping in the channels is the sedimentation. When in a stretch of a river the sedimentation appears the depth decrease. It produces that the load of the commercial ships has to be decreased too. If the sedimentation continues, the load of the ships has to be reduced all the time. In this way there is a point where is not economical to use the inland trade, and the companies can decide to use another mean of transporting.

To avoid this situation, the government of The Netherland uses some methods. For example dredging is a very common activity to avoid the sedimentation. The problem is that this activity is very expensive and is necessary to do it a lot of times. Another alternative is to dig a sand trap upstream the sedimentation zone.

This problem of sedimentation appears in the lower stretch of the river IJssel.

The River IJssel is a branch of the Rhine in the Dutch provinces of Gelderland and Overijssel. River IJssel flows from Westervoort, east Arnhem, until it discharges into the IJsselmeer ("Lake IJssel").

This study is concentrated on the morphology and the sedimentation of the lower IJssel River stretch (in the km 999.5 more or less), downstream Kampen.



Figure 1.1

There are a lot of factors that characterize the morphology and behaviour of this IJssel River stretch:

- The IJssel River has two outlets: The Kattendiep with 400 m length, and the Keteldiep with 4000m length. The main function of the first one is to discharge most of the water volumes and sediments, and the Keteldiep is used for navigation. To improve the function of the Kattendiep there is a groyne at the right bank. This groyne prevents the excessive silting up of the Keteldiep.

- Several works have been carried out in order to improve the incoming and leaving shipping in Kampen:

- The depth of the fairway in the Keteldiep and Lower IJssel has been increased.

- Sand trap has been dredged upstream of the improved stretch. The sand trap purpose is to avoid the shoaling in the inner bend of the IJssel at the crossing highway (N50, bridge site).

- There is a movable bridge over the N50. But the movable part of this bridge is not in the fairway, it is located in the inner bend of the IJssel River at the left bank. The function of this movable part is to let the brown fleet go through a shipyard upstream the bridge. The commercial ships go through the bridge by the fairway. The commercial ships through the bridge for the outer bend.

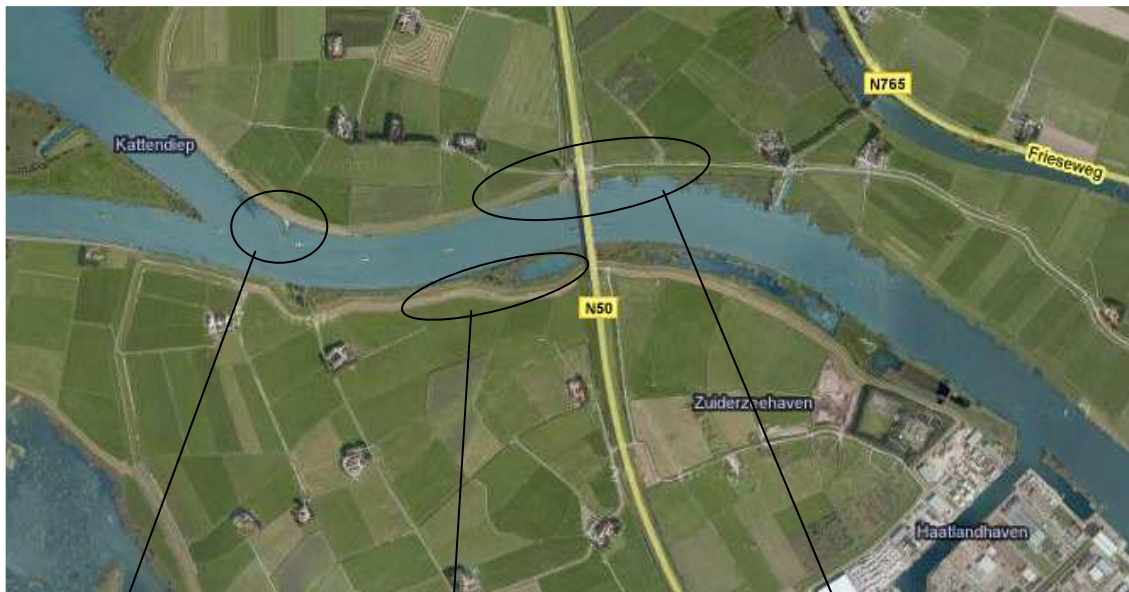


Figure 1.2

Groyne

Sedimentation zone (km 999.8)

Erosion zone

This study is focused in the behaviour and effectiveness of the sand trap.

It is known that sand trap increase the depth of the stretch where it is dug, it reduces the velocity of flow, and it produces the sedimentation of the suspended sediments. Producing this sedimentation over the sand trap, the sedimentation downstream is less than it used to be.

Although the real behaviour of sand traps is not really known. To know the real yearly filling of sand traps and how they move over the bed of the river are knowledge gaps.

Looking for these knowledge gaps, this study tries to answer the main questions about the sand trap dug in the lower stretch of the river IJssel:

- Is true the estimated year filling?
- Is the sand trap improving the situation, and reducing the sedimentation?
- Is it possible to find another layout for the sand trap more effective than the original one?

To carry out this study, a mathematical model has been built with the program Delft3D. The results show that the yearly filling is less than the estimated one, and also show that the amount of sediment that arrive to the sedimentation zone downstream the sand trap is the same than before to dig the sand trap.

Another result of the study is that there is an alternative layout for the sand trap which catches more sediment with less volume than the original sand trap.

So it is possible to conclude that the effect of the sand trap in lower river Ijssel is non-existent and it would be necessary to dig the sand trap nearest to the sedimentation zone.

2 Methodology

2.1 Data used.

To build and calibrate the mathematical model, the following data have been used:

- To define the river bank geometry a GIS file with the Normal Line has been provided by Rijkswaterstaat.
- To include the topography data in the model bed levels data from Baseline have been used.
- The water levels data were obtained by website www.waterbase.nl. But before using them, the original data were transformed from the original data to daily data. The model does not arrive to the IJssel Lake, but the IJssel Lake water level was used for downstream boundary because there were not another possible data.

This simplification was possible because of this part of The Netherland is very flat, and the differences between the IJssel water level lake (km 1001.5) and the water level at the end of the model (km 1000.5) are very small.

The figures 2.1 and 2.2 show that the IJssel lake water level and Kampen water level are very similar, but in the flood periods.

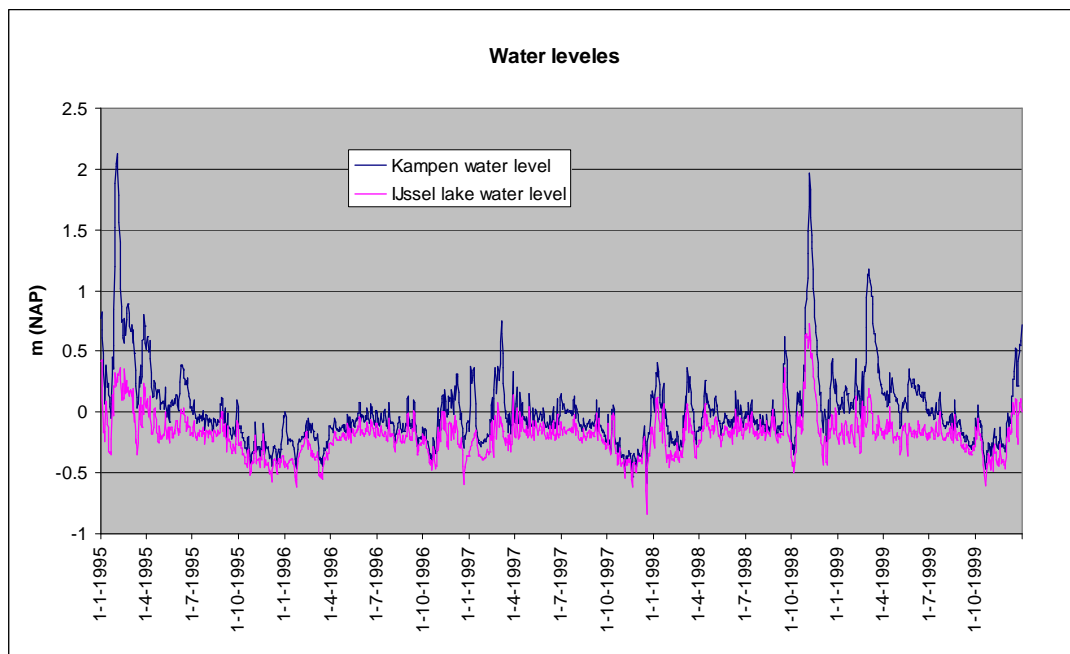


Figure 2.1 water levels in IJsse Lake and Kampen.

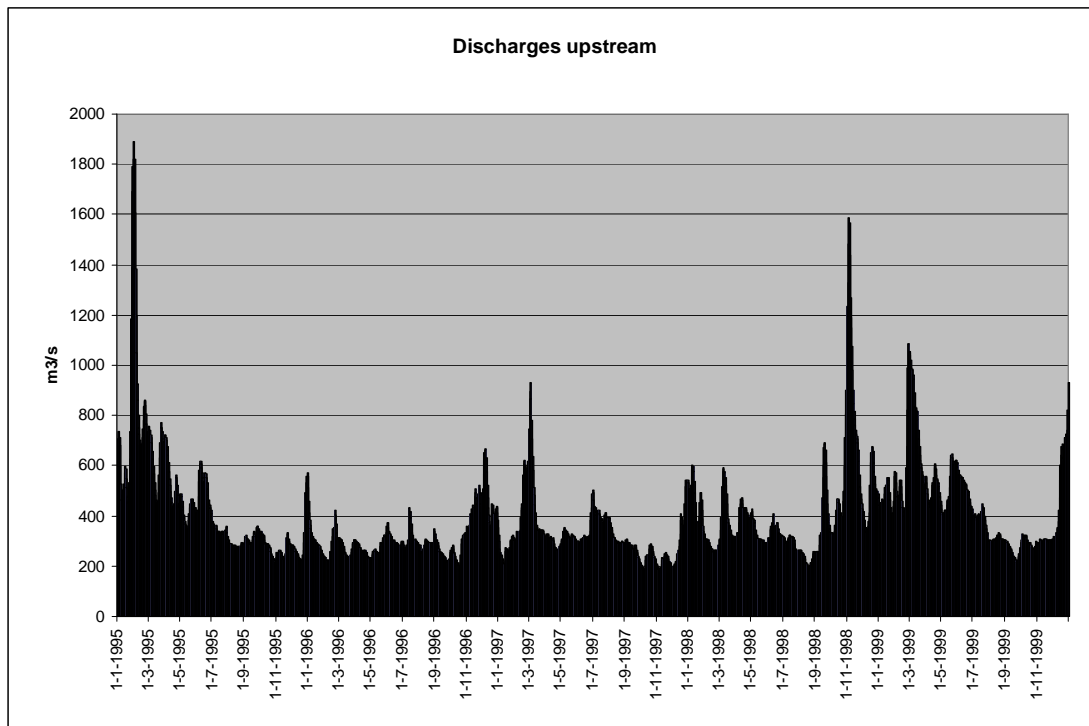


Figure 2.2 hydrogram that shows the flood periods.

Kampen is at 10 km from the lake, and the differences between their water levels are very small (but the flood periods). Therefore the differences between the downstream boundary of the model and the IJssel Lake will be negligible

- The discharge from Olst was used for upstream boundary, and it was provided by Rijkswaterstaat.

- To carry out the hydraulic calibration the water level from Kampen was used. The data that were used were from 2002 to 2004, before the works were carried.

- To morphological calibration bed levels measurements were needed. These data was provided by Rijkswaterstaat. These bed levels data have been obtained averaging over the normal width.

- The characteristics of the sand trap were provided by Rijkswaterstaat. These characteristics are:

Axis sediment trap equal to axis of the river.

Bottom width of the sediment trap equal to 75 m.

Bed level of the sand trap: 1.5 m below mean bed level.

Talus of sand trap slopes equal to 1:3.5.

The sand trap reaches from km 997 to km 998.

- To carry out the calibration after digging the sand trap, data from bed levels of the river after 2004 were necessary. So Rijkswaterstaat sent some pictures of the sounding topography of the Lower IJssel. Using these pictures, the evolution of the sand trap between 2005 and 2006 was studied.

It is important to say that to obtain data for the study was not easy. When the data were asked to Rijkswaterstaat, it sent a DVD with files in GIS format. Inside this DVD was all the data about bed levels that Rijkswaterstaat had. However to read this DVD was not possible. Therefore it was necessary to find another source of data. At the end the quantity of data for this study was very reduce and it produced some problems while the calibrations.

For example during the longitudinal calibration the restricted quantity of data and the small length of the model produced that the results obtained in this calibration were not so good.

Also for the calibration after digging bed levels of the river after 2004 were necessary. But these data were not possible because finding these bed levels took a long time. It was because of the structure to organize of Rijkswaterstaat was changing and it produced that it worked very slowly. Because of that, the pictures (about sounding topography) already mentioned were used.

2.2 Model Used:

Delft3D, version 3.26.00, software has been used to carry out the mathematical model.

This program has been developed by WL Delft Hydraulics. This software is able to carry out a multi-disciplinary approach and 3D computations for coastal, river and estuarine areas. Thus Delft3D can be used for setting-up models that include flow simulations, sediment transport, waves, water quality, morphological development and ecology.

The Delft3D program is composed of several modules, grouped around a mutual interface. All these modules are capable to interact to each other.

The following modules have been used to carry out several parts of the model: Delft3D-FLOW, Delft3D-QUICKPLOT, Delft3D-RGFGRID and Delft3D-QUICKIN.

Delft 3D-FLOW is a multi-dimensional hydrodynamic and transport simulation system, which calculates non-steady flow and transport phenomena as a result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid.

The module Delft3D-RGFGRID has been used to generate the computation grid. This module is a program for generation and manipulation of curvilinear grids for Delft 3D-FLOW. Thus the function of this module is to create, modify and visualize orthogonal and curvilinear grids.

Delft3D-QUICKIN is a program to create, manipulate and visualize bathymetries models for the Delft 3D-FLOW. The module Delft3D- QUICKIN has been used to add the topography data to the model.

Delft3D-QUICKPLOT is a program that can be used to visualise and animate the numerical results produced by the Delft3D modules.

2.3 Computations:

2.3.1 Initial considerations:

Before building the model, some theoretical decisions were needed.

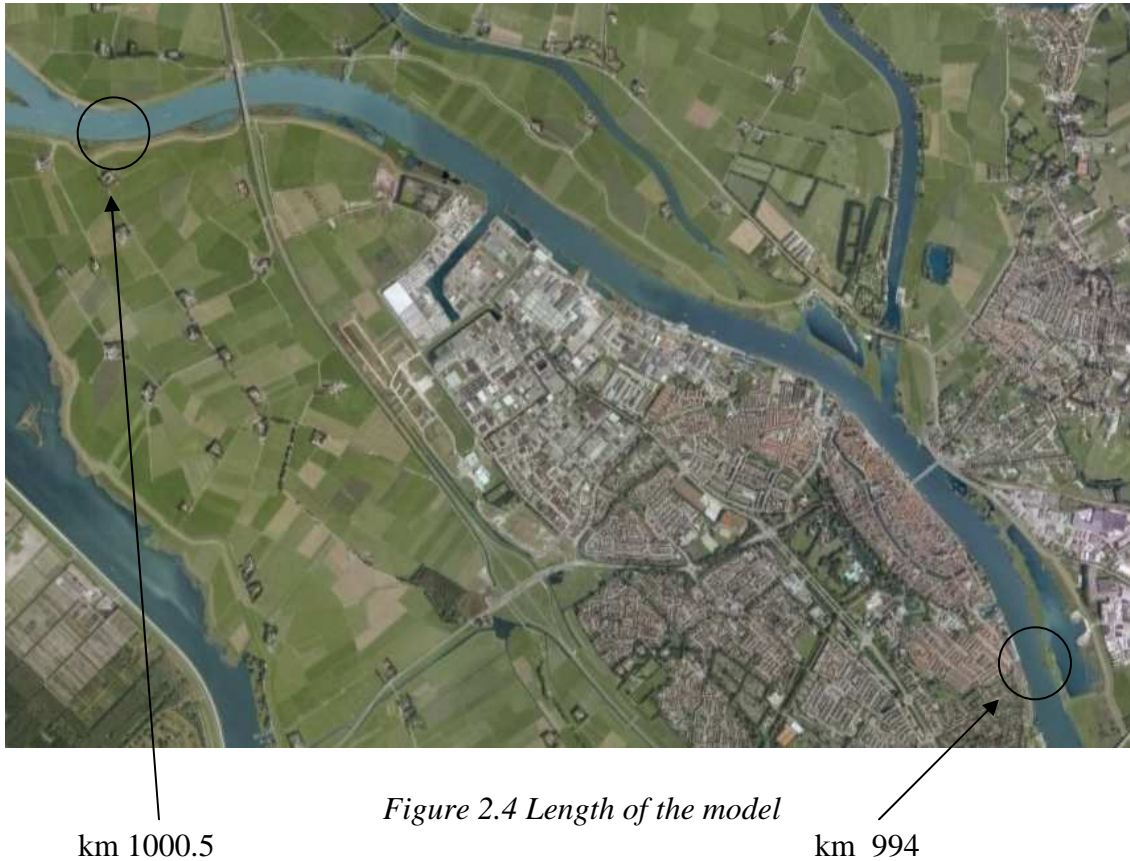
First it was necessary to decide if the flood areas had to be included in the model or not.

The large-scale morphology is primarily determined by the main channel, therefore only the main channel was introduced in the model. Indeed, the location of the flood dykes in the river was very near to the river line which reinforced the decision to study only the river.



Figure 2.3: Flood dikes

Another theoretical decision was the choice of the length of the model. To carry out a morphological study is necessary a model with a bigger length because of the effects of inflow boundaries propagate with a speed of about 1 km/year. Therefore the length of the model was from km 994 to km 1000.5.



2.3.2 Set up the model:

Generation of the computation grid: The first step to set-up the model is to generate the computation grid.

The module Delft 3D-RGFGRID has been used to carry this out. In order to minimize the errors in the finite difference approximations, Delft 3D-FLOW uses curvilinear grids. So grid lines may be curved along land boundaries and channels, so the notorious ‘stair case’ boundaries, that can induce artificial diffusion, can be avoided. Furthermore the curvilinear grid must have two characteristics:

- It should be smooth in order to minimize errors in the finite difference approximations.
- the grid has to be orthogonal. The orthogonal factor has to be 0.05 or less.

Introducing the data of the Normal line in the module Delft3D-RGFGRID the figure 2.5 has been obtained, which represents a sketch of the part of the River IJssel that is going to be modeled.

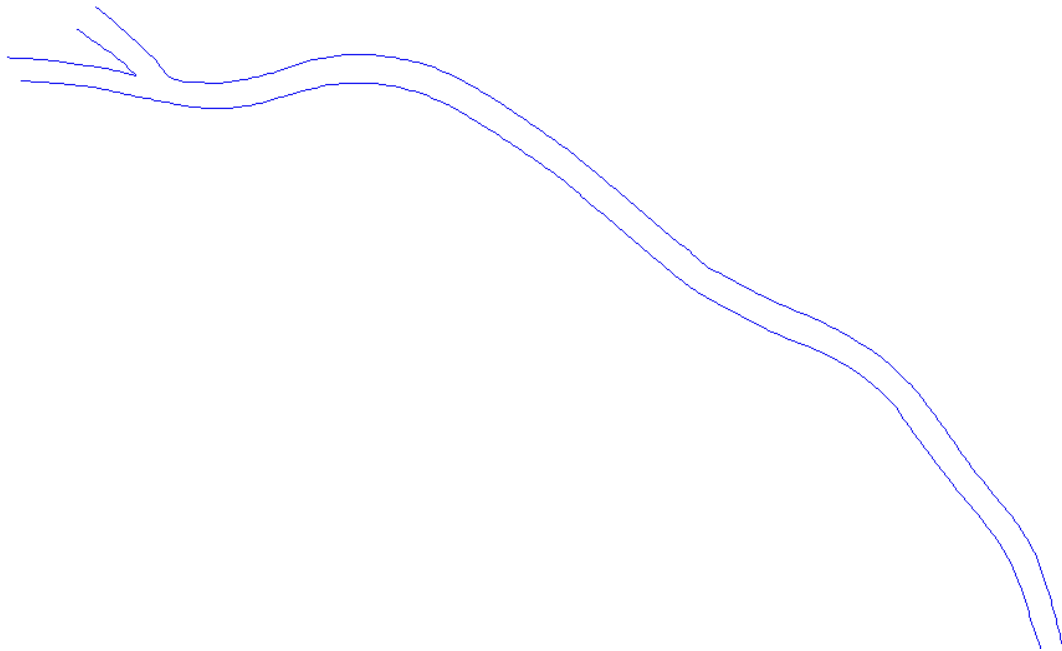


Figure 2.5 Normal Line

Inclusion of the bifurcation in the model would produce a lot of problems because generating grid line in that place would be very difficult, and the results that would be obtained would not be reliable. In addition to this, the main goal of this project is to study the behaviour of the erosion and sedimentation in the last bend, and the behavior of the sand trap. So not to include the bifurcation in the model was decided.

For the same reasons the large groyne, located just before the bifurcation, was decided not to be included.

To make the land boundary, the river bank geometry of the river has been simplified. Thus the real bank has different elements such as groynes and banks which are not represented in the normal line. Therefore the normal line is a simplification of the bank, but this simplification will not affect the results of the model.



Figure 2.6 Example of Normal lines without groynes and banks

After the Normal Line, the 'splines' were built. Thus the model was started with a rough sketch of the grid by lines. Delt3D program has several tools to put the grid lines in the right position. For instance, a grid line can be 'snapped' to a land boundary, this is the method that has been used.

So, after some attempts, and after 'snapping' the 'splines' to the land boundary, the figure 2.7 was obtained.

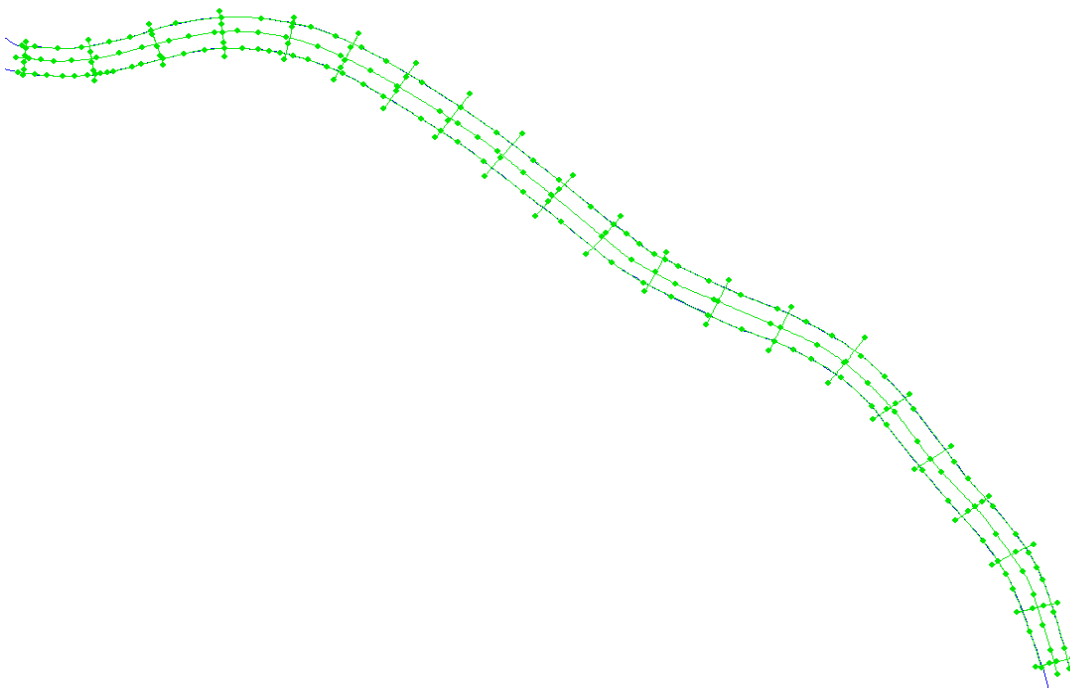


Figure 2.7 ' Splines' following the land boundary

The next step was to create the grid. But first the size of the grid was decided. After some trials a grid of 16 cells on width direction by 160 cells on length direction was created. Therefore the length size of the cells was between 3 and 4 times the size transverse.

This decision was based in the idea that the flow was in M direction (length direction). Therefore the length direction must be bigger than the width direction.

Once the size of the cells was decided, the grid was created. The figure 2.8 shows the result.

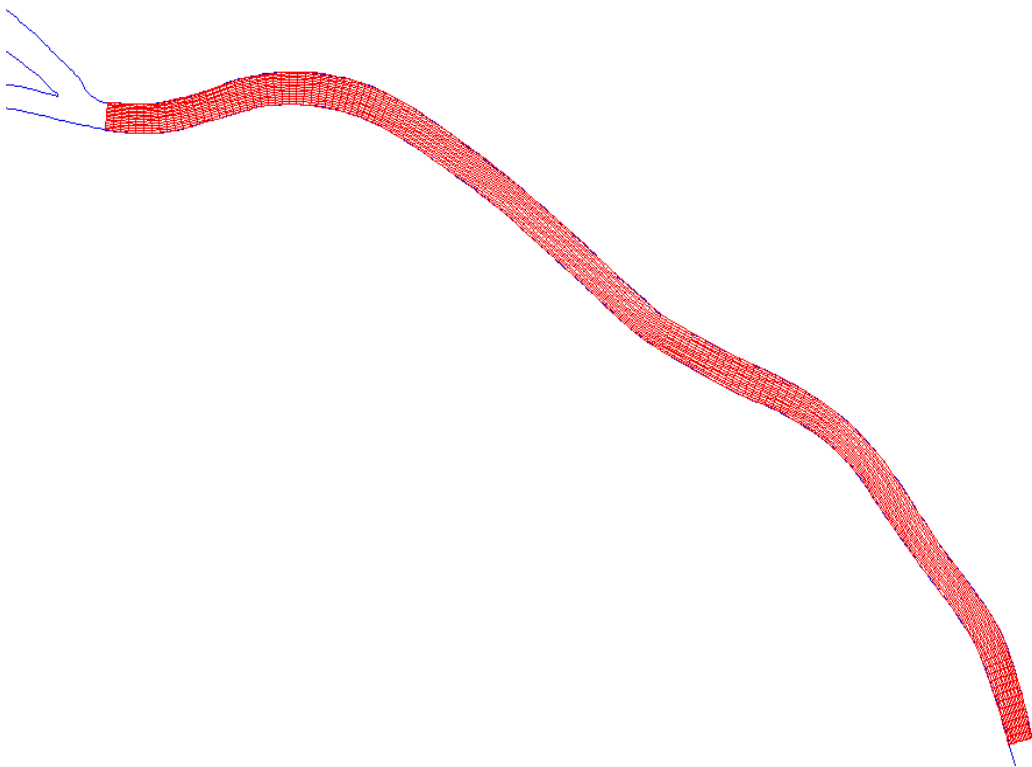


Figure 2.8 Grid of the model

After the grid was done, the grid was fixed to the land boundary, and its orthogonality was increased until reach a value of orthogonal factor of 0.01 (the maximum allowed is 0.05). The figure 2.9 shows the different value of orthogonal.

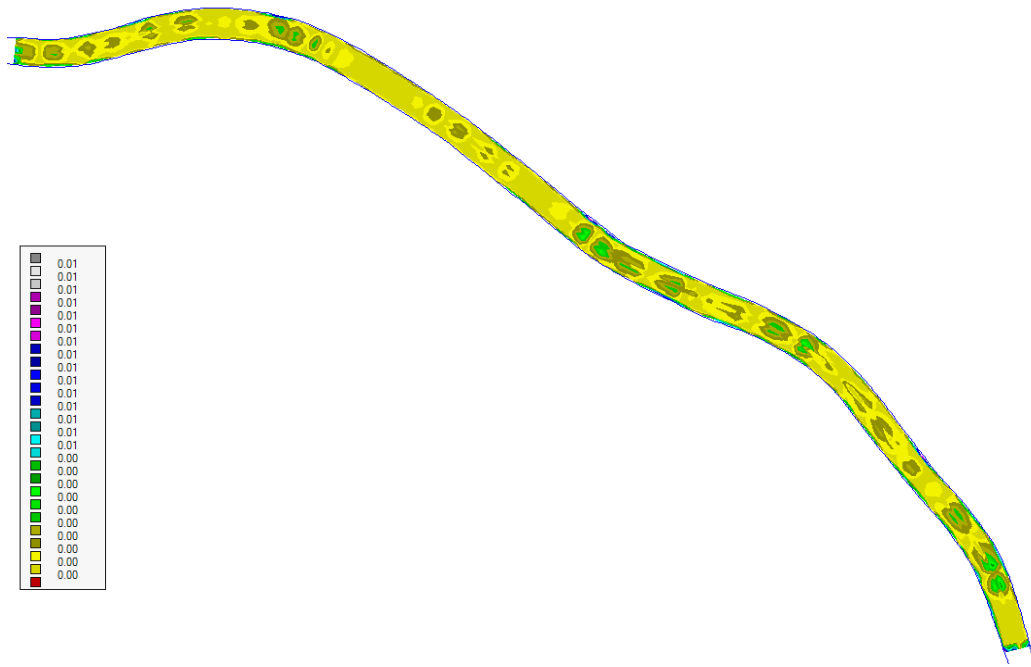


Figure 2.9 The legend shows the different value of orthogonal factor (between 0 and 0.01).

Inclusion of topography data: The topography data from Baseline have been introduced in the model. The figure 2.10 shows the initial bed levels of the model.

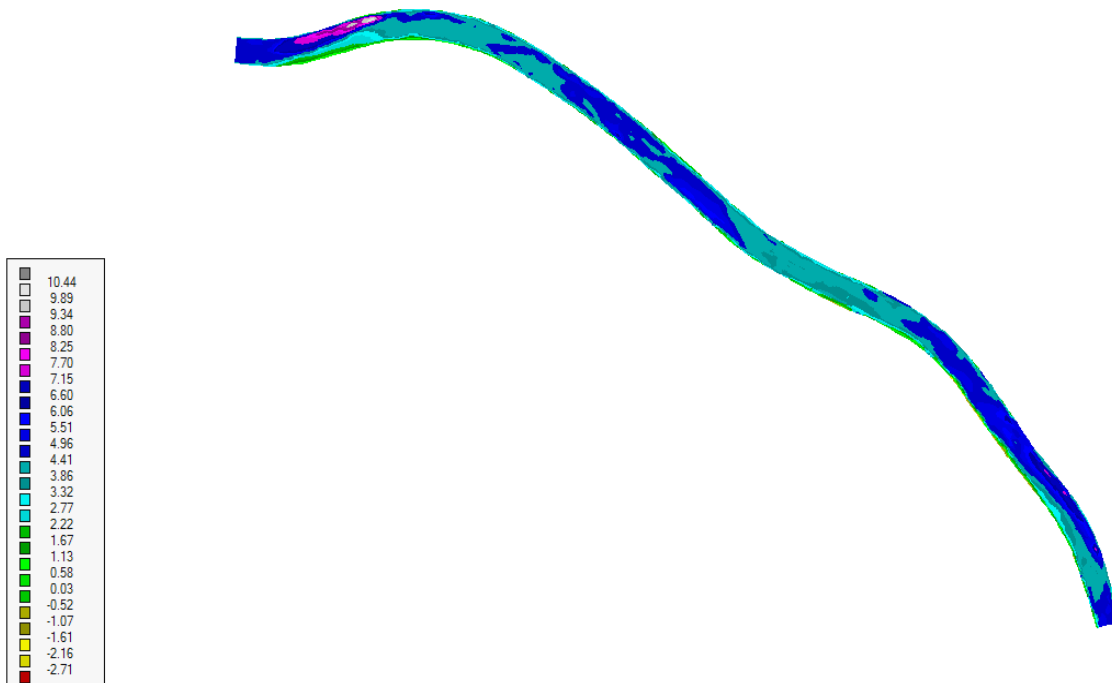


Figure 2.10 The legend shows the bed level (m).

Add sediment data, physical data and boundary conditions : The module Delft3D-FLOW has been used to add the sediment data, the boundaries conditions and to build the model with the grid and the topography data that were already done with Delft3D-RGFGRID and Delft3D-QUICKIN.

The following data were added:

- *Domain*: the file of the grid, the coordinates of our model and the bed topography were introduced.
- *Time frame*: The simulation start time and stop time were introduced.
- *Initial conditions*: Due to the initial conditions were not known, water level “0” and secondary flow “0” were selected for initials conditions.
- *Boundaries conditions*: there are two boundaries: one upstream and another one downstream. The flow condition that was applied at upstream boundary was ‘total discharge’ and forcing type in time-series. And the flow condition that was applied at downstream boundary was ‘water level’.
- *Physical parameters*: here it was added the value of gravity, water density, roughness (Manning) and viscosity.
- *Output*: the start time, stop time and step time to storage the data were decided.

Study of stability of the model: to study the stability of the model, two observation points were chosen: downstream and upstream.

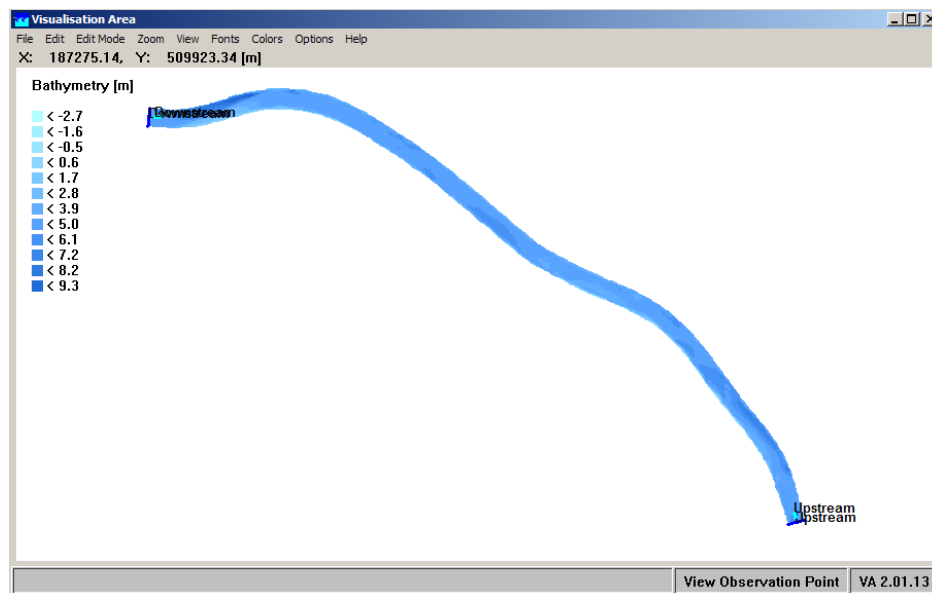


Figure 2.11 Observation points to study the stability of the model

So after running the model the Delft 3DQUICKPLOT program was used to analyze the results.

The figures 2.12 and 2.13 show that the model becomes stable in a few days.

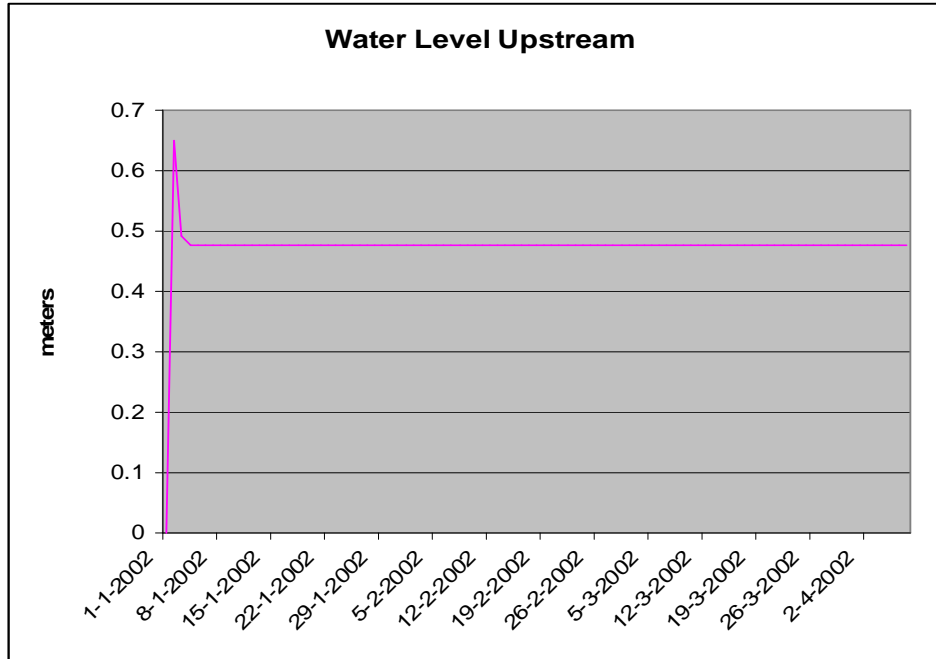


Figure 2.12

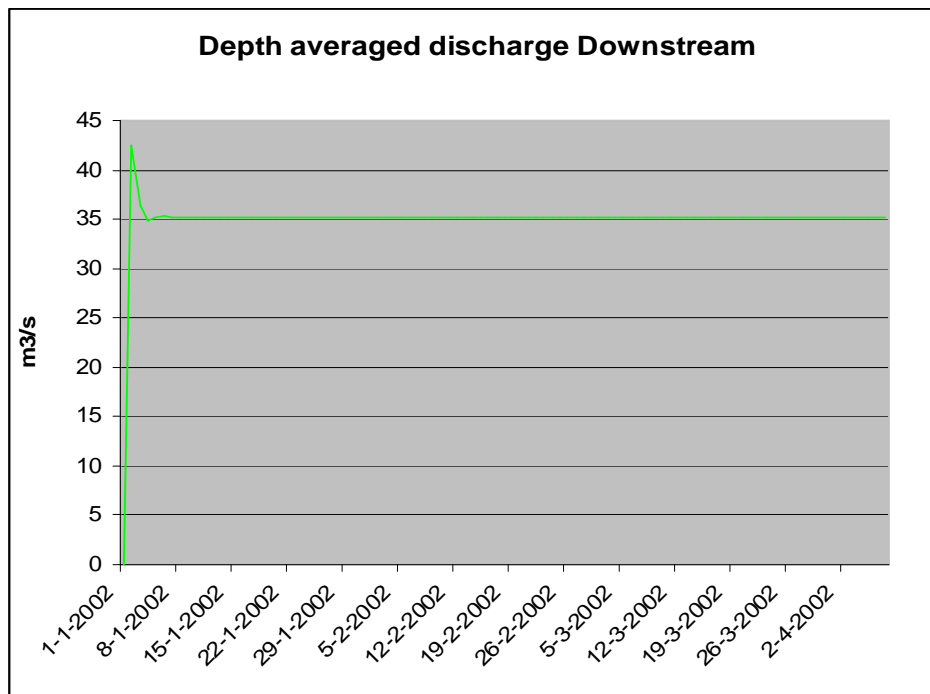


Figure 2.13

2.3.3 Hydraulic Calibration:

Ideally, to carry out the hydraulic calibration of a morphological model, like our model, data about average velocity in the river are used to compare the real data with the data that the model gives. But it was impossible to be done, because there were not real data about velocity of the water in any place of the model.

For this reason, only the data from water levels in the harbour of Kampen have been used.

The roughness of the bed in the model was changed to obtain similar water levels to the measures taken in the river.

In order to know exactly which roughness value was the best the indicator “*Result*” was used:

$$Result = AVERAGE (Value \text{ in the model} - Real \text{ value})^2$$

The figure 2.14 shows the sketch that has been used to carry out this part of the calibration:

Hydraulic calibration								
		TRIAL	0	1	2	3	4	5
Roughness (Manning)			0.04	0.06	0.08	0.02	0.03	0.025
	RESULT	1month	0.084	0.577	1.662	0.021	0.012	0.007

Figure 2.14 sketch of the hydraulic calibration.

The model has been run only 1 month to study the influence of the different changes in the roughness in the model.

In the figure 2.15 shows that the model which produces the best ‘Result’ was the model 5.

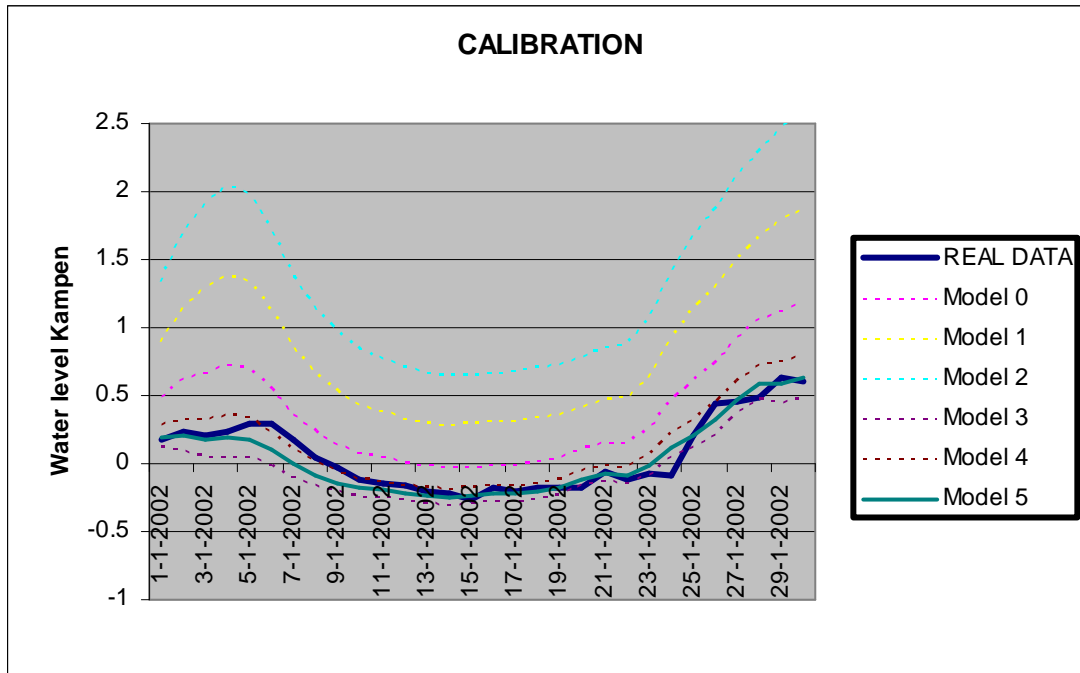


Figure 2.15

Thus, a final run of three months was done to check if for more months the model 5 produces valid results too.

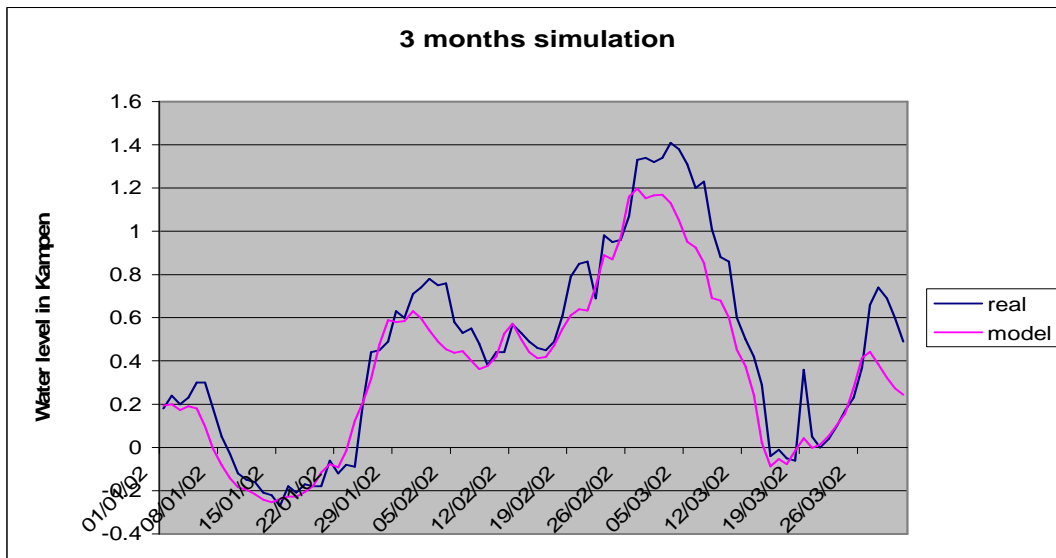


Figure 2.16 Evolution of water level in Kampen in three months.

The figure 2.16 shows the agreement between real data and the results of the hydraulic calibration. However it is possible to see that in the beginning of February, March and April, there are some differences. These dates coincide with floods periods.

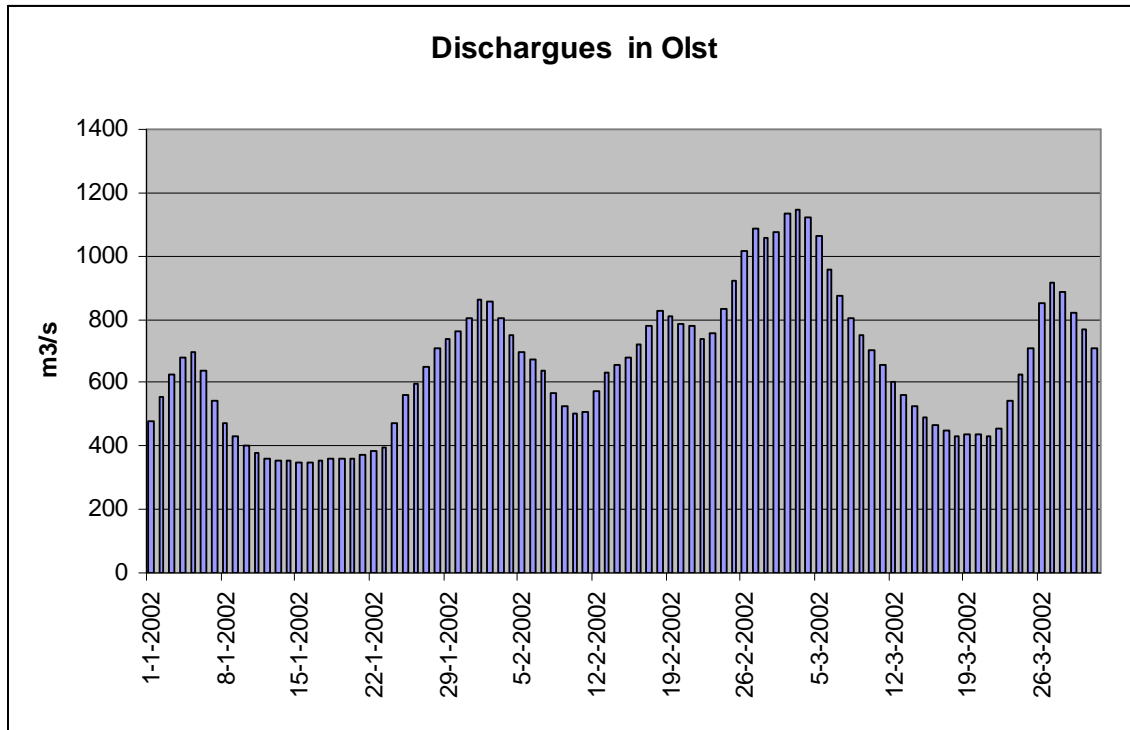


Figure 2.17 Hydrogram of discharges in Olst.

2.3.4 Morphological calibration:

For the morphological calibration, the software Delft3D has been used, and sediment transport has been introduced.

Before beginning the calibration, there were some parameters and questions about the model that were studied:

- *Transport Formula*: First the transport formula for the model was chosen.

After studying the different possibilities (Engelund-Hansen, Meyer-Peter-Muller, Van Rijn 1980...) transport formula of 'Engelund-Hansen' has been used. This formula doesn't take into account the waves and suppose only a total sediment transport.

To calibrate the model, this formula has to be calibrated too, because the formula has one '*calibration parameter*'. So during the morphology calibration this parameter has been changed a lot of times.

- *Parameters of Koch & Flokstra Islope*: Bed-load transport is affected by bed level gradients. Two bed slope directions are distinguished: the slope in the initial direction of the transport and the slope in the direction perpendicular to that.

The primary effect of the transverse bed slope is a change in transport towards the own slope direction. Therefore one formulation for these effects has been chosen between: no effect of bed slope on bed-load transport, Van Rijn (1993) and Koch & Flokstra (1980).

Finally '*Koch & Flokstra*' formula was chosen. In this formula, there are also two parameters (A_{shld} and B_{shld}). These parameters have been changed during the calibration.

- *Grain size*: Before the calibration of the model, the parameter D_{50} has been chosen. The D_{50} value average is 0.4 mm.

Therefore, to get the morphological calibration the next outline has been followed:

1. - Longitudinal Calibration.
2. - Transverse Calibration.

1.- Longitudinal Calibration:

The transport formula chosen for the model is the formula of Engelund-Hansen.

$$S = S_b + S_{s,eq} = \frac{0.05 \alpha q^5}{\sqrt{g} C^3 \Delta^2 D_{50}}$$

- S = Total sediment transport.
- S_b = Bed load transport.
- S_{s, eq} = Suspended sediment transport.
- α = Calibration parameter.
- q = magnitude of flow velocity.
- C = Chezy friction coefficient.
- Δ = Relative density (ρ_s-ρ_w) / ρ_w
- D₅₀ = Grain size diameter.

The longitudinal calibration was done to obtain the calibration parameter of the Engelund-Hansen formula. To obtain the correct value for this parameter the longitudinal bed level profile has to be similar to the measured bed level.

After each computation, the Delft 3D QUICKPLOT was used to obtain the average bed level in each section.

After some computations, the best results were obtained with values of calibration parameter of the transport formula equal to 0.5, 0.65 and 0.8. The results obtained with these values were very similar, because the model was not very sensitive to this parameter. Finally the value of 0.65 was chosen because the results in 1999 were a little bit better than the other results.

The figure 2.18 shows the out line that was followed:

	TRIAL			
	1	2	3	4
<u>Transport Formula : Engelund-Hansen</u>				
Calibration Coef.	1	0.5	0.8	0.65
Bed roughness height	0.024	0.024	0.024	0.024
<u>Koch and Flokstra formula</u>				
Ashld	0.8	0.8	0.8	0.8
Bshld	0.5	0.5	0.5	0.5
<u>Espir coeficient</u>	1	1	1	1
<u>D50 mm</u>	0.4	0.4	0.4	0.4
<u>Morfactor</u>	50	50	50	50

Figure 2.18 Outline of the longitudinal calibration.

To avoid that the computation time was too long, a 50 Morphological factor value was used. Therefore to avoid that the model become unstable due to the high value of the Morphological Factor, constant boundary conditions were used.

Therefore the upstream discharge average (the hydraulic discharge and the morphological discharge are very similar) and the downstream water level average from 1995 to 1999 were calculated:

Average water level downstream: -0.19 m (NAP)

Average total discharge upstream: 226 m³/s

The final results of the model with a calibration parameter of 0.65 are shown in the figures 2.19, 2.20, 2.21:

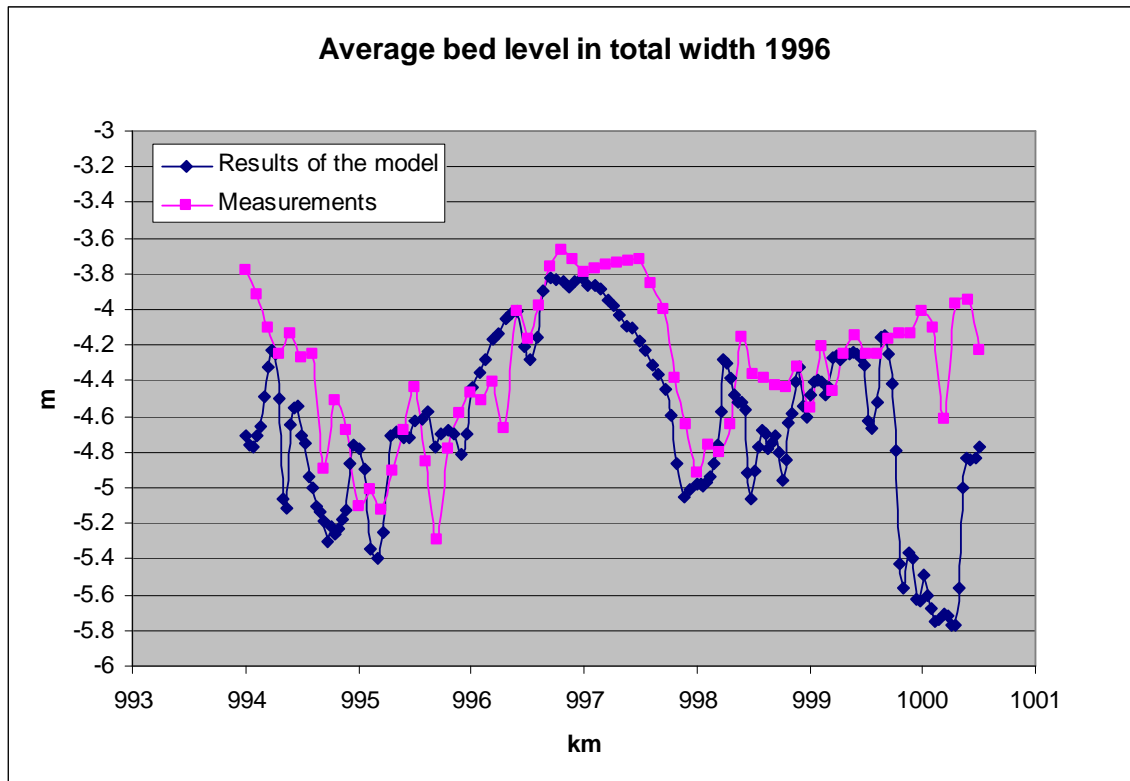


Figure 2.19 Bed levels of the model against real measurements.

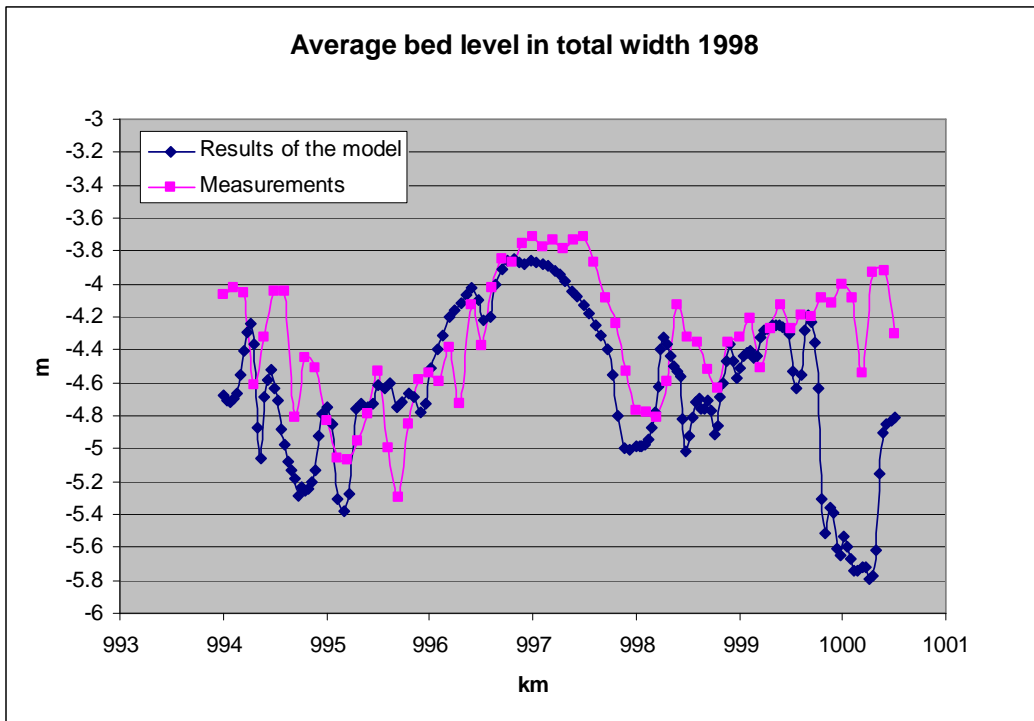


Figure 2.20 Bed levels of the model against real measurements.

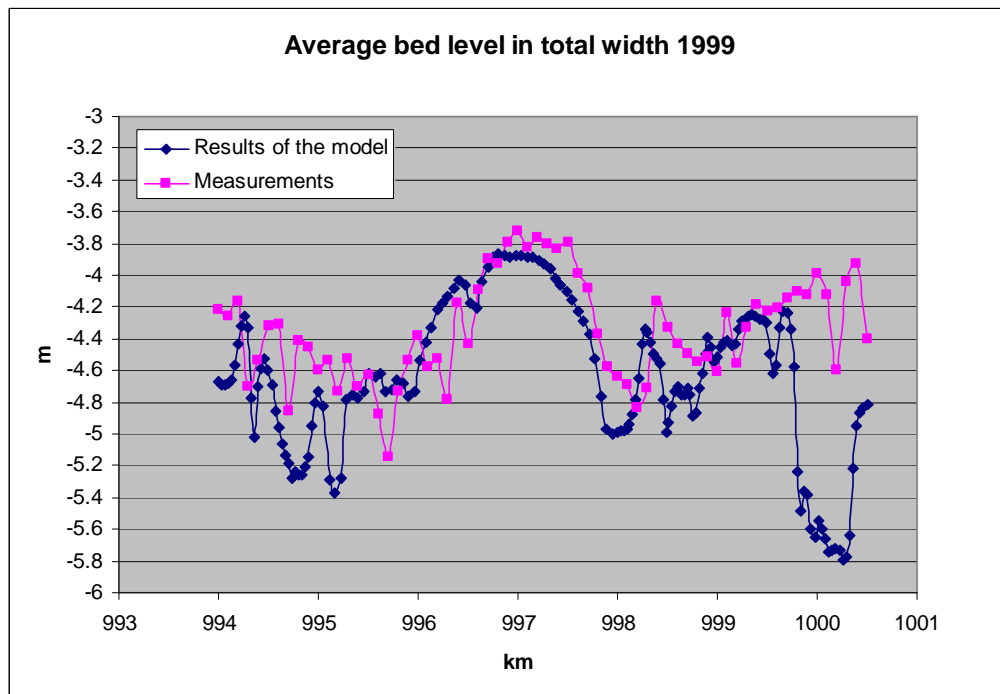


Figure 2.21 Bed levels of the model against real measurements from.

The differences between the model and the real data were not so large in the major length of the river. However in the lower part of the river (after km 999) the differences between the real data and the model were very large.

The reason of these differences is that the initial data used in the model (data from Baseline) are already different from the Rijkswaterstaat data, mainly downstream the km 999.5. Therefore if the initial data of the model are different, it is normal that the evolution for each year of the bed level in the model will not achieve the same value than the measurements from Rijkswaterstaat.

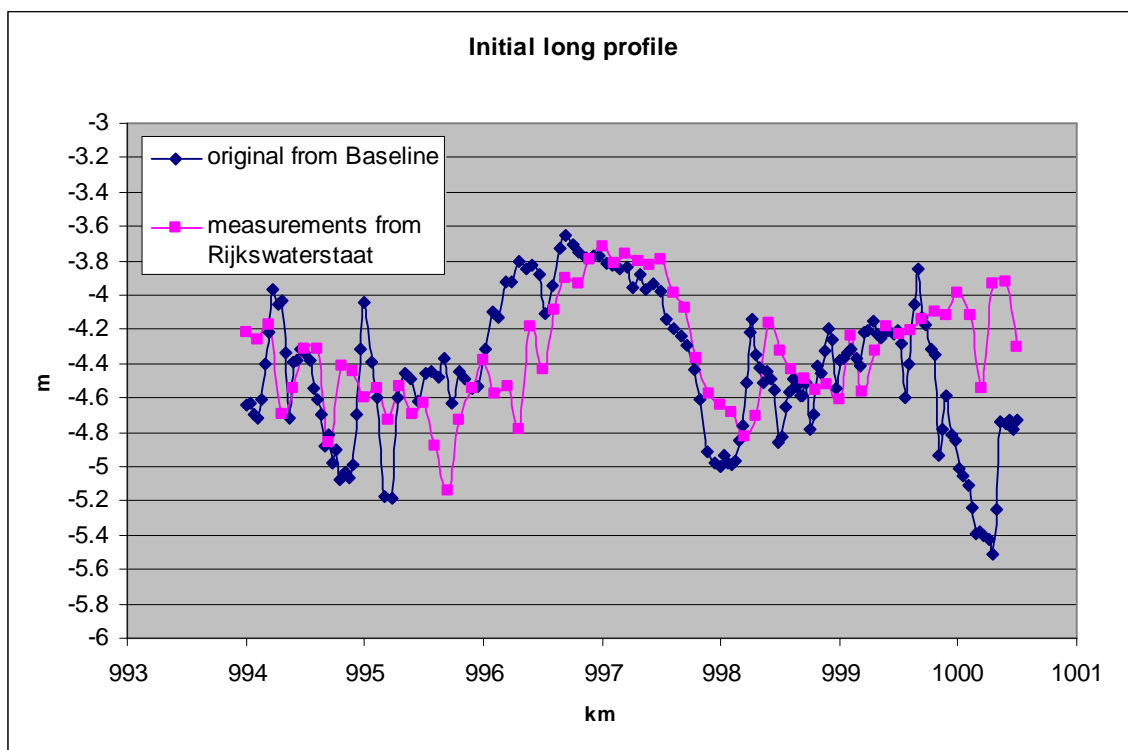


Figure 2.22 Differences between initial data from Baseline and from Rijkswaterstaat

2. – Transversal calibration:

The transversal sediment transport formula of the model is the ‘Koch & Flokstra’ formula:

$$\vec{S}'_b = \alpha_s \vec{S}''$$

- S_b' = Bed load transport affected for transverse slope
- S_b'' = Bed load transport not affected for transverse slope.

$$\alpha_s = 1 + \alpha_{bs} \frac{\partial z}{\partial s}$$

- α_{bs} = user-defined parameter. (default = 1)

With the α_s parameter, the new value of sediment transport is obtained. But the transverse slope affects the sediment transport angle too. The direction of the bed load transport is adjusted according to the following formulation:

$$\tan(\varphi_s) = \frac{\sin(\varphi_\tau) + \frac{1}{f(\theta)} \frac{\partial z_b}{\partial y}}{\cos(\varphi_\tau) + \frac{1}{f(\theta)} \frac{\partial z_b}{\partial x}}$$

Where φ_τ is the original direction of the sediment transport and φ_s is the final direction and $f(\theta)$ equals:

$$A_{sh} \theta_i^{B_{sh}} \left(\frac{D_i}{H} \right)^{C_{sh}} \left(\frac{D_i}{D_m} \right)^{D_{sh}}$$

- A_{shld} = Calibration parameter
- $B_{shld} = 0.5$

The initial bed level used in the computations was a sounding of the bed topography, and therefore the bed level at the end of each computation would look similar to the initial one. It means that the change of the point bars and pools would be very small. So the point bars and pools at the end of the computation would be similar to the point bars and pools in the original bed topography.

The transversal calibration consists of obtain the value of A_{shld} that produces in the model similar length and height of the bars and similar depth of the pools than in the initial bed level. So to carry out the transversal calibration the value of A_{shld} was changed.

To carry out the transversal calibration, plots of three grid lines along the model at the river axis were done. These three grid lines were selected taking into account the effect of the groynes in the bed level, so only the grid lines 3, 4, 5 and 11, 12, 13 were selected.



Figure 2.23 : grid lines selected for the transversal calibration

Therefore focusing on the plots of these three grid lines, the similitude between the length of the bars in the model at the end of the computation and the length of the bars in the initial bed level was checked. Also in these plots, the height of the bars and the depth of the pools were checked. The figure 2.24 shows the outline that has been followed:

	TRIAL						
	1	2	3	4	5	6	7
<u>Transport Formula : Engelund-Hansen</u>							
Calibration Coef.	1	0.5	0.8	0.65	0.65	0.65	0.65
Bed roughness height	0.024	0.024	0.024	0.024	0.02	0.024	0.024
<u>Koch and Flokstra</u>							
Ashld	0.8	0.8	0.8	0.8	0.8	0.6	1
Bshld	0.5	0.5	0.5	0.5	0.5	0.5	0.5
<u>Espir coeficient</u>	1	1	1	1	1	1	1
<u>D50 mm</u>	0.4	0.4	0.4	0.4	0.4	0.4	0.4
<u>Morpfactor</u>	50	50	50	50	100	100	100

Figure 2.24 Outline of the transversal calibration.

Before checking the structure of the bars and pools, the period of time for the computations was selected. In order to get it, some computations with different period of times were run, and after each computation the bed level in a point in the inner bend and the bed level in a point in the outer bend was checked, these points were in the km 999.5 (grid line 140).

When these bed levels became stable it meant that the time period of this computation was the correct one. So after some computations, the bed level in those points became stable for the period from 1995 to 2005.

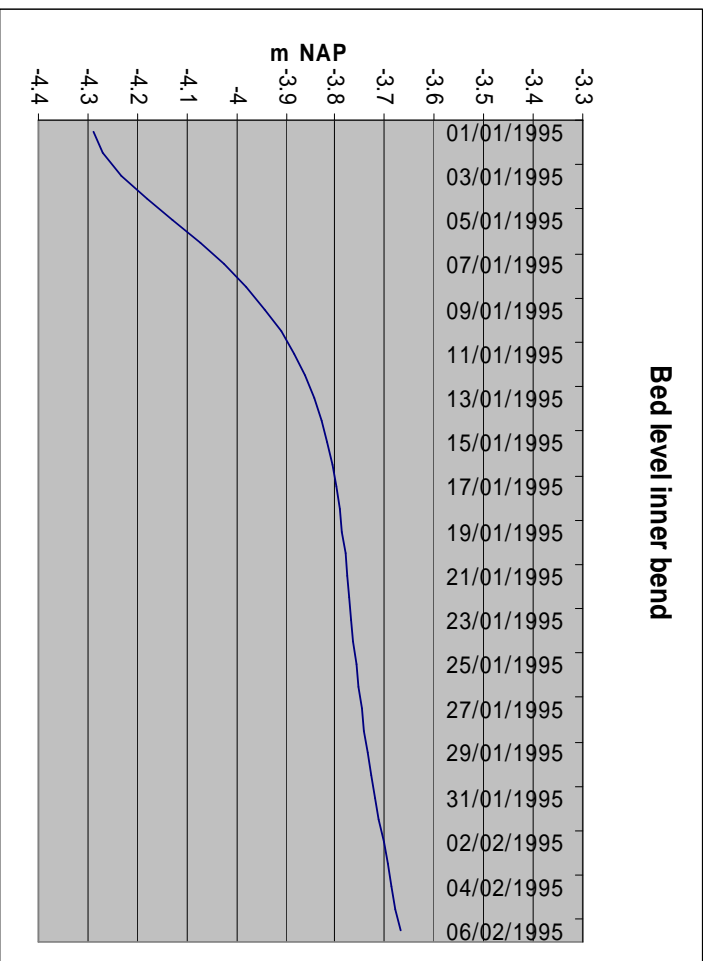


Figure 2.25 Bed level in the inner bend, km 999.5

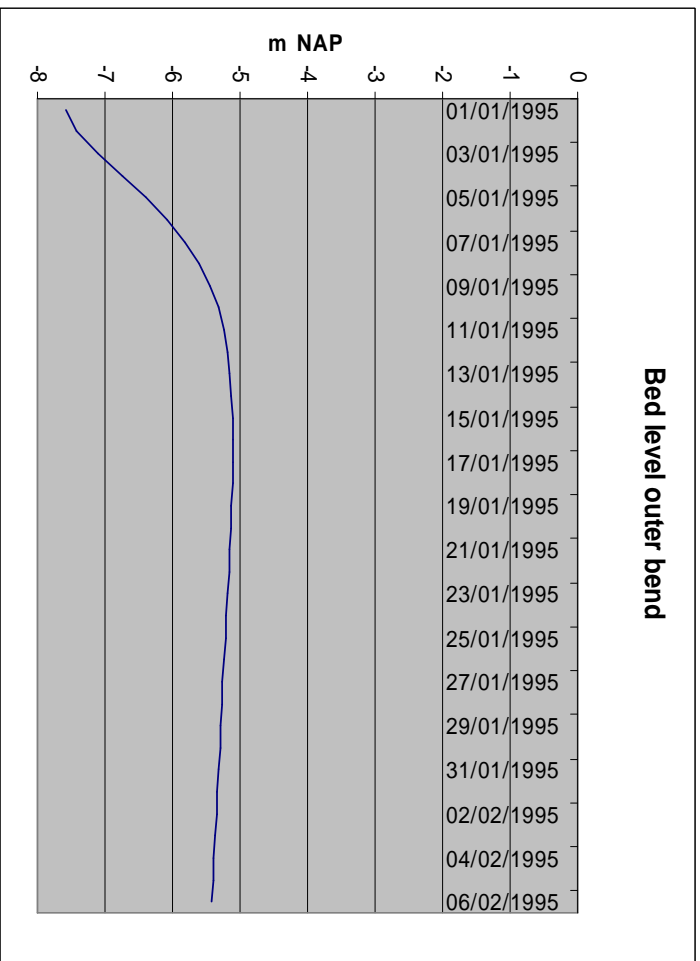


Figure 2.26 Bed level in the outer bend, km 999.5

Once the computation period time was selected, the transversal calibration was done. To carry out the simulation, the value of the Morphological Factor was increased from 50 to 100.

the results of the trial 5, 6, 7 are shown close to the original bed level to make easier the comparison between them :

TRIAL 5:

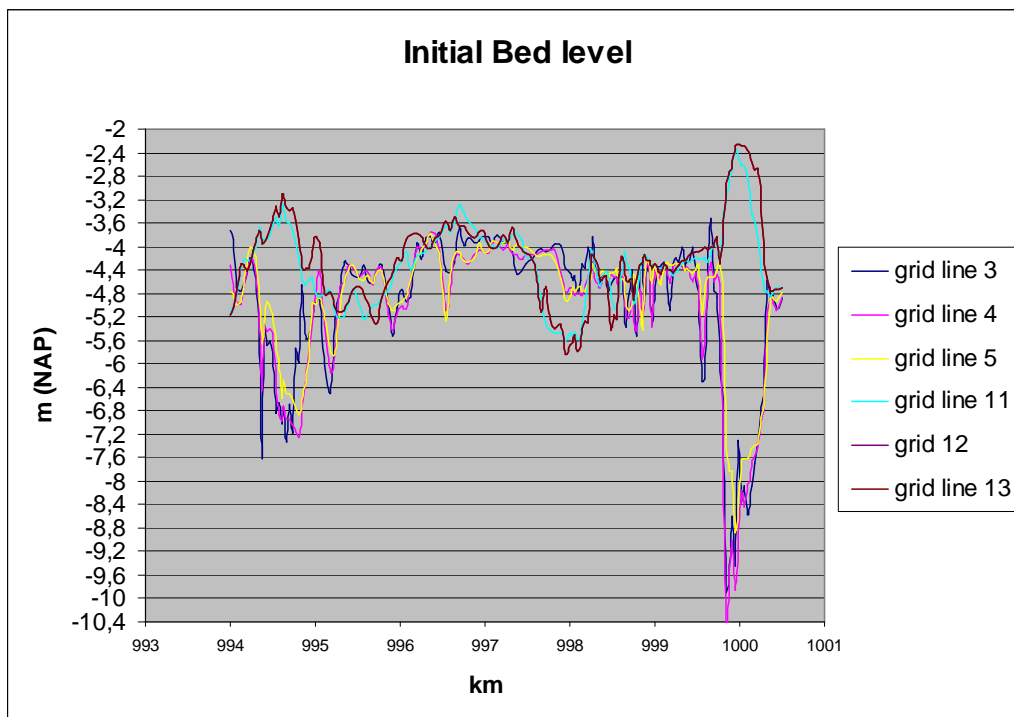


Figure 2.27 Initial bed level (measurements from Baseline)

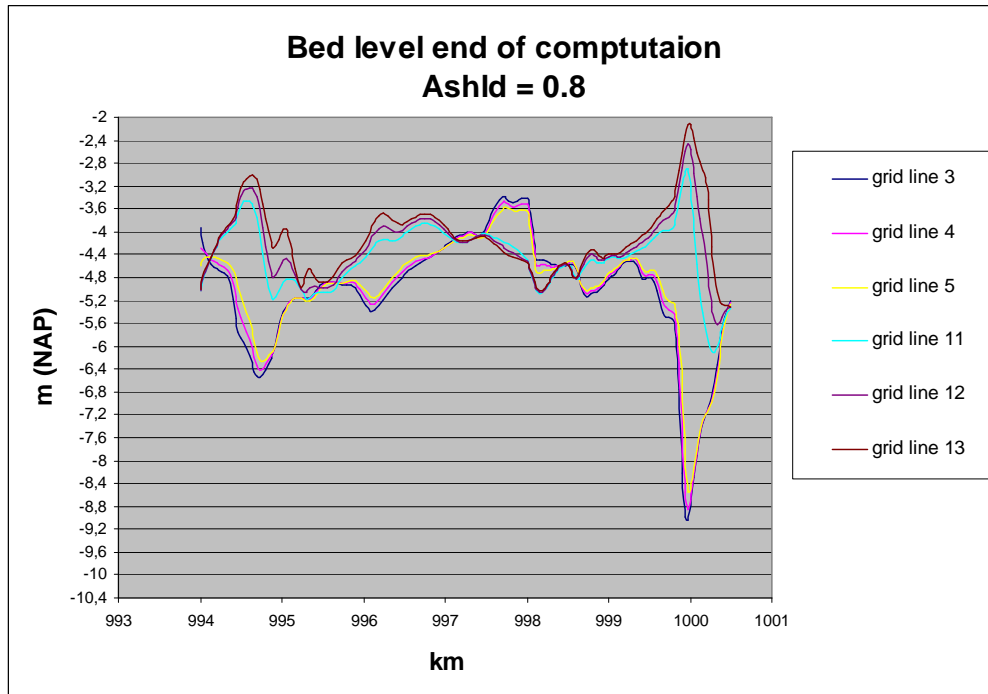


Figure 2.28 Bed levels at the end of computation ($A_{shld} = 0.8$).

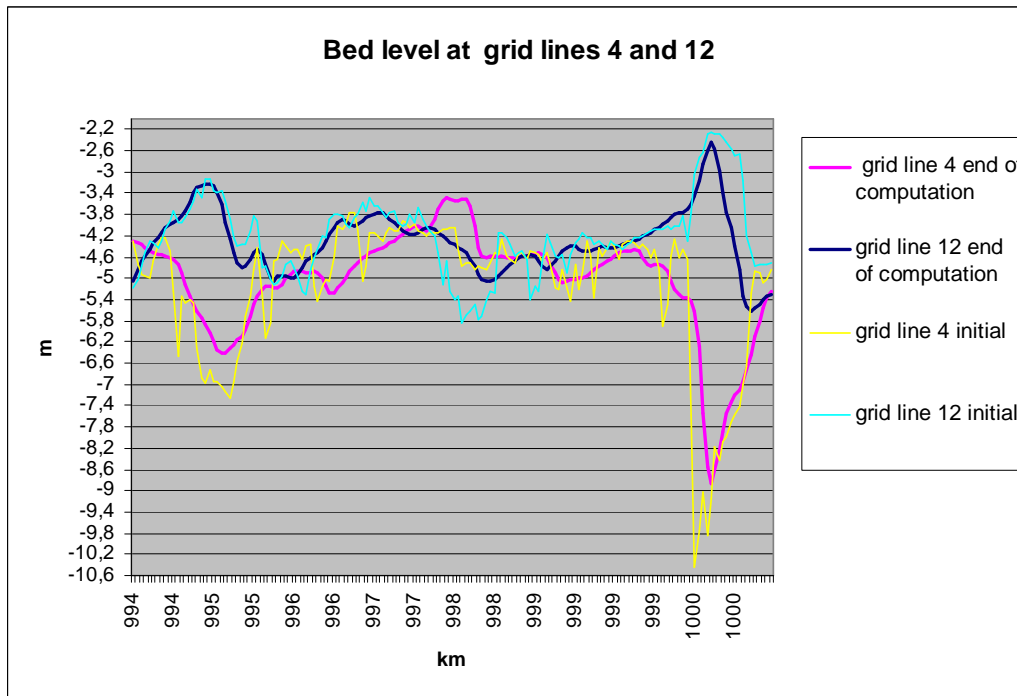


Figure 2.29 Initial Bed levels against Bed levels at the end of computation.

With these figures, the similarity between the length of the bars at the end of the model and the length of the bars in the initial bed level was checked.

A numerical value was calculated to have a general idea about the difference between the original bed level and the bed level after the calculation. The definition of this value was:

$$\text{TOTAL} = (\text{Initial Bed Level} - \text{End Bed Level})^2$$

This value was calculated for each grid line and then the results were added:

	grid line 3	grid line 4	grid line 5		grid line 11	gid line 12	grid line 13
VALUE	94	88	45		53	43	26

TOTAL VALUE	346
--------------------	------------

TRIAL 6:

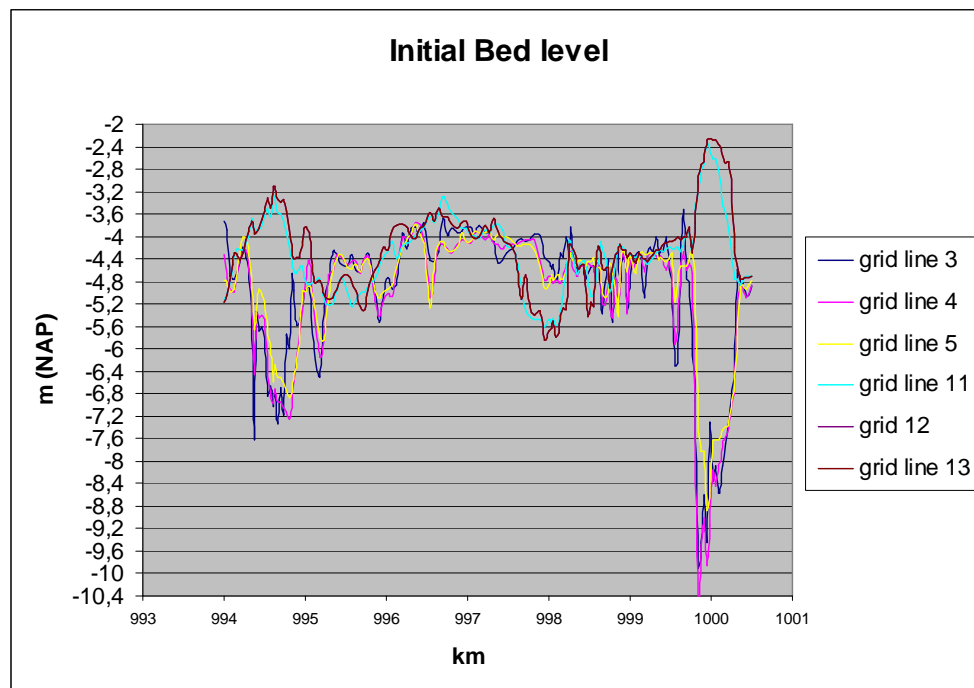


Figure 2.30 Initial bed level (measurements from Baseline)

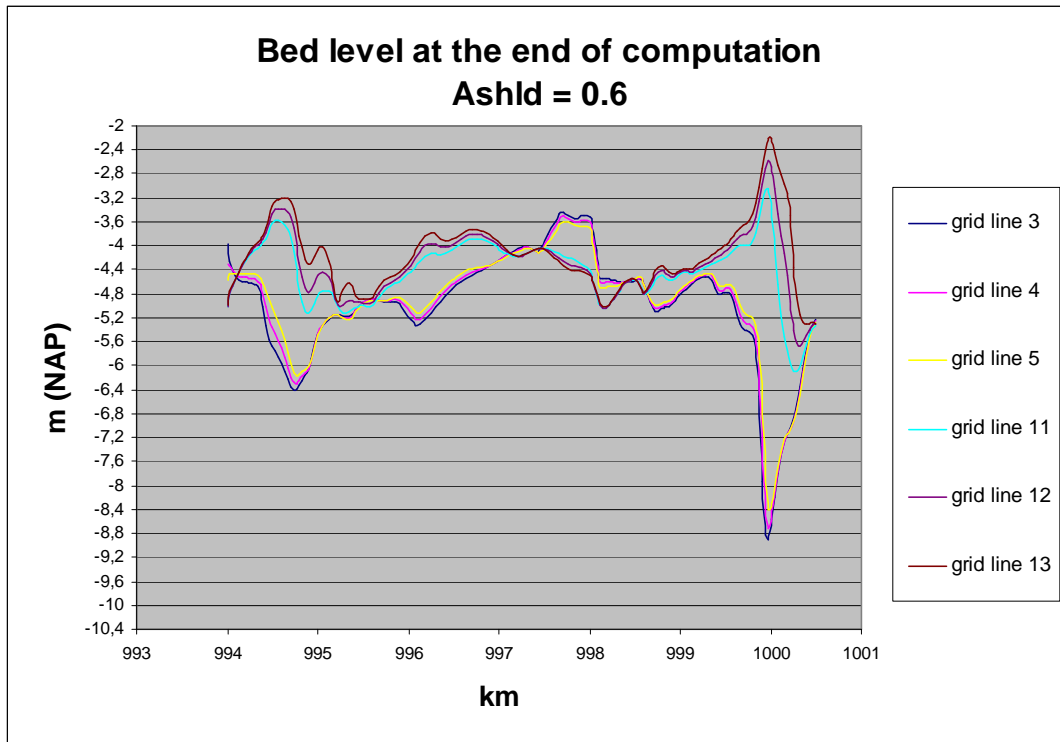


Figure 2.31 Bed levels at the end of computation ($A_{shld} = 0.6$)

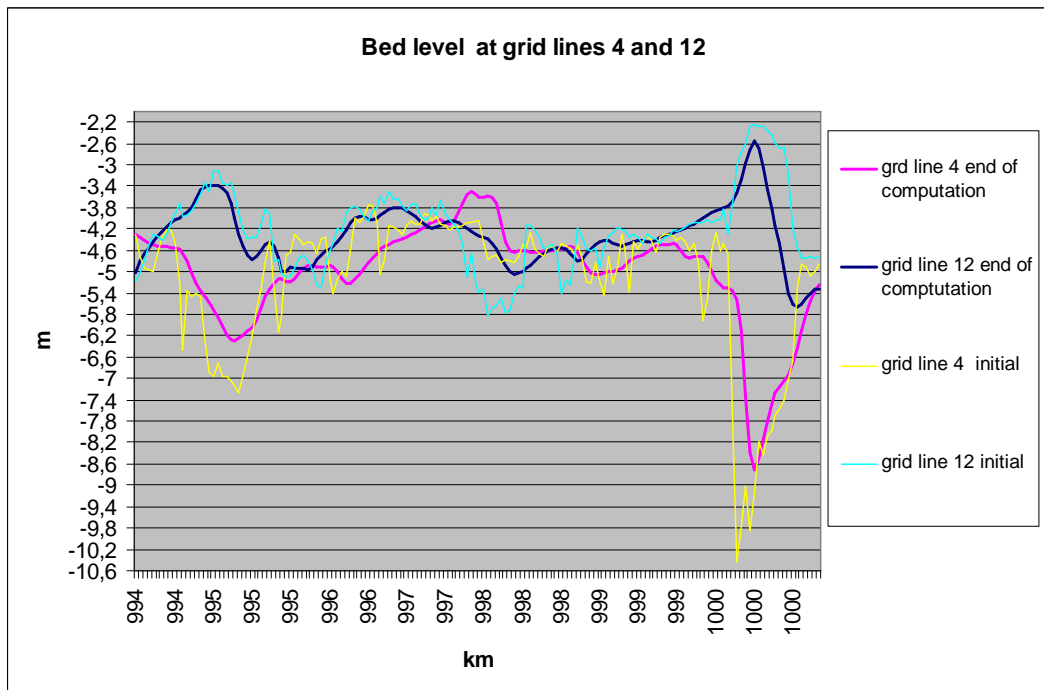


Figure 2.32 Initial Bed levels against Bed levels at the end of computation.

	grid line 3	grid line 4	grid line 5		grid line 11	gid line 12	grid line 13
VALUE	97	93	46		56	47	24

TOTAL VALUE	364
--------------------	------------

The results of the trial 6 are worse than the results of the trial 5. It can be checked in the plots and also in the number value.

So after these two computations the value of Ashld was increased to check if it was possible to get better results.

TRIAL 7:

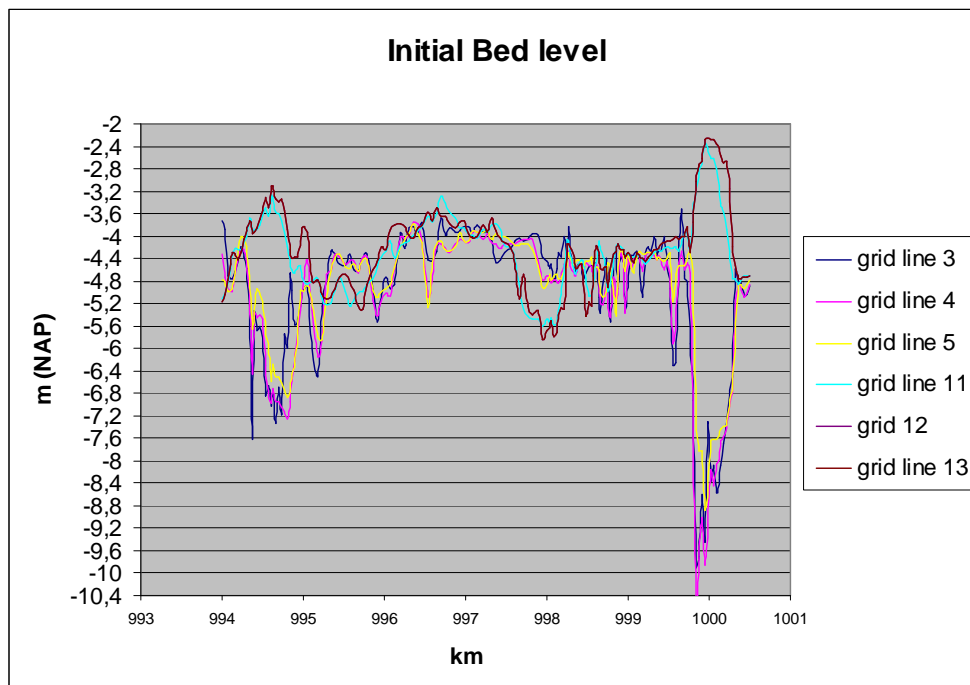


Figure 2.33 Initial bed level (measurements from Baseline)

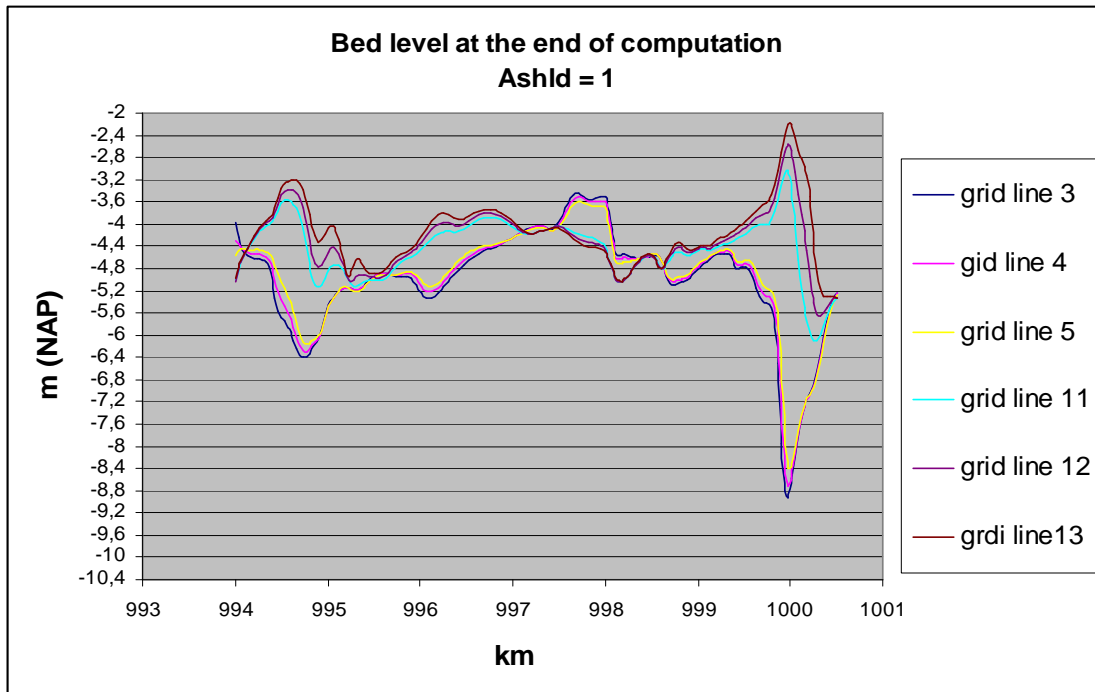


Figure 2.34 Bed levels at the end of computation ($A_{shld} = 0.1$)

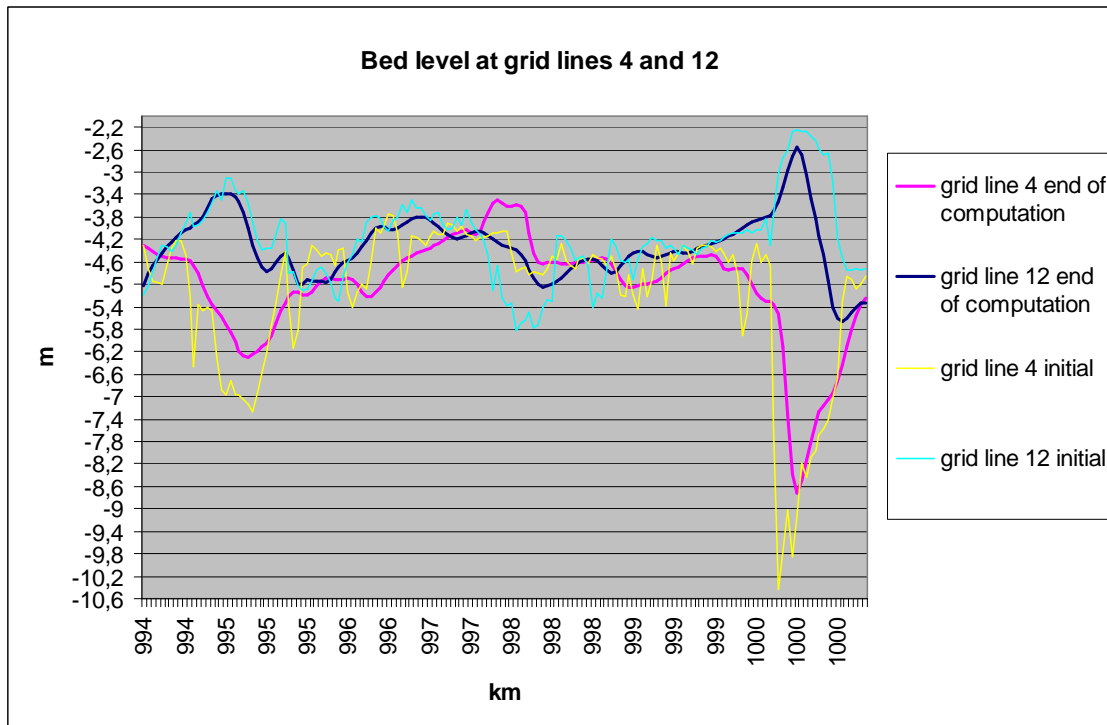


Figure 2.35 Inicial Bed levels against Bed levels at the end of computation

	grid line 3	grid line 4	grid line 5		grid line 11	grid line 12	grid line 13
VALUE	91	85	44		51	41	26
TOTAL VALUE		336					

Maybe if all the plots are compared it is not too easy to guess what trial is better. But if the different results of parameter “TOTAL VALUE” are compared, the trial 6 is the best result.

3.-Conclusion: Therefore, after the transverse calibration and the longitudinal calibration, the morphological parameters values are:

- Calibration parameter of the transport formula:
 - o (Engelund-Hansen) = 0.65.
- Koch and Flokstra formula :
 - o Ashld = 1
 - o Bshld = 0.5
- Roughness (Manning) = 0.024
- Espir coefficient = 1
- $D_{50} = 0.4$ mm

2.3.5 Implementation of the sand trap and final calibration:

In this calibration the parameter that was necessary to calibrate was the parameter “BED”. This parameter is the multiplication factor for bed-load transport vector magnitude. This parameter is implemented inside a morphological file that is used for the Delft3D-FLOW.

This calibration consisted of finding a correct value of the parameter “BED” which produced an evolution of the sand trap in the model similar to the evolution of the sand trap in the pictures.

To introduce the sand trap in the topography of the model, two operations were done:

1. - First the influence of the sloping parts was studied: the sloping was so high, and therefore a vertical sand trap slope was supposed.

2. - Using Delft3D – QUICKPLOT the bed level average in the place of the sand trap was calculated. To calculate this bed level average, the effect of groynes in the banks (left and right) was removed. Thus the bed level average between km 997 and km 998 was:

$$\text{Average Bed Level} = -4.8 \text{ m}$$

After the mean bed level was calculated, using the program Delft3D- RGFGRID a value of 1.5 m was subtracted to the original bed level. Therefore the final bed level was -6.3 m.

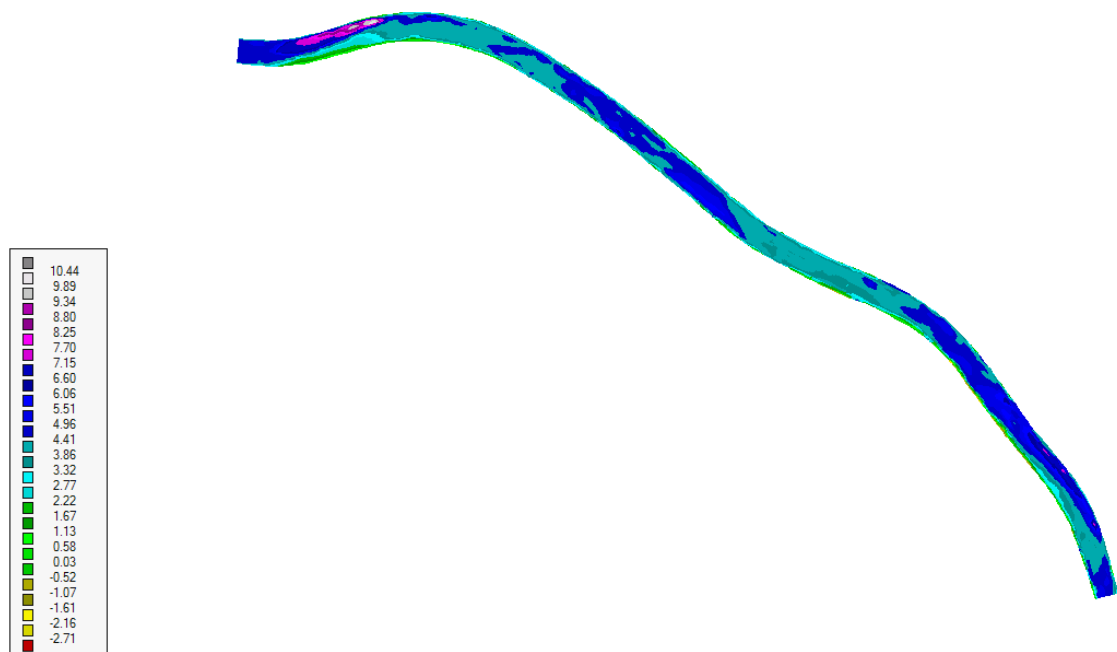


Figure 2.36 Bed levels before to implement the sand trap (the legend shows the depth of the bed).

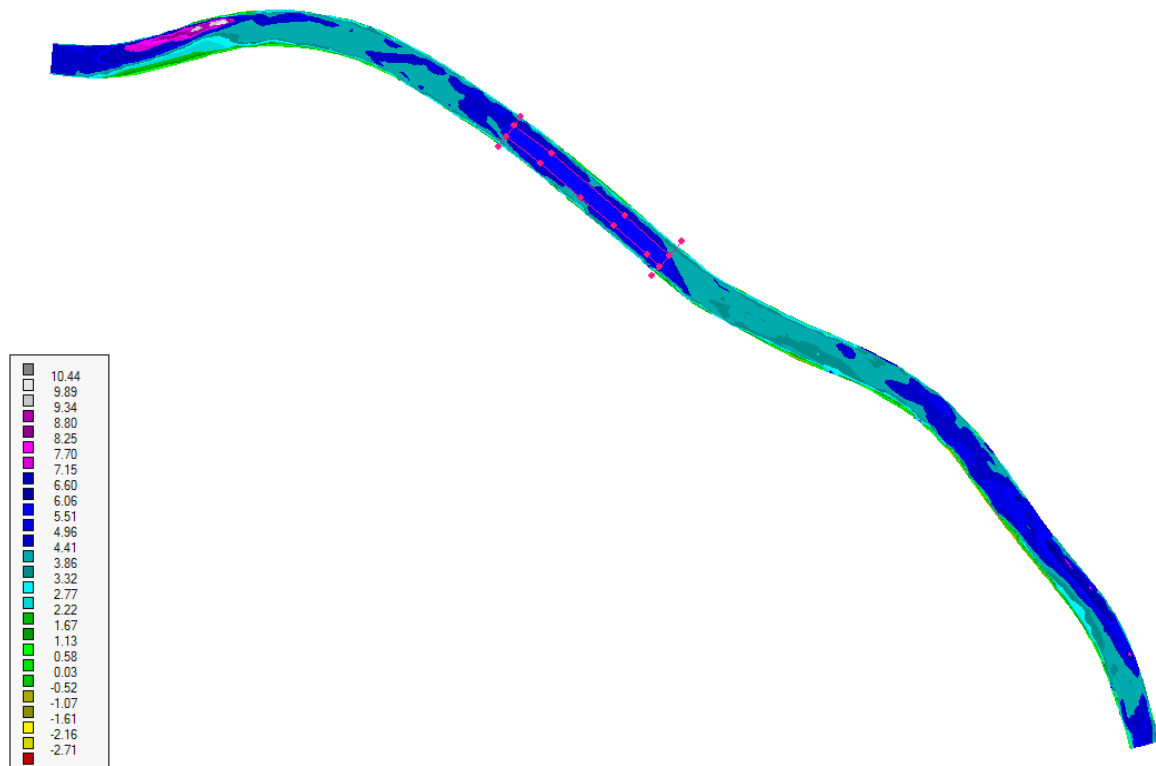


Figure 2.37 Bed level after building the sand trap: the red line indicates the place where the sand trap was dug. (the legend shows the depth of the bed).

Once the new topography was introduced in the model, the calibration of the model was done.

Using the evolution sand trap pictures, the evolution of the sand trap between 2005 and 2006 was studied.

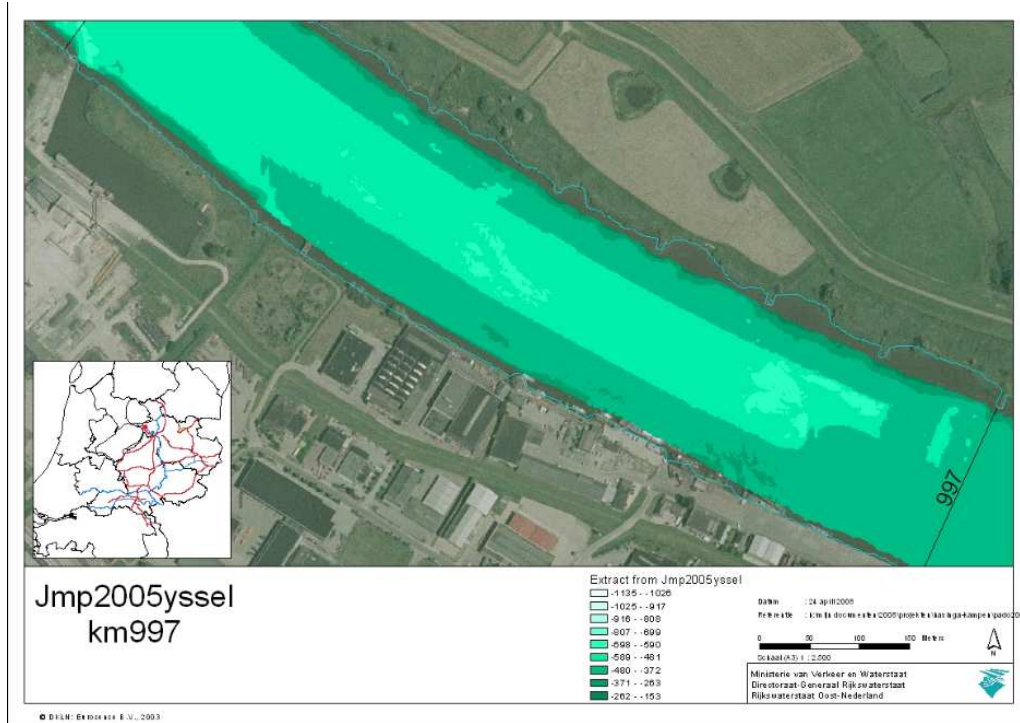


Figure 2.38 Sand trap Bed level in 2005.

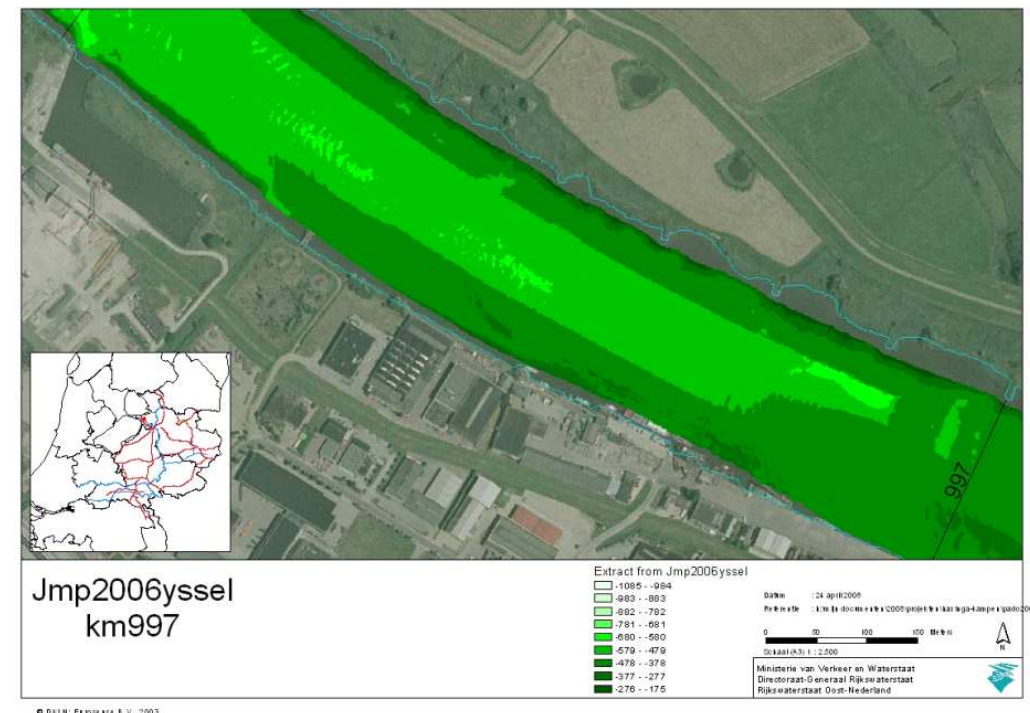


Figure 2.39 Sand trap Bed level in 2006.

The evolution of the upstream boundary of the sand trap was studied in these pictures and the results were that between the years 2005-2006 the upstream boundary of the sand trap moved about 80-100 m. This was the information that was used to carry out the calibration.

To carry out the calibration after the works, the boundaries conditions were changed from constant boundaries conditions to variable boundaries conditions.

Therefore, the daily water level downstream and the daily discharge were used. The period that was selected for these data was from 2005 to 2007. This period was selected because the pictures of the sounding data which were used for studying the movement of the sand trap, were from 2005 to 2006.

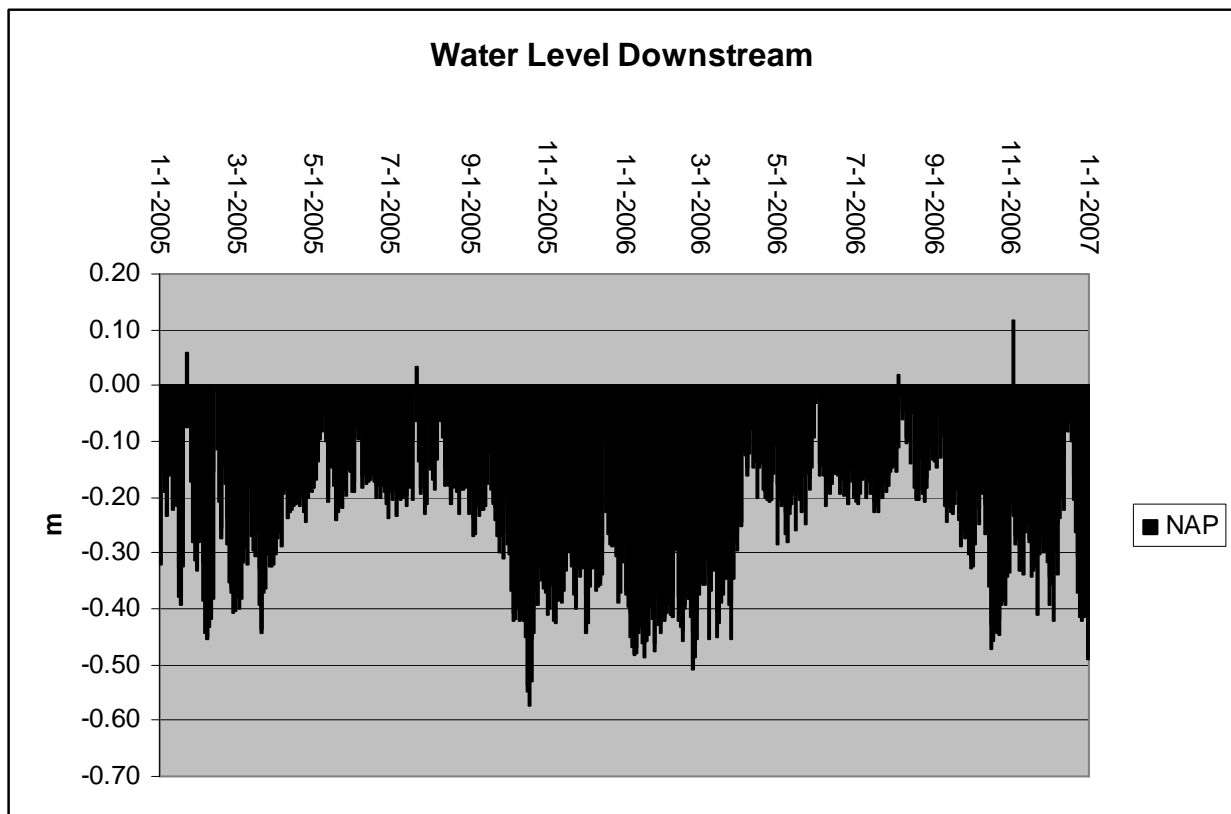


Figure 2.40 Daily water levles in IJssel river.

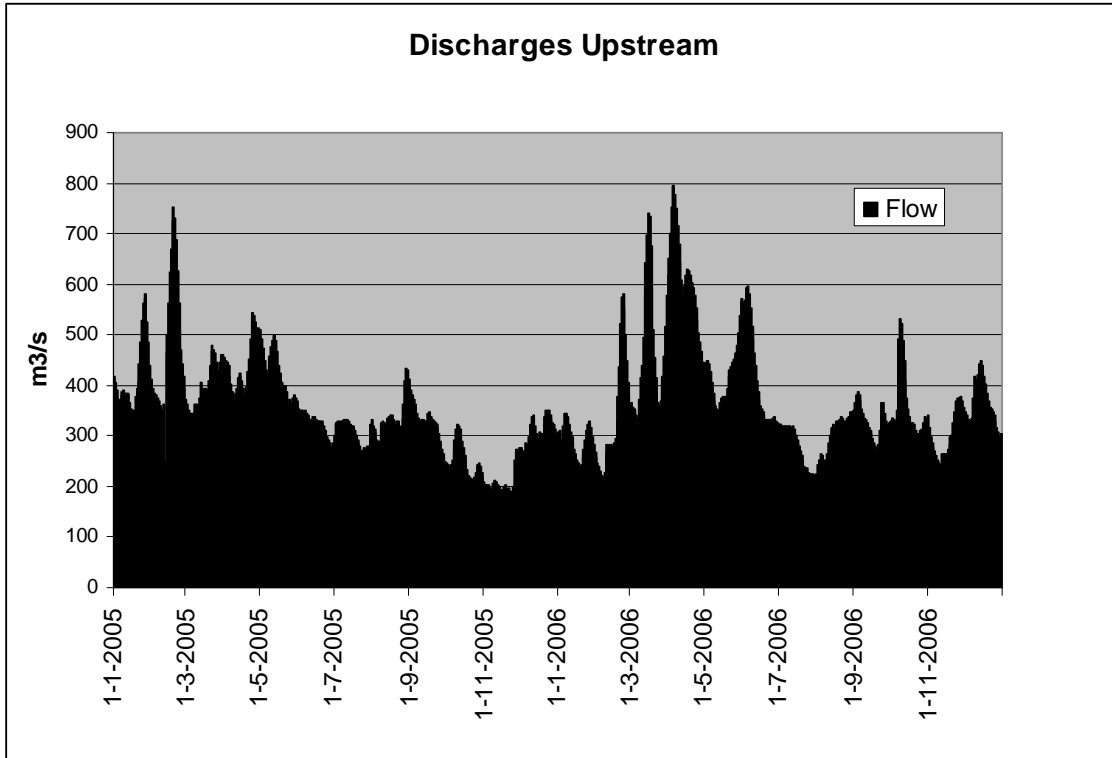


Figure 2.41 Daily discharges in Olst.

Once the boundaries conditions were changed, the model was run with different values of “BED”.

▪ $BED = 1$

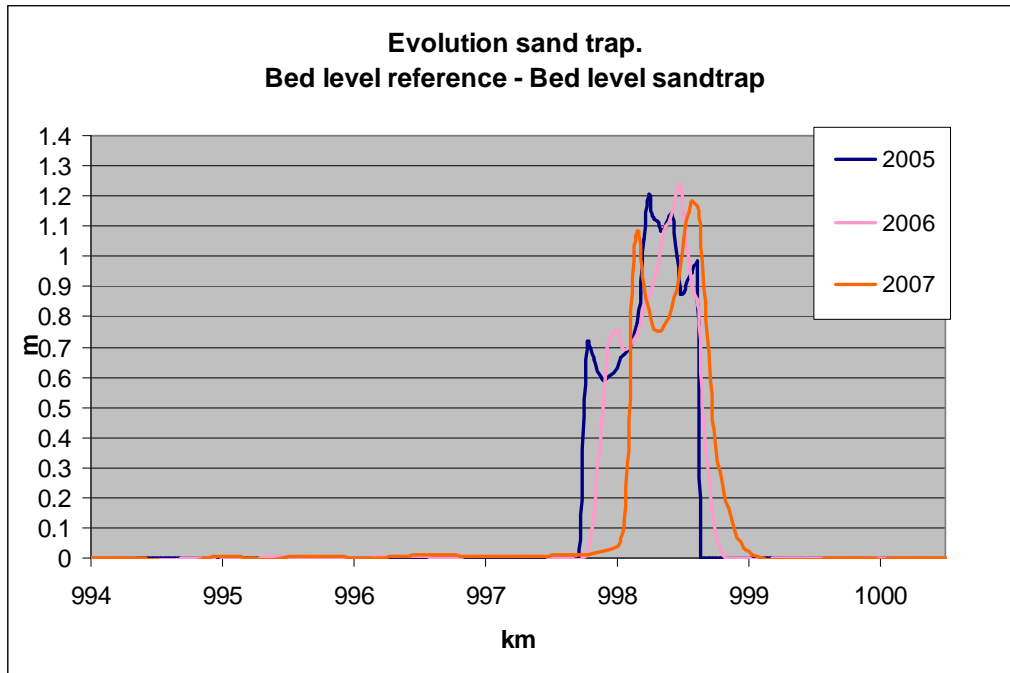


Figure 2.42 Evolution of sand trap with Morfactor = 1

▪ $BED = 0.5$

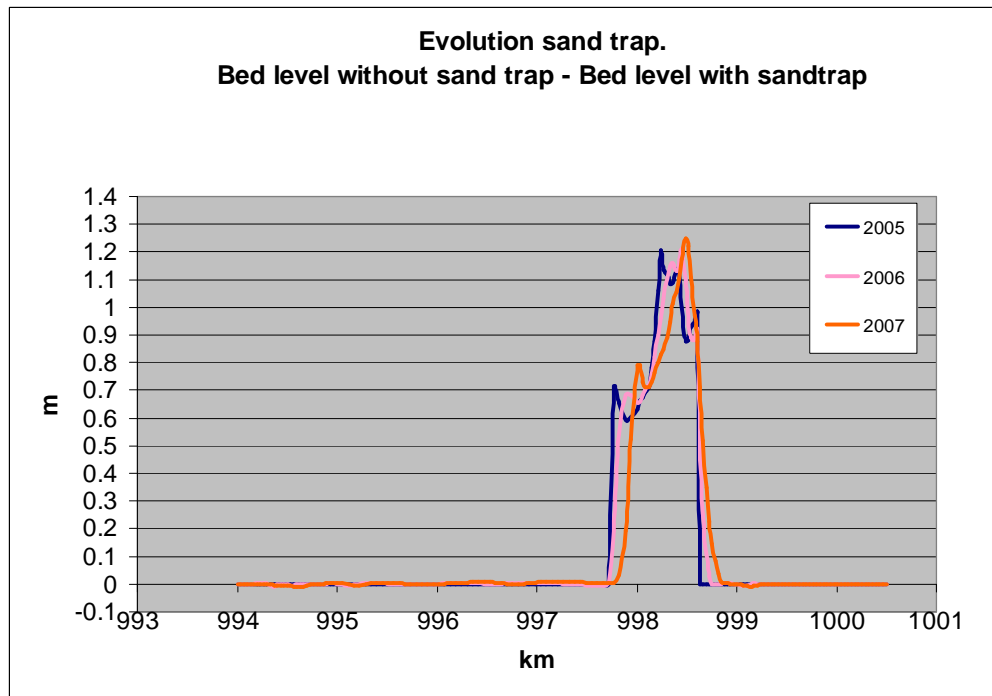


Figure 2.43 Evolution of sand trap with Morfactor = 0.5

The Figure 2.43 shows that the movement of the sand trap is between 80 and 100 m, therefore the value of 0.5 was chosen.

With this last parameter the model was totally calibrated.

2.4 Effect of different transport formula:

In the last calibrations the transport formula was the Engelund – Hansen formula. That is a total load formula, including bed load and suspended load. However, using this formula the model doesn't take into account the gradual adaptation of suspended-sediment to changing flow conditions which are modelled with the advection-diffusion equation.

Therefore the model was studied with another transport formula: the Van Rijn 1984 formula in combination with Galappattis model. This model takes into account the gradual adaptation of suspended sediment transport.

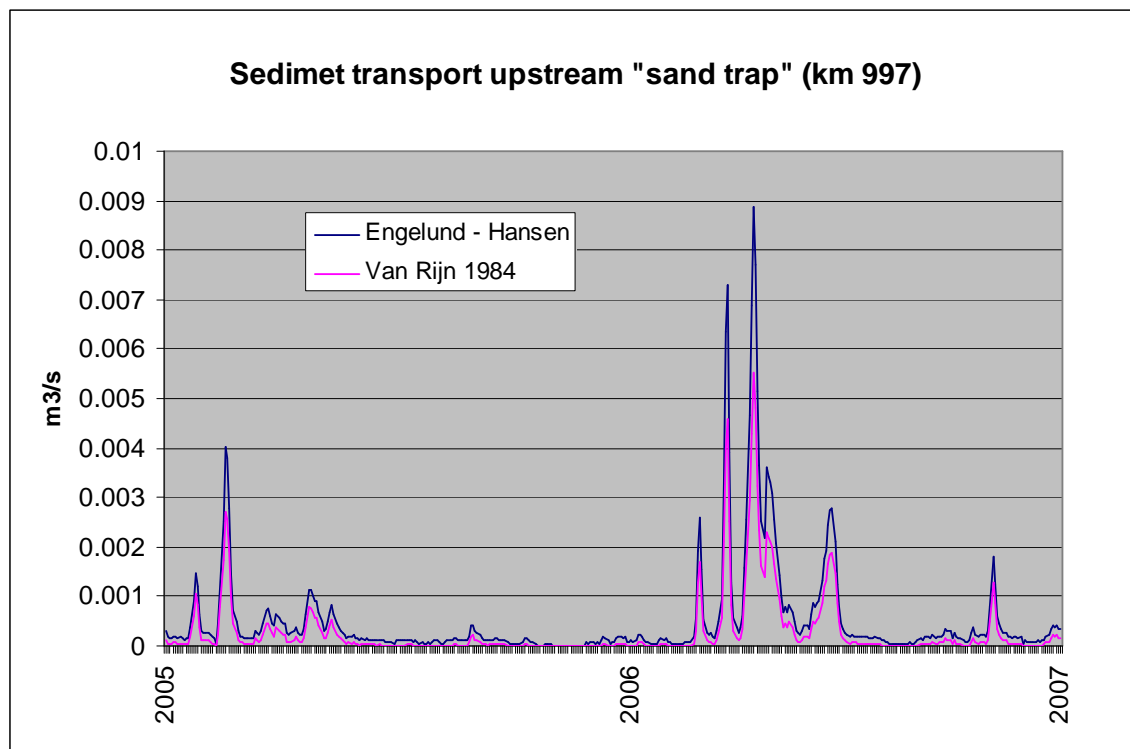


Figure 2.44 Sediment transport with different transport formula (km 997)

The figure 2.27 shows that the sediment transport is very different depending on the transport formula that is used. Indeed the amount of sediment that arrives to upstream boundary of the sand trap is not the same if the transport formula is changed. It's clear that with the Engelund- Hansen formula the sediment transport in that km is higher than with the Van Rijn 1984 formula.

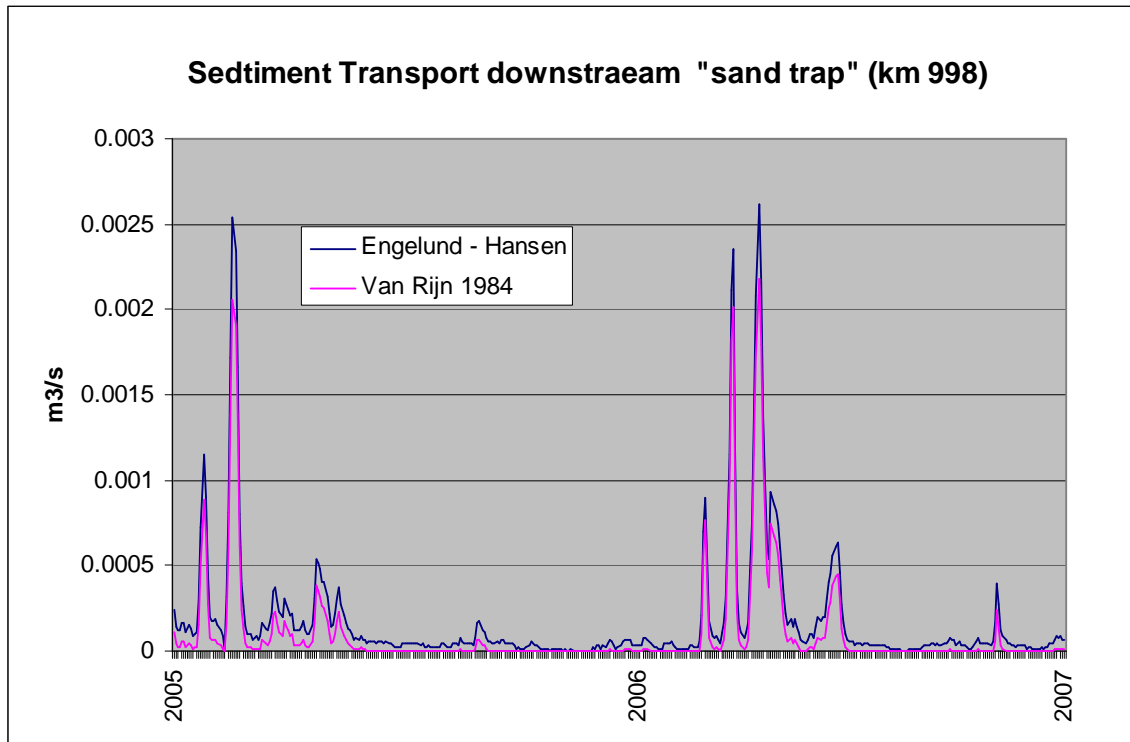


Figure 2.45 Sediment transport with different transport formula (km 998)

The figure 2.45 is similar to the figure 2.44. It means that the sediment transport is higher with the Engelund-Hansen formula than with Van Rijn one.

After the formula effect in the sediment transport was studied, the effect of the Van Rijn formula in the sand trap was studied. To carry out this study, the cumulative sediment transport upstream the sand trap (km 997) and downstream the sand trap (km 998) was studied:

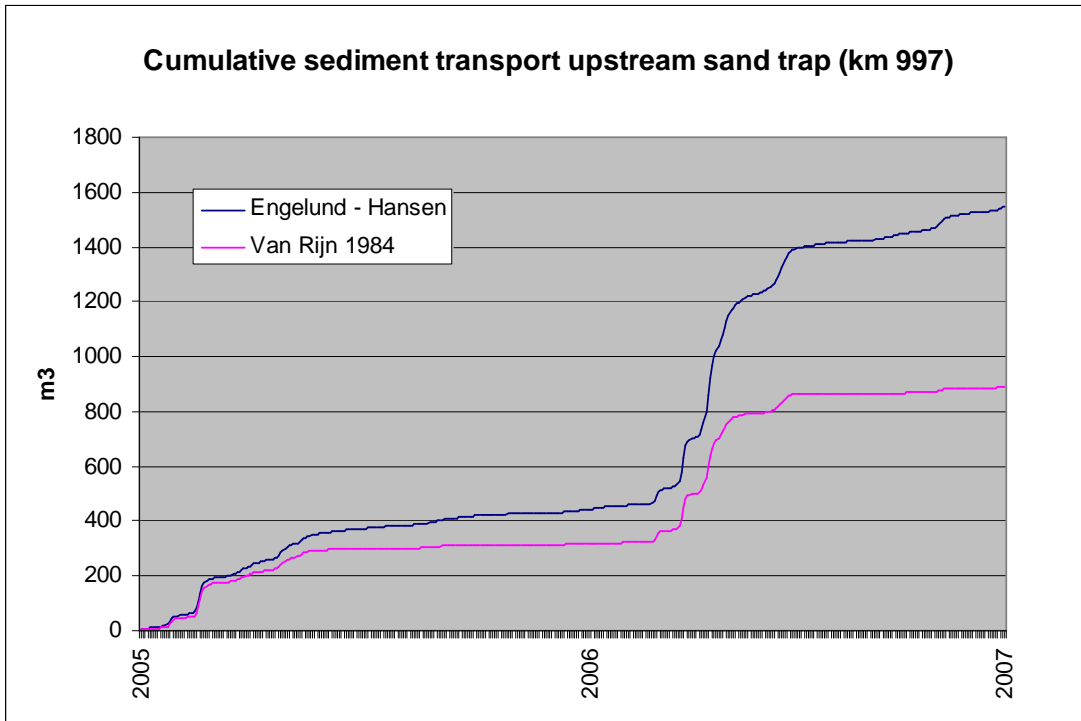


Figure 2.46 Cumulative sediment upstream sand trap.

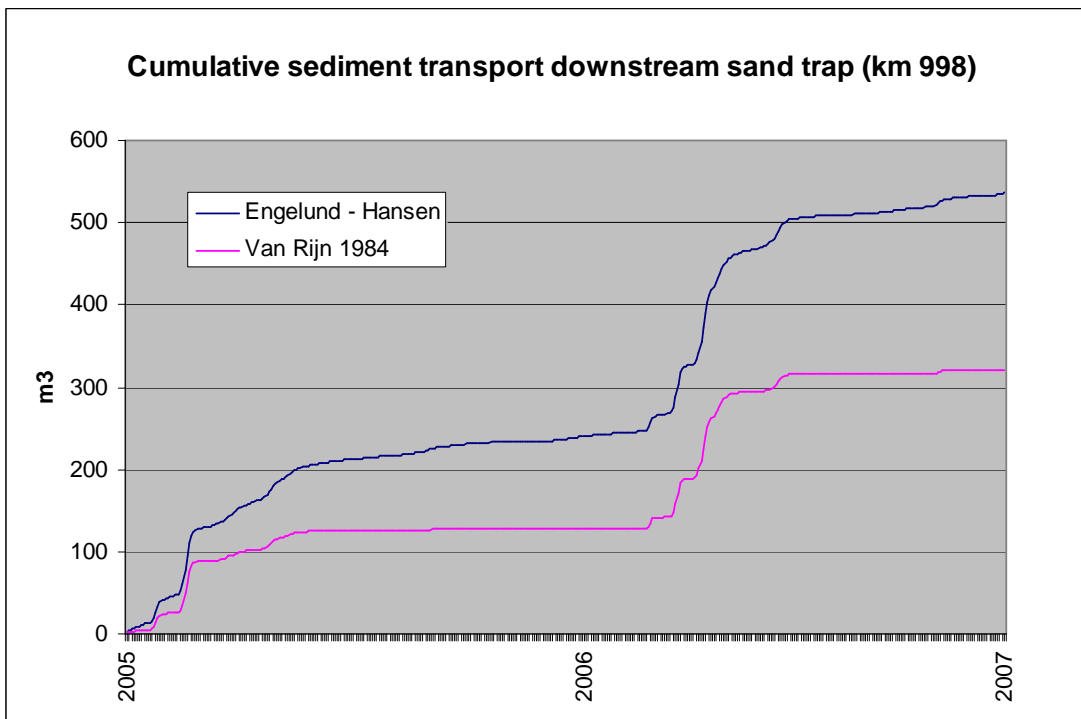


Figure 2.47 Cumulative sediment downstream sand trap

Using these figures and the data that they are from, the following results were obtained:

YEARLY SEDIMENT TRANSPORT				
	Engelund Hansen (m³)		Van Rijn 1984 (m³)	
	Upstream sand trap	Downstream sand trap	Upstream sand trap	downstream sand trap
2006	444	240	318	127
2007	1104	296	571	193

The results with Engelund-Hansen formula are quite different than the results with Van Rijn 1984 formula.

As it said in the beginning of the chapter, the Van Rijn formula distinguishes between sediment transport below the reference height, which is treated as bed-load transport, and the sediment transport above the reference height, which is treated as suspended-load. In the column of water, the relationship between the suspended sediment transport and the bed load transport is where the advection-diffusion phenomenon is implemented in the model.

Because Van Rijn formula includes this phenomenon, this formula was chosen for the model.

2.5 Influence of the bridge over the sediment zone.

In the lower part of the river there is a bridge and downstream there is a bend. In this bend there is a sedimentation zone which produces that the depth in that zone was very low.

This bridge has a pier in the middle of the river, and maybe it should produce some effects over the sedimentation zone (figure 2.48).

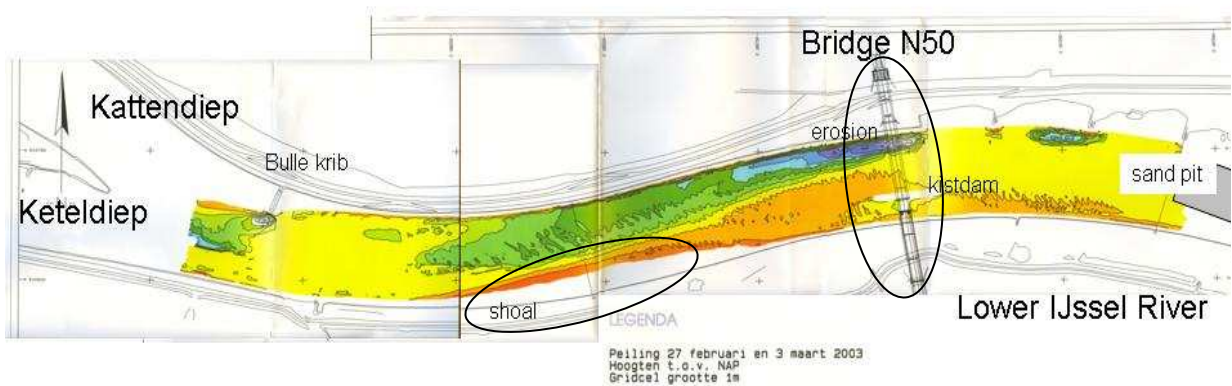


Figure 2.48 Location of sedimentation zone and bridge.

The bridge was introduced in the model using the option of “*Thin Dam*” in the program Delft 3D – Flow.

The option *Thin Dam* is used to introduce in the model objects with dimensions lower than the grid dimension. In this case the width of the pile of the bridge is 5 m and it is very small if it is compared with the width of the computation grid.

The characteristic of this *Thin Dam* is that it is a very thin object that avoids flow exchange between two adjacent computational cells.

So to check the bridge pile affectation, the sediment transport results of the model with the bridge were studied and compared with results of the model without the bridge:

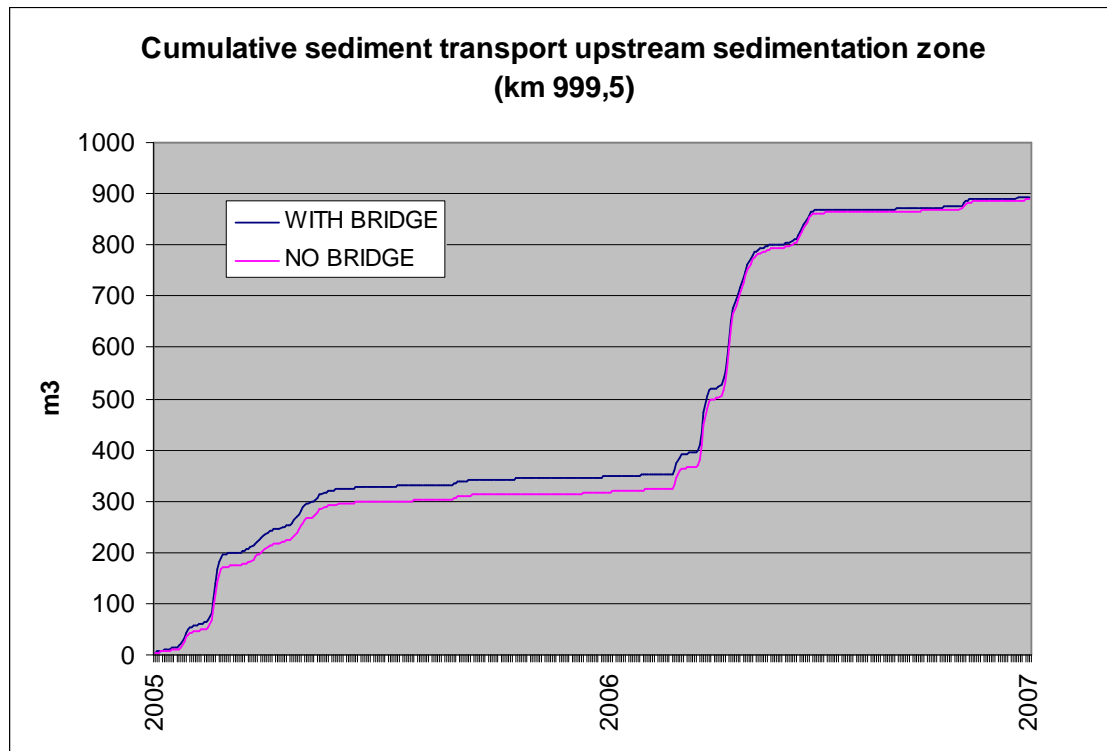


Figure 2.49 Cumulative sediment transports km 999.5

The figure 2.49 shows the cumulative sediment transport that arrives to the sedimentation zone just after the bridge. The difference is not too much, but it is enough to introduce the bridge in the model.

Therefore after these verifications, the bridge was introduced in the model and the model was totally finished.

3. Results & Discussions

3.1 Final model and the effect of the sand trap.

Results

- Evolution of the sand trap with the formula of Van Rijn

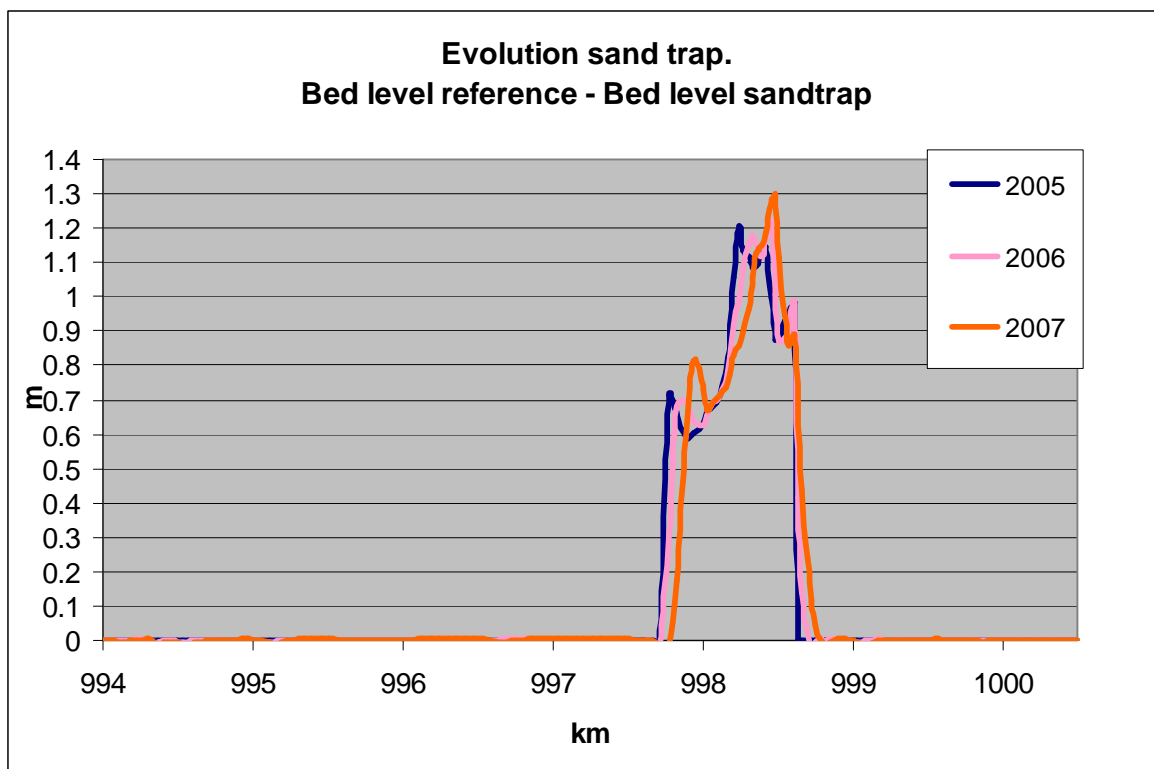


Figure 3.1 Evolution of sand trap

- Sediment transport over the sand trap:

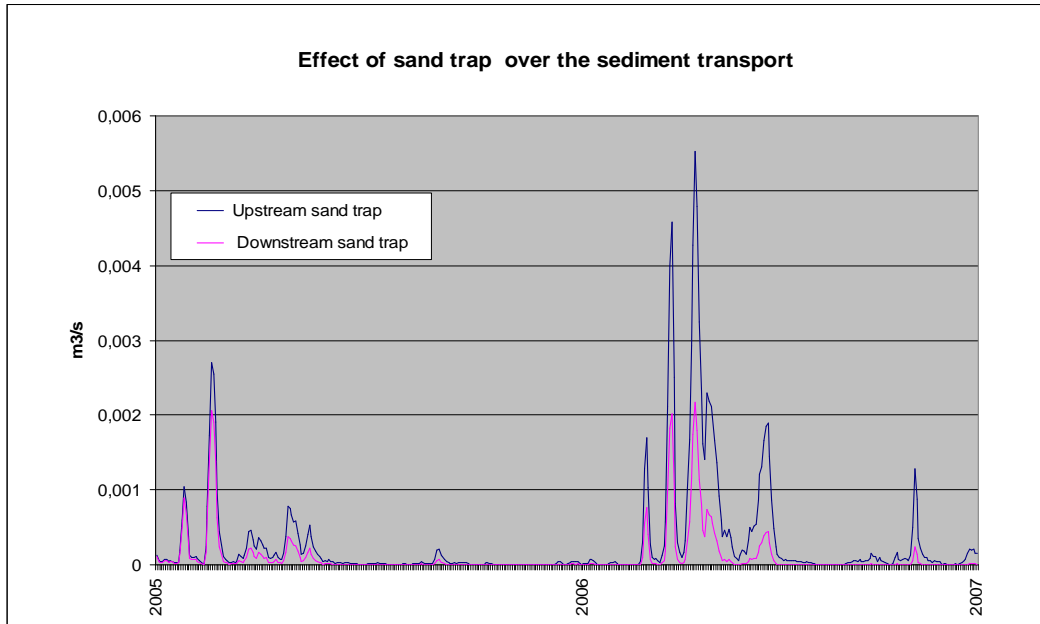


Figure 3.2 Sediment transport in km 997 (upstream sand trap) against km 998 (downstream sand trap)

- Cumulative sediment transport over sand trap:

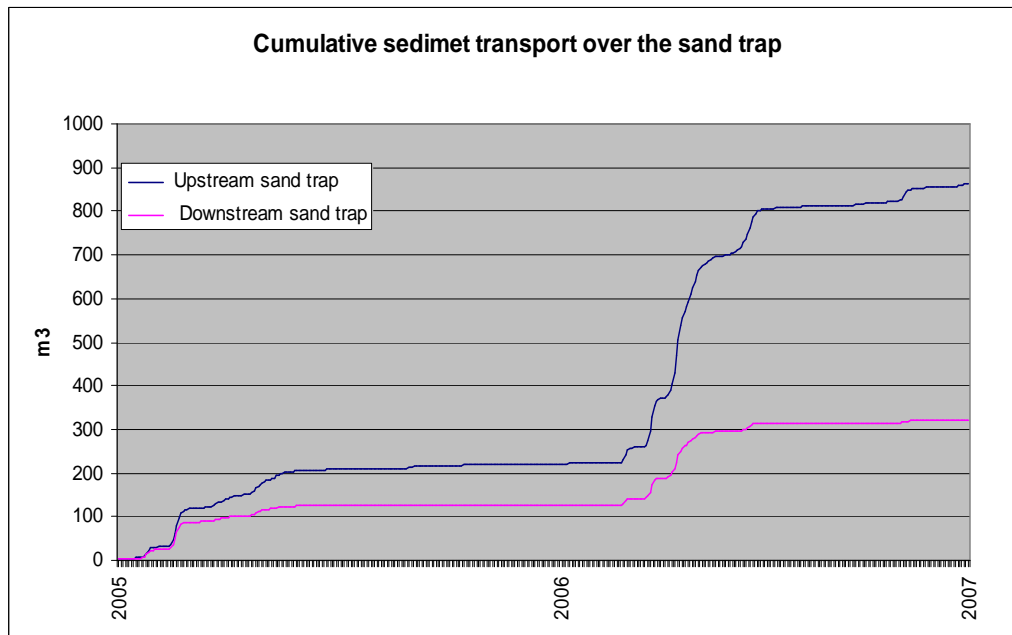


Figure 3.3 Cumulative sediment transport in km 997 (upstream sand trap) against km 998 (downstream sand trap)

- Effect of the sand trap over the erosion zone in the lower part of the river (from km 999.5 to km 1000) :

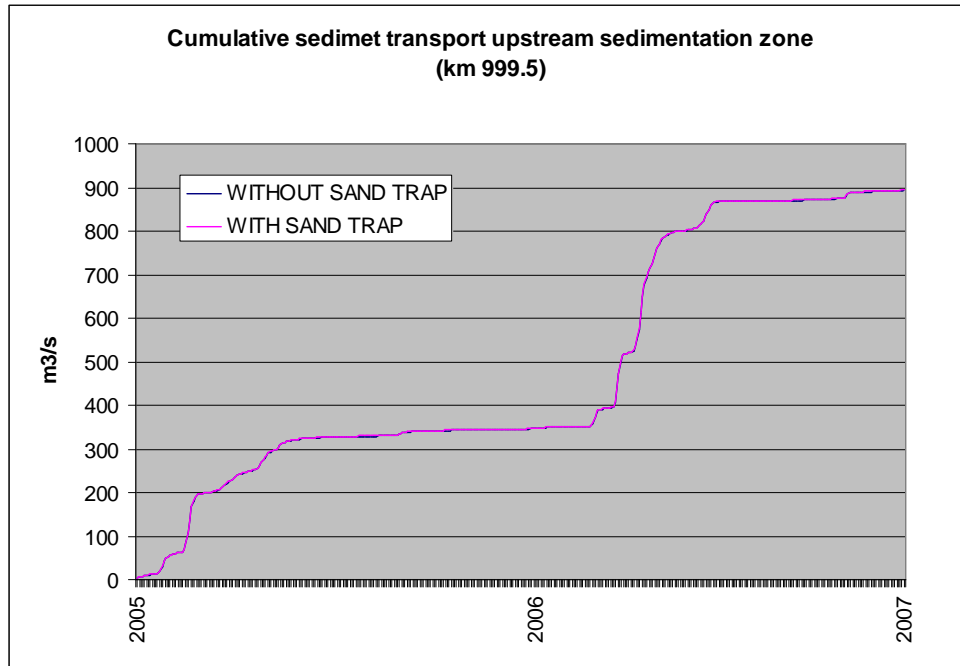


Figure 3.4 Cumulative sediment transport km 999.5

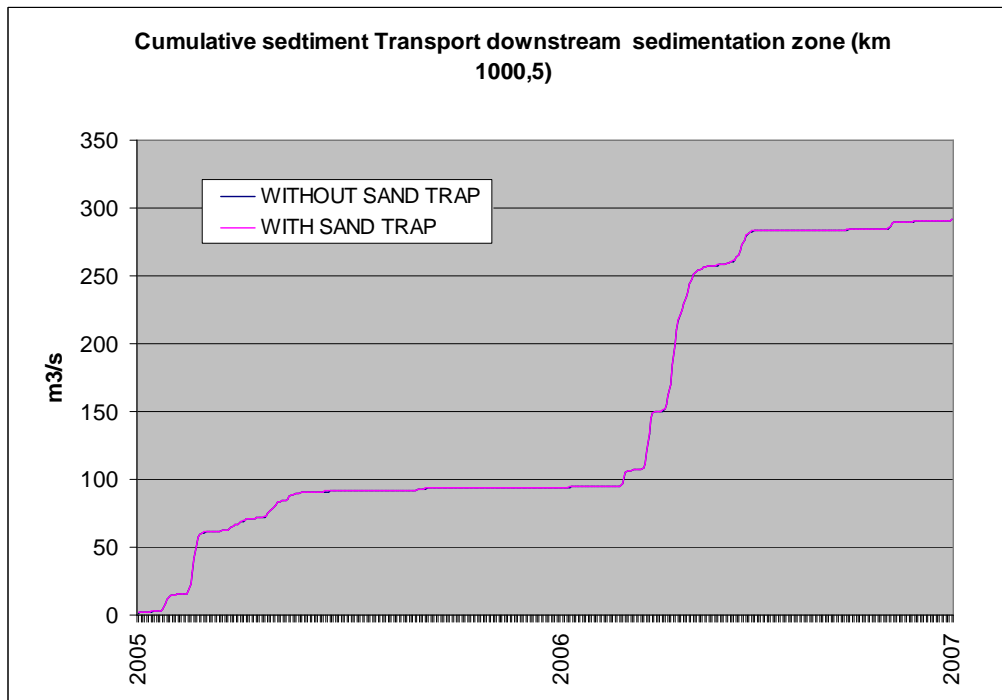


Figure 3.5 Cumulative sediment transport km 1000.5

Discussion

The figure 3.1 shows the sand trap evolution from 2005 to 2007. This figure is very similar to the figure obtained with the Engelund Hansen formula, in fact the movement of the sand trap is the same, but the filling of it is not the same.

Surface (m²)	170
Filling per year (m³)	6400
Movement (m)	87

The figure 3.2 shows that the sand trap works ok, because the sediment transport upstream the sand trap is bigger than the one downstream the sand trap. It means that there is sedimentation in the sand trap.

The figure 3.3 shows the effect of the sand trap over the cumulative sediment transport, with this figure is easier to check the amount of sediment transport that the sand trap avoids.

YEARLY SEDIMENT TRANSPORT		
Sand trap (m³/year)		
	Upstream sand trap	Downstream sand trap
2006	221	127
2007	643	193

The figures 3.4 and 3.5 show that cumulative sediment transport that arrives to the sedimentation zone is the same with or without sand trap. Therefore the effect of the sand trap over the sediment transport is non-existent.

3.2 Evolution bed levels from km 998 to km 999.5

Results

To try to find a reason for not efficiency of the sand trap, the evolution of the bed level in the stretch between downstream sand trap (km 998) and the upstream boundary of the sedimentation zone (km 999.5) was studied.

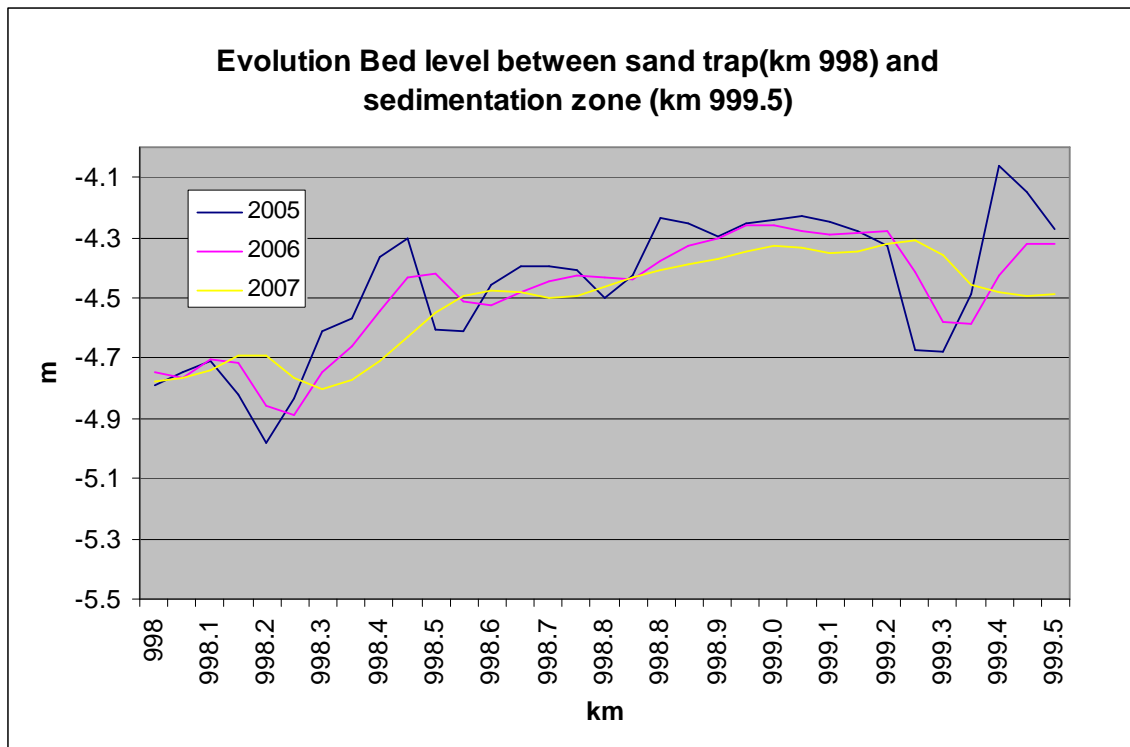


Figure 3.6 Evolution of bed level without the sand trap (average over all the width).

The figure 3.6 shows the evolution of the bed level in the stretch between km 998 (where the sand trap would be) and the km 999.5 (where the sedimentation zone begins). These bed levels are from the model without the sand trap.

Studying the figure 3.6 and after analyzing the data where the figure is from, the volume of erosion was calculated:

Calculation of volume of erosion	
Total (m ³)	7876
Yearly (m ³)	3938

Chart 1

Once the bed level evolution was studied in the model without sand trap, the same research was done in the model with sand trap:

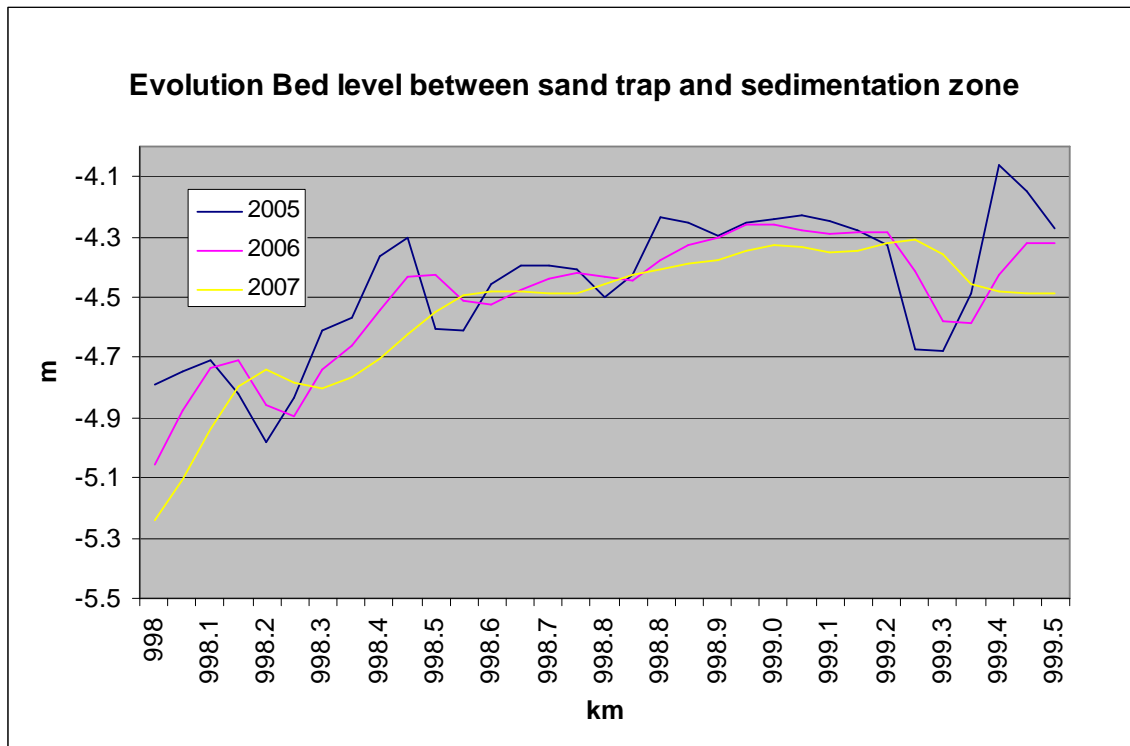


Figure 3.7 Evolution of bed level with the sand trap (average over all the width).

With the figure 3.7 and the data where it is from, the volume of erosion over this part of the river was obtained:

Calculation of volume of erosion	
Total (m ³)	12826
Yearly (m ³)	6413

Chart 2

Discussion:

If the charts 1 and 2 are compared, it is easy to check that the erosion from km 998 to km 999.5 with the sand trap in the model is bigger than the erosion without the sand trap in the model.

So, in the model with sand trap, the river takes sediments from this stretch leaving them in the sedimentation zone.

The figure 3.7 shows the effect of the sand trap over the bed level. There is an important erosion between km 998 and km 998.2, this erosion wasn't in the figure 3.8. So focus in this erosion it is possible to guess the zone that is affected for the sand trap.

4. Different alternatives to the original sand trap

As in the results of the point 3.1 was said, the effect of the sand trap over the sedimentation zone was very weak. For this reason was decided to study different alternatives for the original sand trap.

The different alternatives to study were grouped in two different groups : group A and group B.

4.1 Alternative group A:

These alternatives consisted of sand traps with the same volume than the original sand trap, but different dimensions.

The location of the sand trap was also changed; the sand trap was moved downstream, so the end of the sand trap was in the km 998.5. The sand trap was moved downstream to try to put it nearest to the sedimentation zone

Inside group A, two alternatives were studied: *alternative A.1* and *alternative A.2*.

4.1.1 Alternative A.1

In the alternative A.1, the length of the sand trap was from 1000 m to 1500 m. To maintain the original volume, the bed level was reduced from -6 m in the original sand trap to -5.5 m. Also the beginning of the sand trap was moved from km 998 to km 998.5.

ALTERNATIVE A.1

Length (m)	1500
width (m)	75
Bed level (m)	-5.5

Volume of dredging (m ³)	112500
--------------------------------------	--------

Volume of original sand trap (m ³)	112500
--	--------

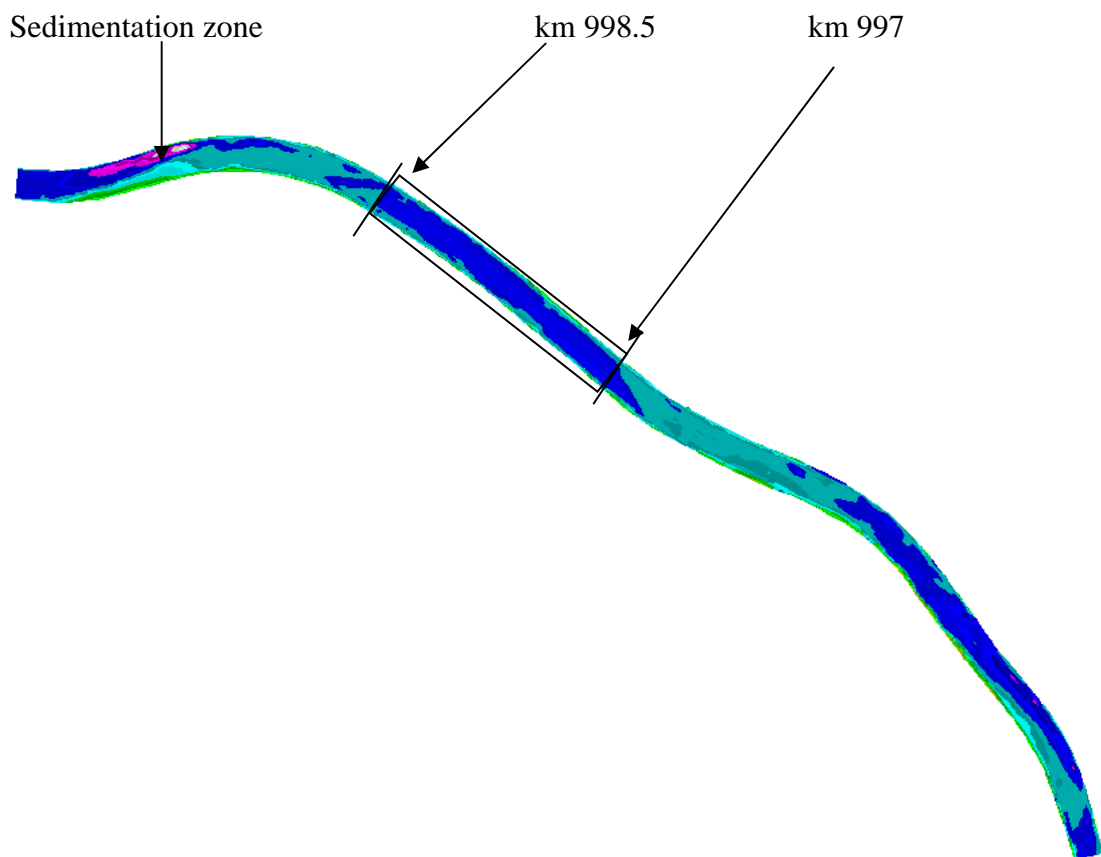


Figure 4.1 New location of sand trap.

This new sand trap was introduced in the model, and the effect of the sand trap over the sedimentation transport was studied. This effect of the new sand trap over the sediment transport was compared with the effect of the original sand trap over the sedimentation transport.

The place of the sand trap was changed; therefore the cross-sections that were used to study the sediment transport were changed.

The chart 3 shows that the new sand trap reduces the downstream sediment transport. It means that the effectiveness of the new sand trap is bigger than the effectiveness of the original sand trap.

	Original Sand trap (m ³)		Modified sand trap (m ³)	
	Upstream sand trap	Downstream sand trap	Upstream sand trap	Downstream sand trap
2006	221	127	228	82
2007	643	193	646	174

Chart 3. Different effectiveness of the sand traps.

Once the effectiveness of the new sand trap was studied, the effectiveness of the new sand trap over the sedimentation zone was studied:

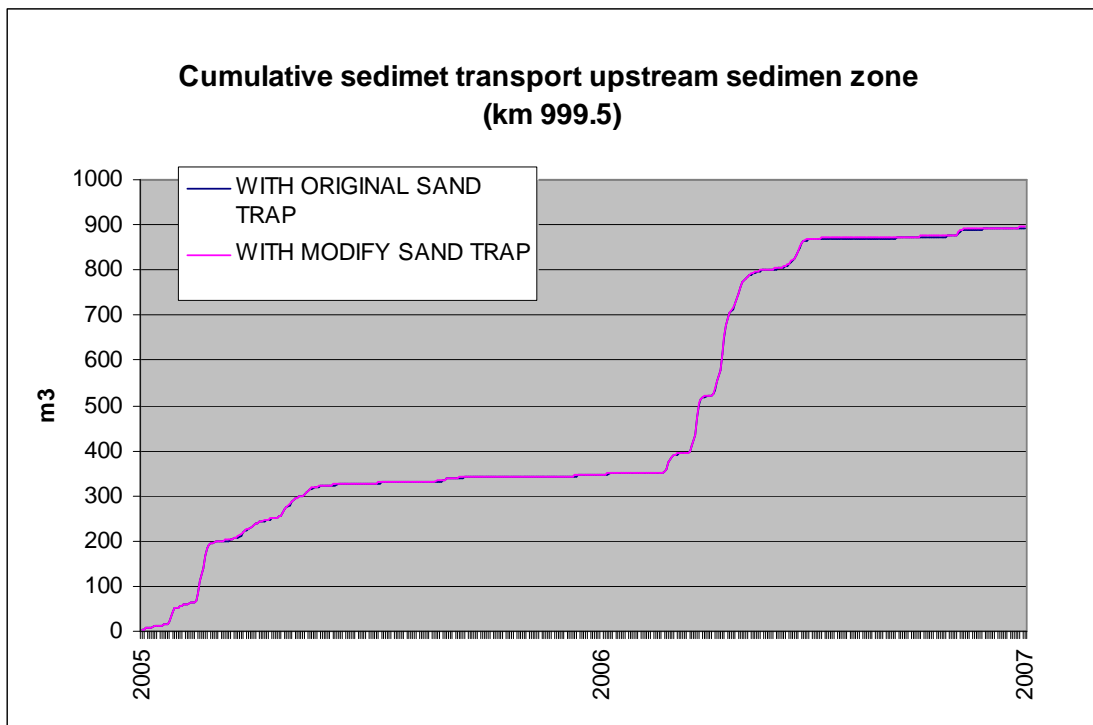


Figure 4.2 Cumulative sediment transport in the km 999.5

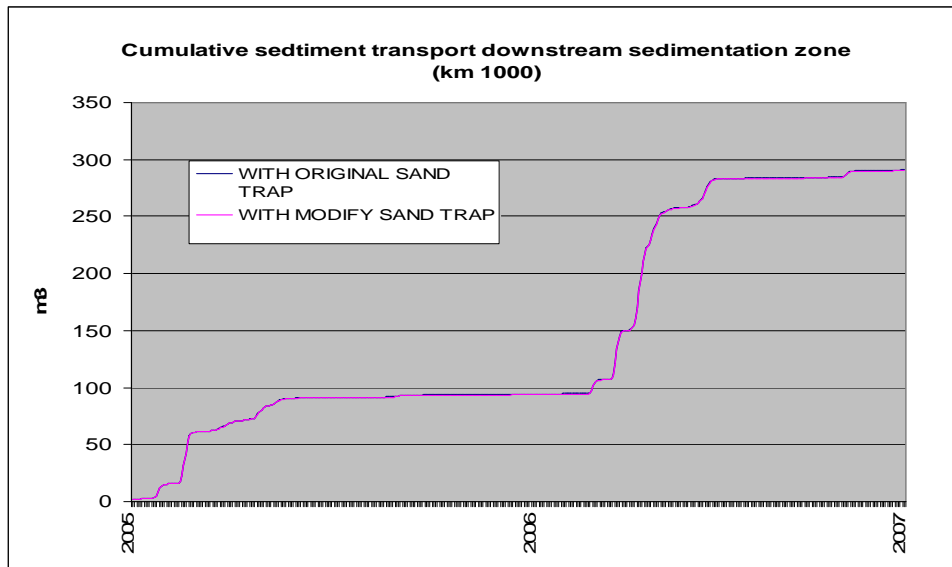


Figure 4.3 Cumulative sediment transport in the km 1000.

The figures 4.2 and 4.3 show the effectiveness of the sand trap over the erosion zone is almost insignificant again.

The evolution of bed level between downstream boundary of the sand trap (km 998.7) and upstream the sedimentation zone (km 999.5) was studied to know the evolution of the sand trap.

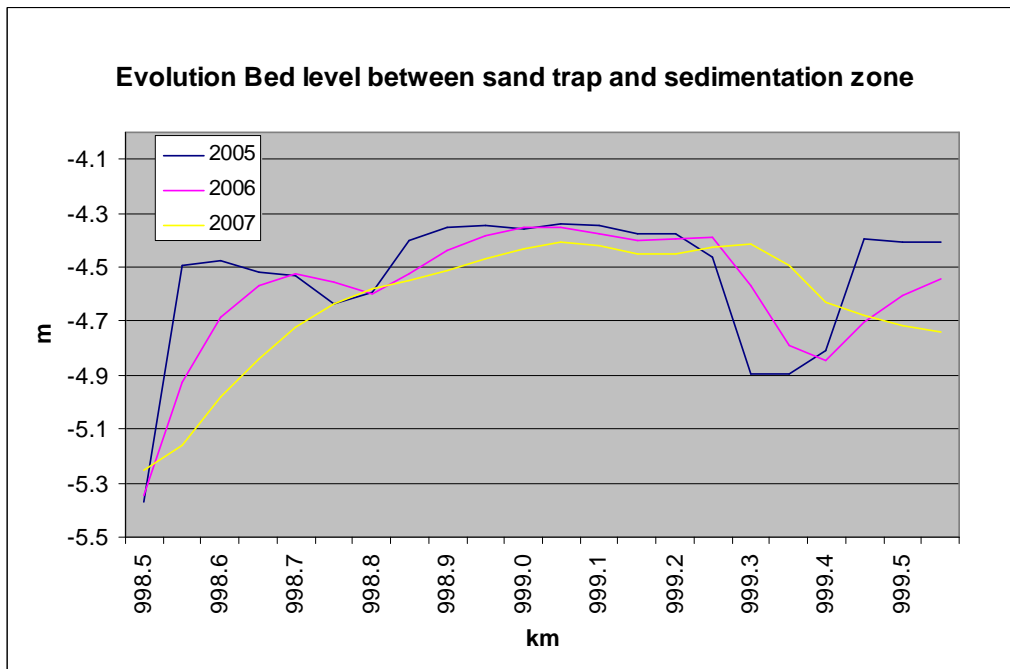


Figure 4.4 Evolution of bed level between km 998.5 and 999.5

The sand trap of the alternative A.1 catches more sediment than the original one; therefore the erosion downstream of the sand trap is bigger than in the original situation. This erosion is concentrated in the first kilometres (from km 999.5 to 999) after these kilometres there is an important sedimentation (from km 999.2 to km 999.4)

4.1.2 Alternative A.2

In the alternative A.2, the length of the sand trap was increased from 1000 m to 1700 m. The river length was not more to avoid dredging in the bends. To maintain the original volume, the bed level was reduced from -6 m in the original sand trap to -5.3 m. Again the beginning of the sand trap was moved from km 998 to km 998.5.

ALTERNATIVE A.2

Length (m)	1700
width (m)	75
Bed level (m)	-5.3

Volume of dredge (m ³)	102000
------------------------------------	--------

Volume of original sand trap (m ³)	112500
--	--------

In the alternative A.2 the total volume to dredge was less than in the original sand trap.

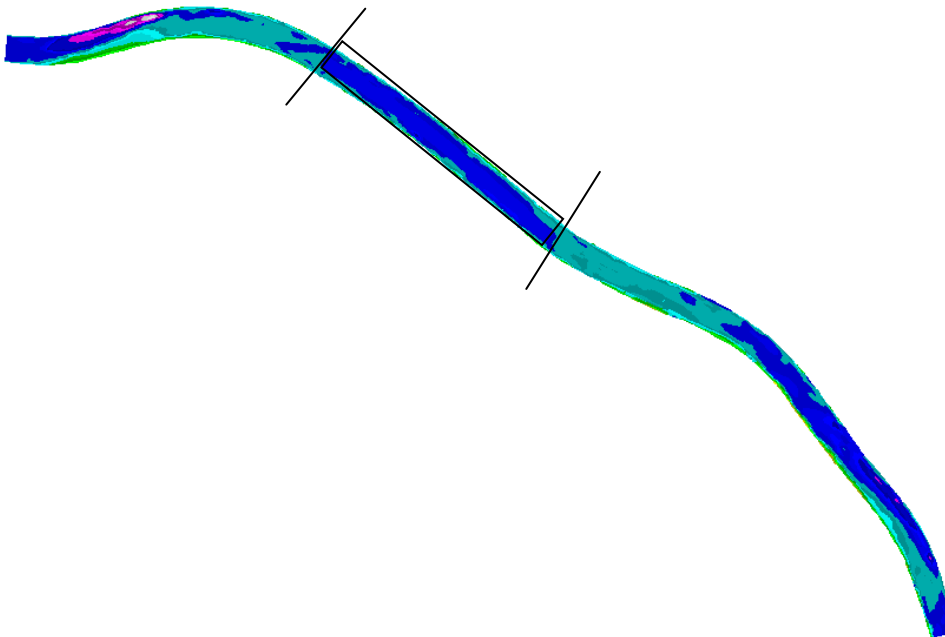


Figure 4.5 Location of the new sand trap.

To study the effect of this new sand trap, the same procedure used for the alternative A.1 was followed. So the chart 4 shows the effectiveness of the new sand trap:

	Original Sand trap m ³		Modified sand trap m ³	
	Upstream sand trap	Downstream sand trap	Upstream sand trap	Downstream sand trap
2006	221	127	344	94
2007	643	193	863	194

Chart 4. Different effectiveness of the sand traps

The chart concludes that the new sand trap, of which volume is lower than the original one, is more effective than the actual sand trap.

After, the modified sand trap effect over the sedimentation zone was studied:

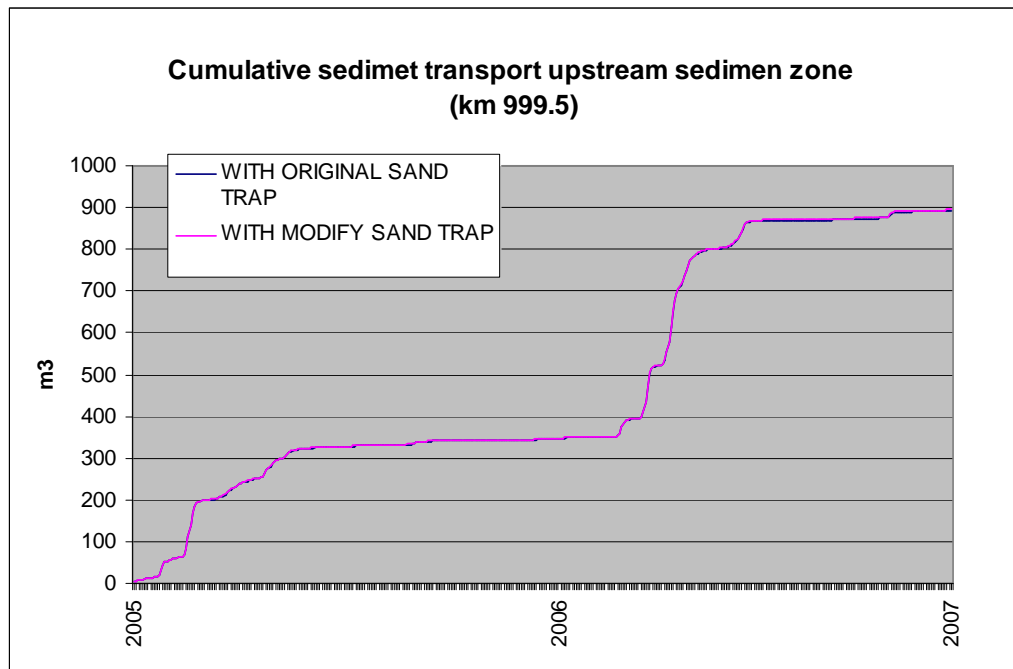


Figure 4.6 Cumulative sediment transport in the km 999.5.

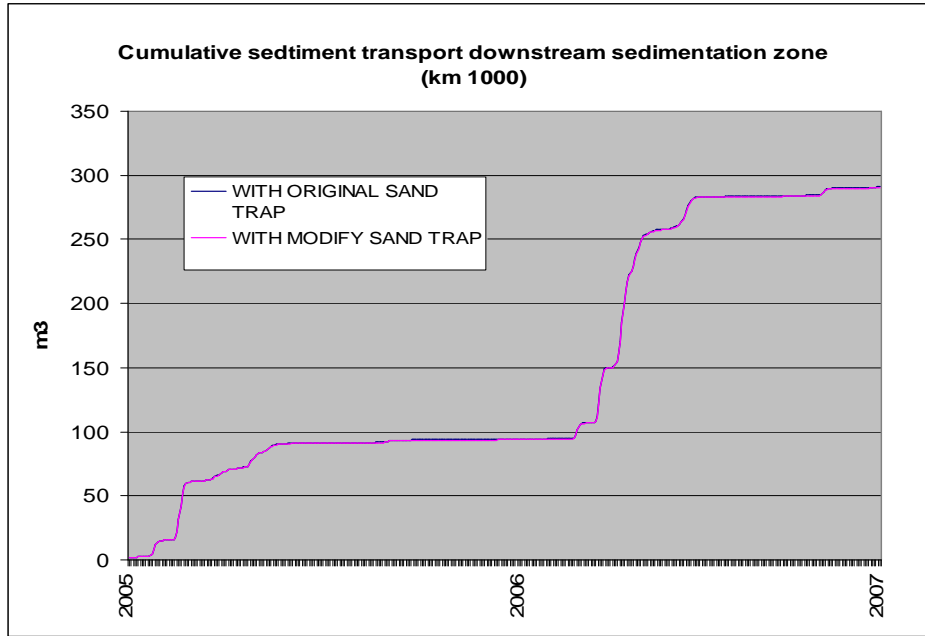


Figure 4.7 Cumulative sediment transport in the km 1000.

Again, the new sand trap had not any effect over the sediment transport in the sedimentation zone.

The evolution of bed level between downstream boundary of the sand trap (km 998.5) and upstream the sedimentation zone (999.5) was studied again.

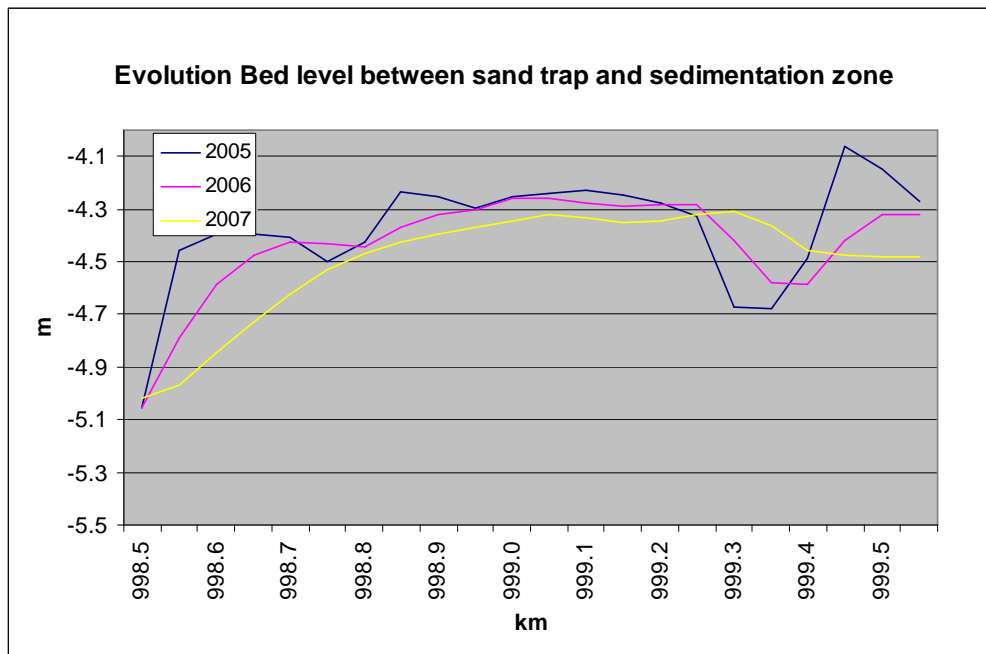


Figure 4.8 Evolution of bed level between km 998.5 and 999.5

4.2 Alternative group B.

This alternative B was with more length than the alternatives A.1 and A.2 and deeper. Therefore the volume to dredge was bigger than the original volume:

ALTERNATIVE B	
Length (m)	1750
width (m)	75
Bed level (m)	-6
Volume of dredge (m ³)	196875
Volume of original sand trap (m ³)	112500

The modified sand trap was located from the bend upstream the harbour of Kampen to the bend just upstream the bridge.

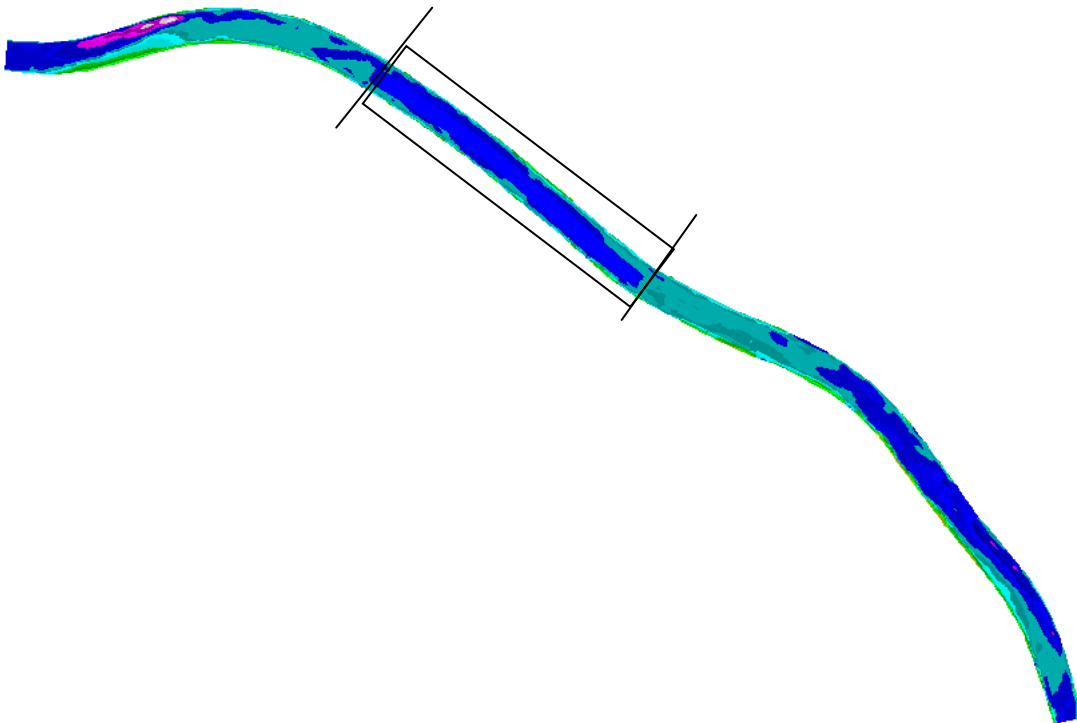


Figure 4.9 Location of the new sand trap (from km 996.7 to km 998.7)

So the sand trap in the alternative B was bigger than the original one, and therefore with more effect over the sedimentation transport:

	Original Sand trap m ³		Modified sand trap m ³	
	Upstream sand trap	Downstream sand trap	Upstream sand trap	Downstream sand trap
2006	221	127	425	62
2007	643	193	946	134

Although the modified sand trap was bigger than the original sand trap, it is easy to check in the figures 4.5 and 4.6 that its effect over the sediment transport in the sedimentation zone was non-existent again.

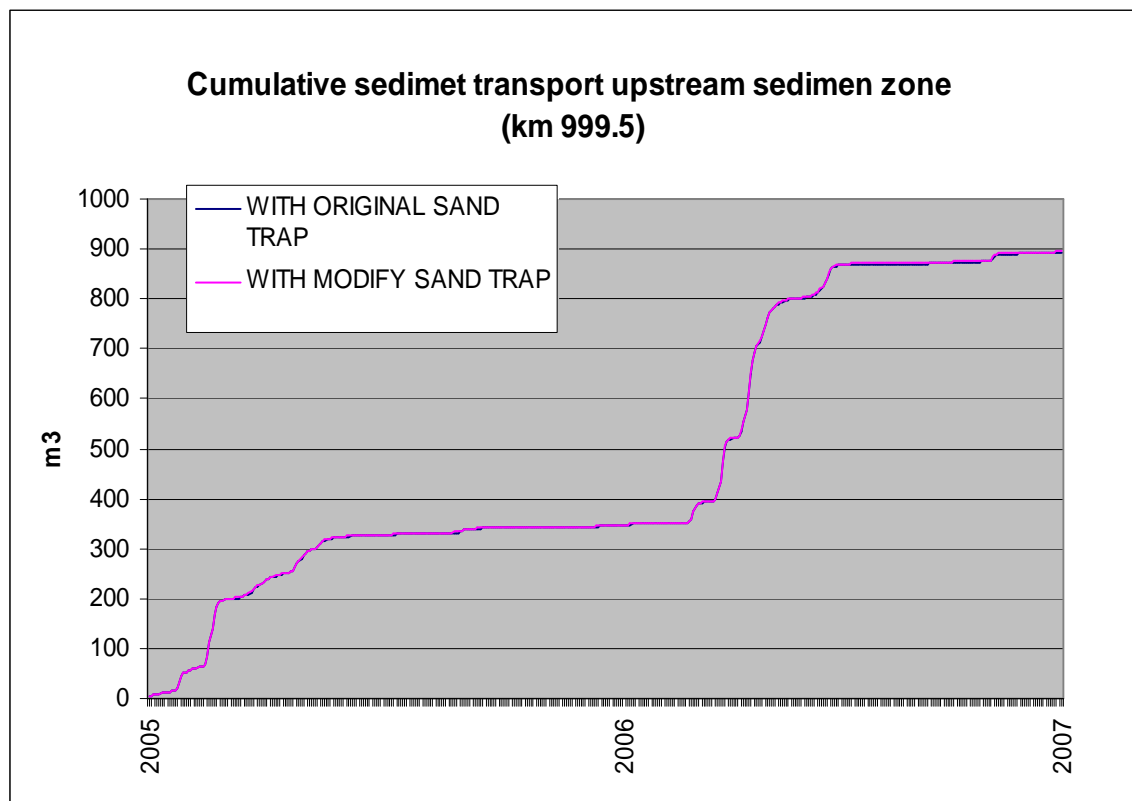


Figure 4.10 Cumulative sediment transport in the km 999.5

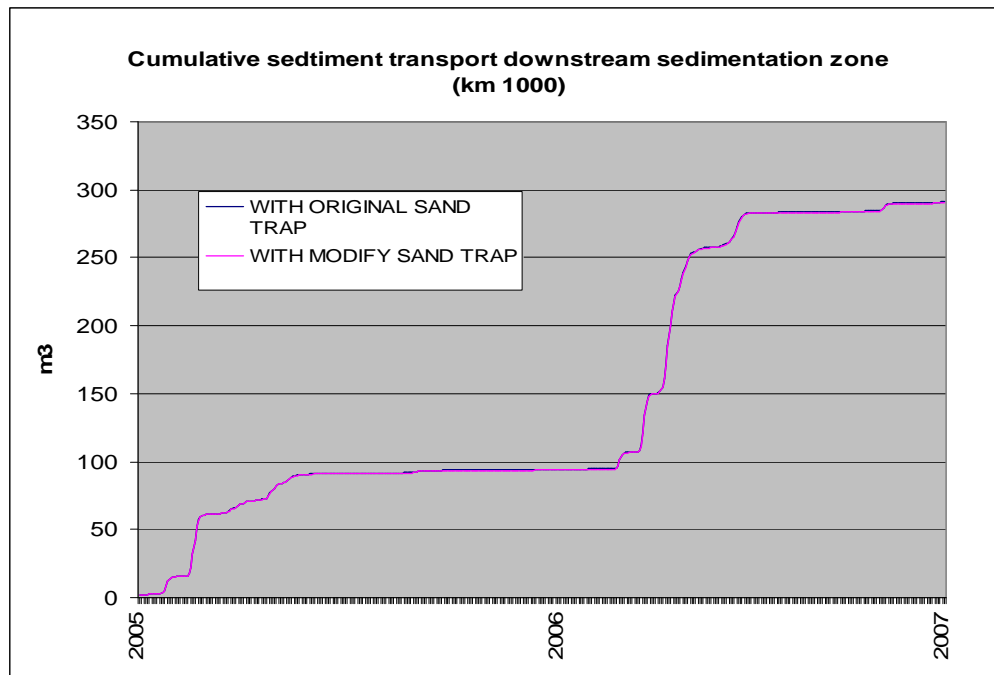


Figure 4.11 Cumulative sediment transport in the km 1000

Evolution of the bed level with the alternative B:

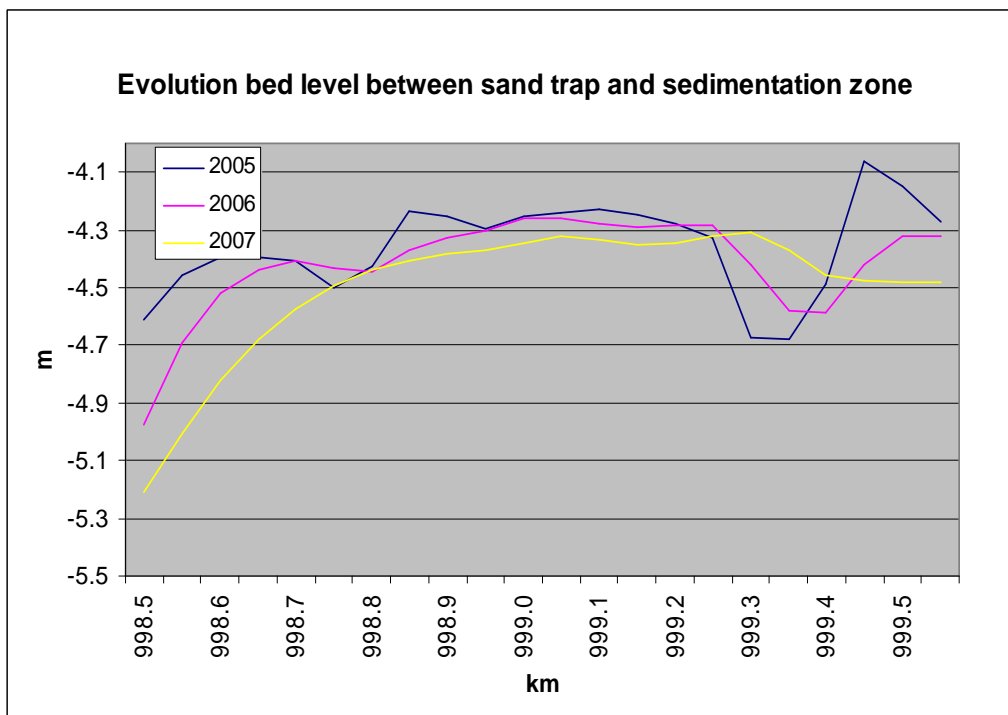


Figure 4.12 Evolution of bed level between km 998.5 and 999.5

5. Conclusions & Recommendations

During this report, the construction of the model of the river IJssel has been explained.

Once the model was constructed, the effectiveness of the sand trap was studied, and the following conclusions were obtained:

- The filling of the sand trap is 6400 m³/year, which is less than the estimated filling in the project (20000 m³/year). Therefore the effectiveness of the sand trap is less than it was expected in the project.
- The sand trap construction produces an increase of the erosion just after it. But this effect does not arrive to the sedimentation zone, it only affects the first 200 m downstream the sand trap. Therefore, the main goal of the sand trap (to reduce the sedimentation between km 999.5 and km 1000) is not reach.
- The alternative A.1 with the same volume dredged, produces better results than the original sand trap, because the amount of sediments that it catches is bigger than the original one. However its effects over the sedimentation zone are non-existent too.
- The alternative A.2 (sand trap with less volume than the original sand trap) produces better results than the original one (because fo the same reason than the alternative A.1). This conclusion is very important for designing of future sand traps. Because dredging a sand trap with more length but shallower is possible to obtain better results.
- The alternative B shows that to construct a bigger sand trap is not a solution to reduce the sedimentation downstream of km 999.5 (sedimentation zone).

This model can be used in future researches to try to find a better solution to reduce the sedimentation after km 999.5. To study the effect of a sand trap nearest the sedimentation zone (in the bend just before the bridge) would be a good study. However the effect of the erosion over the pile of the bridge will have to be considered in the model.

Once the topography data of the sand trap after 2004 is available, a better calibration of multiplication factor will be possible, and therefore the model will be improved.

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