# M. Sc. Thesis

## Cross-shore transport of heavy minerals

**R.J.E. van Broekhoven**

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# Preface

**Subject of thesis**
"Cross-shore transport of heavy minerals"

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Feb - Oct 2002: WL Delft Hydraulics

**Objective**
Create better understanding of cross-shore sediment transport processes in relation to the presence of heavy minerals and to make recommendations on how to model this correctly with Unibest-TC.

**Contents of this thesis**
Using Unibest-TC to compute cross-shore transport of heavy minerals. Data from previous research in this area will serve as a tool and for validation.
Knowledge resulting from this will be used to create a better understanding when using heavy minerals in beach nourishments and to give insight in new erosion figures resulting from this.

The author wishes to express his gratitude towards Marcel Stive for his great contribution in realising a possibility to work with coastal engineering colleagues in Brisbane, Australia. Gratitude is also expressed to Dirk-Jan Walstra for his input in this thesis work and to Don Ginsel for proof reading my documents as well as trouble shooting in case of a MS-Office crisis.

# Abstract

*"Een land dat door de zee wordt bespoeld, is nooit klein."*

"A nation, washed by a sea, is never small"

This statement by Dr.ir. Cornelis Lely not only embodies the wish of a nation but also implicates a motivation for coastal engineers all over the world: to ensure that the sea will not wash away the land.

It is this motivation that also forms the basis of this thesis work. From previous research it has become clear that adding heavy minerals to the sediment at the beach, may lead to a considerable reduction of beach erosion. In other words: it can help to realise more durable beaches with less human interference.

When this is considered, the question arises whether it is possible to simulate beach profile evolution and sediment transport processes in case of differences in sediment density. Can a numerical model such as Unibest-TC deal with differences in density, although it was not developed for this?

To examine this, reliable field or experimental data is required. This was found in the Scheldt wave flume experiments (Koomans and Bosboom, 2000). In these experiments, the impact of heavy minerals on beach profile evolution was investigated. If these experiments can be modelled successfully, than research has come a step closer to modelling full-scale beach nourishments with heavy minerals.

A set-up for the experimental conditions in Unibest-TC is made and tested in numerous runs to fine-tune hydraulic and roughness parameters. These runs are performed in a non-morphological state, which means that bottom changes are not calculated. The results from these runs are compared to the experimental results. The parameters that were not measured in the experiments, but which are needed for modelling in Unibest-TC, are determined from the comparison.

After finishing these tests, simulations of the experiments can commence.
For modelling a beach with a uniform mixture of quartz and heavy minerals, the density of the sediment was changed in the program code. It was changed to fit the theoretical value of a 60 - 40 mass percentage ration between quartz and zircon. This resulted in a mean sediment density of 3,220 kg/m$^3$.

When the results are reviewed it becomes apparent that Unibest-TC can reproduce trends in sediment transport and beach profile evolution. For the outer surf zone and the breaker zone, the results are in good correspondence to the experimental data.

For modelling a beach with a narrow strip, or “placer”, of heavy minerals, the local grain size was enlarged. By this manner, hydraulic equivalence was ensured in terms of fall velocity. This method is not without problems because other specific behaviour of heavy minerals could not be implemented. Furthermore, the location of the placer can not be defined horizontally. This means that it has to be defined in terms of waterdepth.

After testing, it is concluded that Unibest-TC is not very well prepared to simulate narrow placers of sediment, placers consisting of different density and/or grain size. It is not expected that difficulties, as described above, can easily be overcome. The most important recommendation is that sediment density should become a user-defined parameter and that this parameter, amongst others, becomes a function of the cross-shore distance. It is expected that this will enable Unibest-TC to perform good long-term morphodynamic calculations, for beaches nourished with heavy minerals.

It is clear that further research is necessary before nourishments with heavy minerals can be carried out. In the end, it is expected that the use of heavy minerals in beach protection can be a very attractive and innovative possibility for sandy beaches that suffer from erosion.

# Table Of Contents

# 1 Introduction

In recent years a significant amount of research has been conducted on the separation processes generated by wave action. In particular (suspended) sediment transport, occurring within the surf zone due to wave induced shear stress, was focussed on the influence of coarser and/or heavier grains in these processes.

Different researchers concluded that the occurrence of heavy minerals in the near shore area can have positive effects on the beach in terms of slope stability or in terms of erosion figures. One researcher in particular (Eitner, 1996) even states that the positive influence of heavier grains is even bigger than the influence of coarser grains. Experimental research conducted by Koomans (2000) clearly points out that "an increase in sediment density can lead to a considerable reduction of beach erosion".

Hamm *et al.* (1998a) shows that, amongst others, grain size is a parameter that must be considered in the design of a beach nourishment. The sediment density is not deliberated, although there is reason enough to suspect that an increase in sediment density can lead to a considerable reduction of beach erosion. What does this knowledge comprehend in relation to the engineering practice and the beaches of The Netherlands in particular, where beach nourishments are carried out to great extent and therefore justify research into this subject?
(Since 1991 a volume of about 7 million cubic meters of sand was used every year in beach nourishment projects to maintain the very dynamic Dutch coastline.)

This thesis deals with the specific impacts of using heavy minerals in the cross-shore beach profile. This research aims to help resolve the question whether the Dutch beaches can be further protected by adding heavy minerals to the sediment.
The author wishes to do so by gaining specific knowledge about heavy minerals and its specific hydraulic properties in wave action and current processes. This is followed by investigating if and how this knowledge can be implemented in an existing computer model, Unibest-TC.

The ultimate goal will be to contribute to the knowledge on beach dynamics. How can it be influenced in such a way that a more durable state is reached with less interference? It is expected that sediment, enriched with heavy minerals, can lead to a more durable state of the beach and that successful modelling will contribrute to this goal.

## 1.1 The nearshore coastal profile

The area in the direct vicinity of the shoreline can be divided into a number of area's, such as the surf zone and the swash zone. On numerous occasions in this report references will be made towards different areas within the shoreline area, as illustrated in Figure 1-1

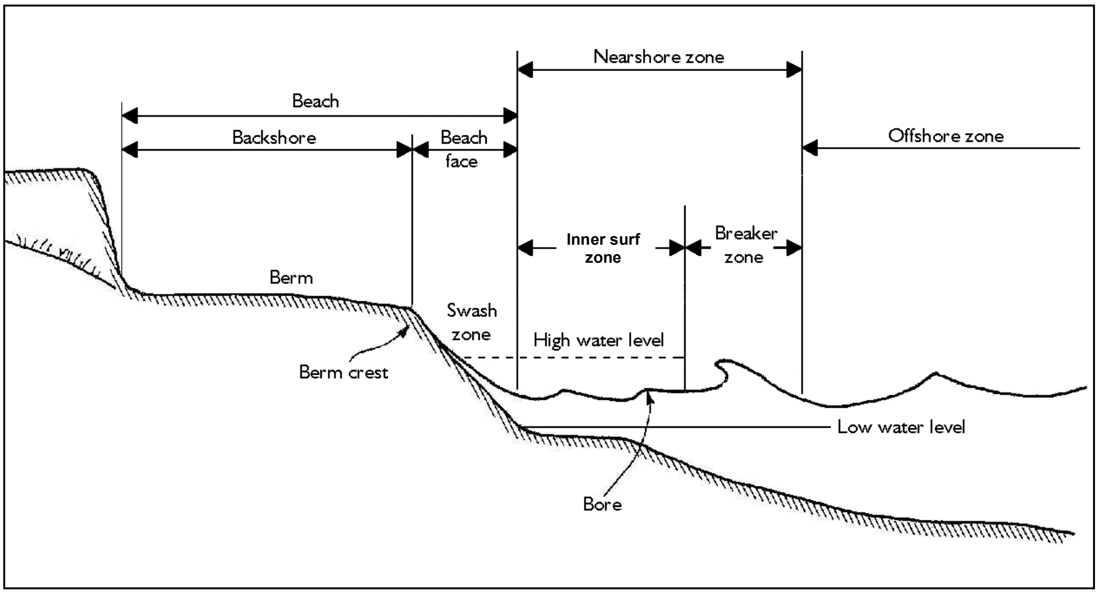

*Figure 1-1; The nearshore coastal profile*

It is the "nearshore zone" which is of particular interest for this research. Processes that occur in the swash zone (and elsewhere on the beach) will not be taken into account. These processes are poorly understood and not an integral part of the transport and hydrodynamic sub-models of Unibest-TC.

The processes in the surfzone and in the offshore part of the profile are of great interest for this research since it is expected that the presence of heavy minerals can have a great impact on the formation of breaker bars and the magnitude of local erosion or accretion.

## 1.2 Sediments[1]

Sediments on the present Dutch coast are mainly composed of what is called "terrigeneous clastic grains", commonly referred to as sand. These sands are fragments of rocks or minerals derived after centuries of physical and/or chemical breakdown of the source rock. During the transport by gravity, water wind and ice, these fragments are further broken down.

The resulting sediments can have a large range of grain sizes. A widely adopted scale of grain size classification is the Wentworth scale, illustrated in Figure 1-2.

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[1] *Part of this text originates from the PhD Thesis "Sand in Motion" (Koomans, 2000)*

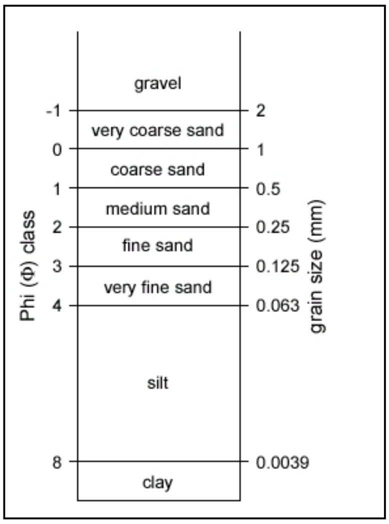

*Figure 1-2; Wentworth size classification for sediment*

Heavy minerals are minerals that have densities larger than quartz (> 2,650 kg/m$^3$). Zircon, with a specific density of 4,400 kg/m$^3$ is one these heavy minerals.

The heavy minerals have in common that, besides their large density, they are more resistant to weathering than soft minerals. Therefore, heavy minerals can be concentrated in the sediment and they will mainly be found in the finer sand fractions. This is because the finest fraction of "soft" minerals (such as quartz) is "easily"[2] transformed into clay minerals.
Furthermore, heavy minerals - like zircon - are very distinctive from quartz, because its natural high radio-nuclear activity and its apparent difference in colour to quartz.

Locally, heavy minerals in Dutch beach sands can be concentrated up to approximately 30% (Schuiling *et al.*, 1985) but the total mean concentration of heavy minerals in Dutch beach sands is low (approximately 1%).
For more detail on heavy mineral specific properties the reader is referred to the available literature.

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[2] *When looked upon in a geological time scale of 10,000s of years*

## 1.3 Explanation of terms; erosion vs. accretion

Erosion and accretion are two concepts, which will be referred to on more than one occasion in this thesis. Since these are terms not always very clearly understood, this can cause misconception of how they should be interpreted.

Illustrated in Figure 1-3 is a typical display of sediment transport rates in the cross-shore profile. The way this kind of figure is interpreted in this thesis is assessed below.

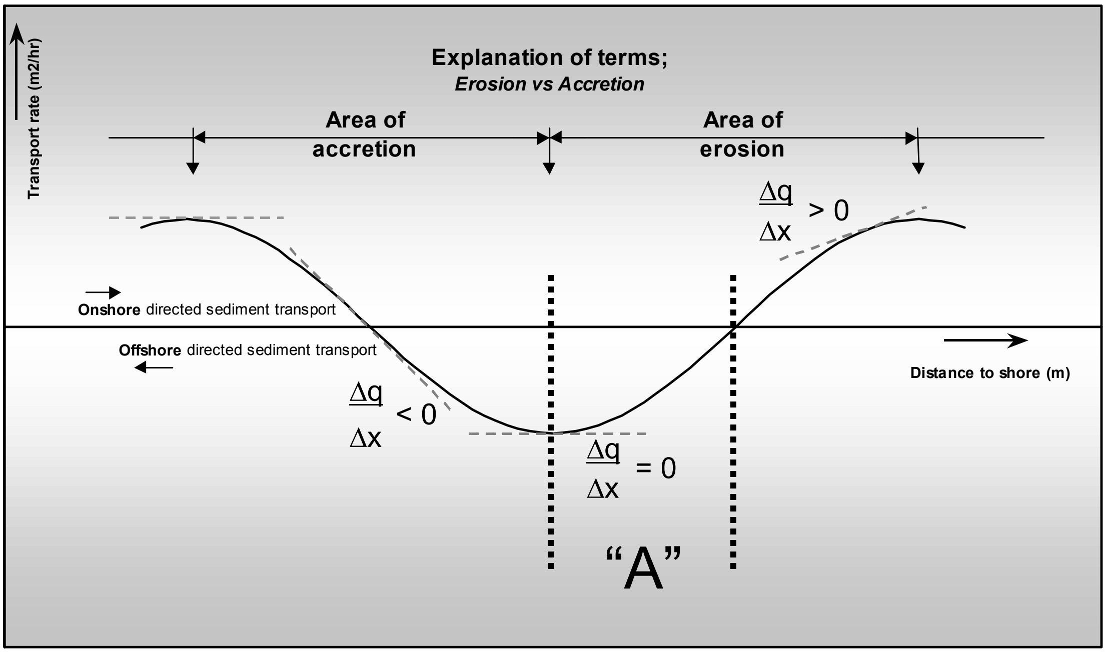

Figure 1-3; Explanation of terms: Erosion vs. accretion

In the areas where the transport of sand is positive, it is onshore directed, not to be confused with accretion[3]!

In the figure two areas of accretion and erosion are illustrated. In the area where the gradient Δq/Δx shifts from zero to a positive value, there is erosion. When this coincides with negative values for the transport rate, it means that this part is eroded and that the eroded sediment is transported offshore. This part of the erosion area is marked as region "A".

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[3] *Accretion is defined by the difference between the transport that leaves and the transport that enters a given area with strict boundaries. When this difference is negative, accretion has occurred.*

## 1.4 Problem analysis

Considering the outcome of previous research it is reasonable to assume that using heavy minerals in beach nourishments can have a positive[4] influence in terms of beach slope stability and erosion. Research conducted by Koomans (2000) states that "an increase in sediment density can lead to a considerable reduction of beach erosion".
Koomans' conclusions are based on the outcome of his experimental work that was conducted as a part of the European MAST-III project SAFE (performance of Soft beach systems And nourishment measures For European coasts).

What remains is the question: can the existing computer models predict this reduction of erosion correctly when heavy minerals are present. And if so, what does this mean on a larger scale, for the engineering practice?

Insight in the possibilities of computer models is necessary to answer the question: should heavy minerals be considered in the design of beach nourishments? (This of course from an engineering point of view, not an economic one.) From this problem analyses the following problem was defined:

***What happens when modelling the cross-shore sediment transport with UNIBEST-TC after "starting" with a more or less uniform sand mixture[5] and how well does this represent transport processes[6] of the beach profile in relation to the experimental data?***

It should be noted that Unibest-TC was designed for sandy beaches. The transport formulas that are used in the program are tuned for sediment, uniform in density. Therefore, the sediment density is not a user-defined parameter, and possible secondary effects are not implicated.

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[4] *Positive meaning: Leading to a more durable state of the beach*
[5] *A uniform mixture of quartz and heavy minerals.*
[6] *Processes which can lead to erosion or accretion of the beach*

## 1.5 Objective

From the problem analysis, which is stated above, the following objective was generated:

***Create better understanding of cross-shore sediment transport processes in relation to the presence of heavy minerals and make recommendations on how to model this correctly with Unibest-TC.***

To achieve this goal, a number of questions are formulated.

1. What research was conducted into sorting of mixtures with different grain sizes or densities and how could this knowledge be used in this research?
2. What is the outcome of the experiments conducted by Koomans (2000)?
3. How well can Unibest-TC model and reproduce the outcome of the experiments conducted by Koomans and which conclusions can be drawn towards using Unibest-TC for modelling beaches with heavy minerals?
4. What can be considered as a good enough solution for modelling heavy mineral enriched sediment when comparing this to the experimental data?
5. What is the outcome when modelling a beach with heavy minerals in Unibest-TC and what conclusions can be drawn towards the application of heavy minerals for beach protection?

It is expected that by answering these questions valid conclusions can be drawn such that the objective as stated above will be met.

## 1.6 Limitations

Certain limitations have to be considered. A great deal of this thesis includes the modelling of experiments that were conducted in a laboratory wave flume. Therefore, both limitations from the computer model as well as from the laboratory data are considered here.

The experimental set-up determines the limitations with respect to the calibration and validation. This means:

- No tidal influences
- No wind influence
- Calculations while developing and validating the model will be made for waves with an angle of approach of 90 degrees. This angle is with respect to the shoreline. This means that no wave induced long-shore current or refraction will be present.
- Calculations will be made with initial slopes that are identical to that of the Scheldt wave flume experiments.
- Calculations will be made for two different sediment types. These will be different in specific density and grain size and be compatible with the sediments used in the research conducted by Koomans (2000)
    - The first will be quartz with a specific density of $2.43 \cdot 10^3$ kg/m$^3$, a D50 of 129μm and a D90 of 187μm
    - The other will be zircon with a specific density of $4.40 \cdot 10^3$ kg/m$^3$, a D50 of 115μm and a D90 of 153μm

With respect to the use of Unibest-TC, the limitations follow from the manner in which this computer model was constructed:

- The model is developed and tuned for field conditions, similar to what can be found on the Dutch beaches. This means that density is thought to be uniform and is not a user-defined parameter.
- For the undeep part of the profile, known as the swash-zone, no hydrodynamic or transport formulas are included. The sediment transport in this area, as well as on the dry beach, consists of an extrapolation of transport from the last computed wet gridcell.
- A basic assumption in the model is that the coast is uniform in longshore direction. Input and output are two-dimensional and differences with respect to the longshore direction can not be presented.

## 1.7 Approach

The approach chosen to set the objective is best explained by Figure 1-4.
The goal is defined by the problem analysis and the objective as presented in paragraph 1.4 & 1.5.

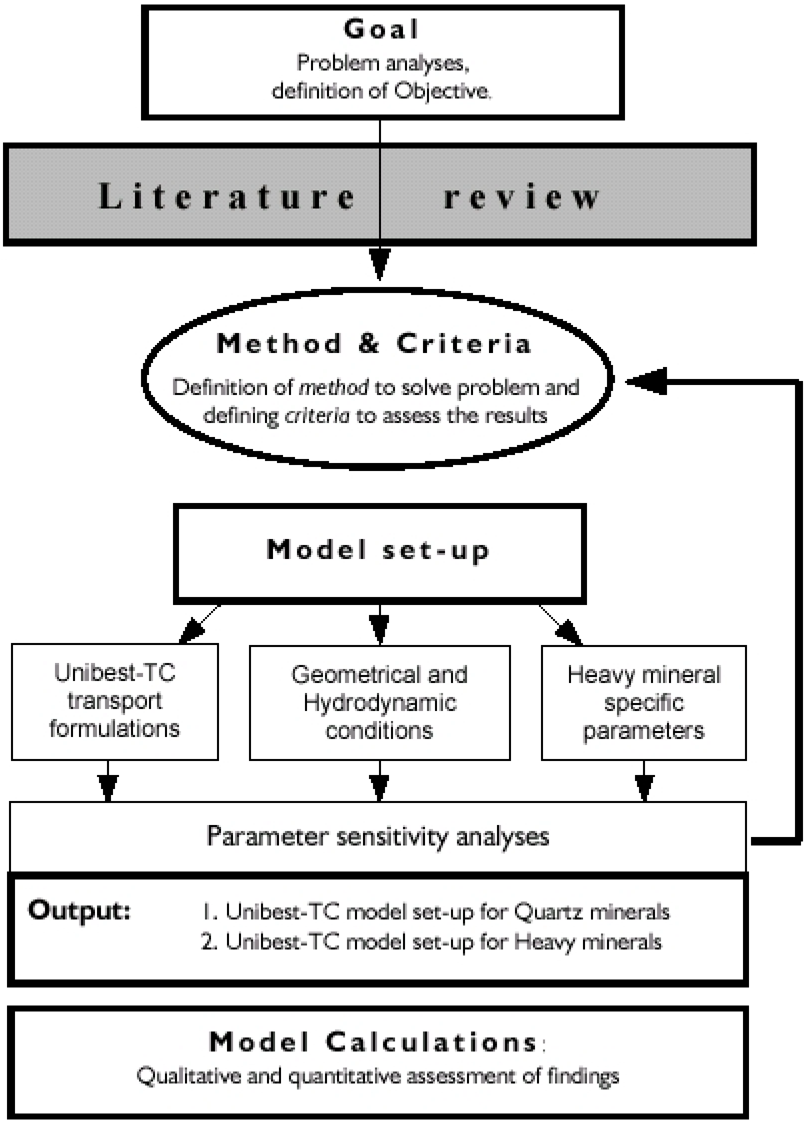

*Figure 1-4; Research approach*

With the necessary literature review, influencing the process from the background, this leads to a dynamic problem solving method and criteria of what will be defined as a satisfactory solution to the problem. This part called “Method & Criteria” is influenced by feedback from the sensitivity analyses (see chapter 4) in which the model set-up is prepared.

## 1.8 How to read this report

A brief description of the following chapters is presented.

In chapter 2, the relevant literature is reviewed. From this literature, important information was used in the development of the model set-up. The influence of grain size and sediment density is the main topic. Theories on equilibrium beach profiles and the influence of sediment density are presented. A big part of this chapter deals with the experiments that were conducted in the Scheldt Wave Flume of WL | Delft Hydraulics. Both experimental set-up and the results of these experiments are reviewed.

The choice was made not to present all the sub-models that are used in Unibest-TC. Chapter 3 only describes a few aspects of the way that Unibest-TC is built up. However, the presented aspects are critical for a good understanding of the process that is described in chapter 4. It is considered to be interesting for those readers that have no knowledge of Unibest-TC and its sediment transport definitions.

Chapter 4 can be considered as a calibration of Unibest-TC to the Scheldt flume experiments. Non-morphological calculations are presented and these calculations are used to determine values of parameters that were not measured in the experiments. In the last part of this chapter, the model set-ups are discussed for the different runs. Time-series of these runs are also presented.

The findings of the model calculations are gathered in Chapter 5. This chapter comprehends the validation of the Unibest-TC runs against the experimental results. Each typical serie of runs is presented individually and the findings for all time-series are presented here. The chapter finishes with a short assessment of all the runs that were performed.

Finally, Chapter 6 provides the reader with the conclusions that were drawn towards using Unibest-TC as a tool to simulate the presence of heavy minerals in the sediment at the beach. Naturally, recommendations are made towards the use of Unibest-TC for this particular topic in the future, as well as recommendations for further research.

# 2 Literature review and previous studies

In this chapter some basics of coastal engineering are reviewed. Also, the results from two earlier conducted studies into the effects of density graded sediment are included. In general, this chapter deals with the impact of differences in grain size and sediment density on beach profiles and sediment transport processes.

The empirical theory on equilibrium beach profiles is presented in paragraph 2.1. This theory is used to demonstrate the impact of differences in grain size on local beach slopes.

The manner in which heavier grains are transported differently from quartz grains is presented in paragraph 2.2. This paragraph concentrates on the research conducted on selective transport (Tánczos, 1996).

Finally, the set-up and the results of the Scheldt wave flume experiments on graded sediment (Koomans and Bosboom, 2000) are presented in paragraph 2.3.

## 2.1 Equilibrium beach profiles

This paragraph deals with the theory of equilibrium beach profiles (Dean, 1977-1991). This theory is based on the idea that beach profiles tend to shift towards an equilibrium profile of which the steepness depends on the amount of wave-energy that is dissipated and the sediment particle diameter.
The basic equilibrium beach profile is given by the following formula[1]:

$$h = A(x_0 - x)^{2/3},\ \mathrm{A} = \left[\frac{24\mathrm{D}_*(D)}{\rho g^{3/2}\kappa^2}\right]^{2/3} \qquad (2\text{-}1)$$

This simple relation, empirically suggested by Bruun (1954), between the water depth at a seaward distance, x from the origine $x_0$, and the scale parameter A is to be interpreted as the equilibrium beach profile resulting from uniform wave energy dissipation per unit water volume.
The uniform wave energy dissipation per unit volume is formulated as:

$$D_* = \frac{1}{h}\frac{\delta}{\delta x}\left(EC_G\right) \qquad (2\text{-}2)$$

where $E$ and $C_G$ are the wave energy and group velocity, respectively.
Other parameters in equations 2-1 and 2-2 are:

$D$ = sediment particle diameter [m]
$\rho$ = water mass density [kg/m$^3$]
$g$ = gravity [m/s$^2$]
$\kappa$ = wave breaking parameter [-]
$x$ = distance from shoreline [m]

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[1] *The coordinate system used here is based on the same coordinate system that is used in Unibest-TC and is illustrated in chapter 3. The origine, $x_0$, is located at the point were mean water level and the beach intersect.*

Later, Moore (1982) analysed a number of published beach profiles and developed the relationship between A and D as shown by the solid line in Figure 2-1.

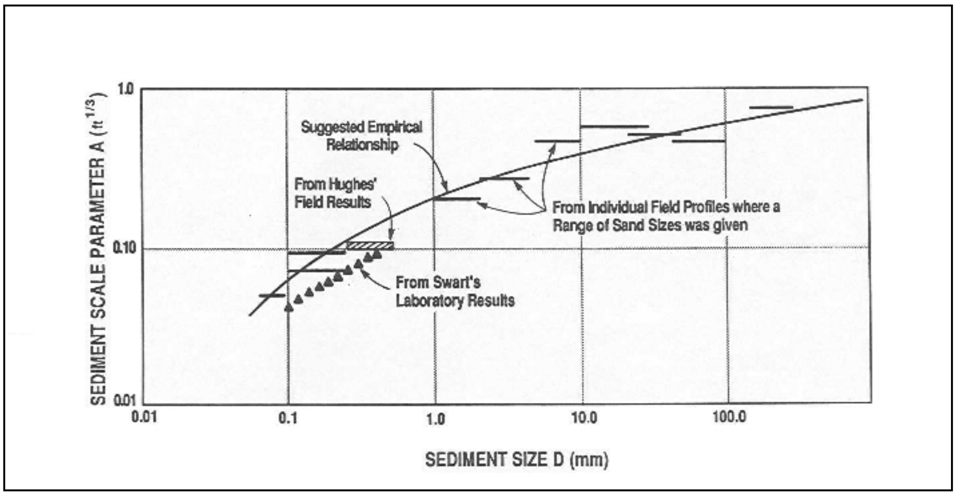


*Figure 2-1; Beach profile factor, A, vs. sediment diameter, D. (Dean 1989)*

### 2.1.1 Impact of grain size on profile development

The theory of basic equilibrium beach profiles can be used to illustrate the effects of water level rising or beach nourishments on the equilibrium to which the profile will tend to evolve. It can also be used to illustrate differences between equilibrium profiles for different grain size distributions. This is presented in Figure 2-2.

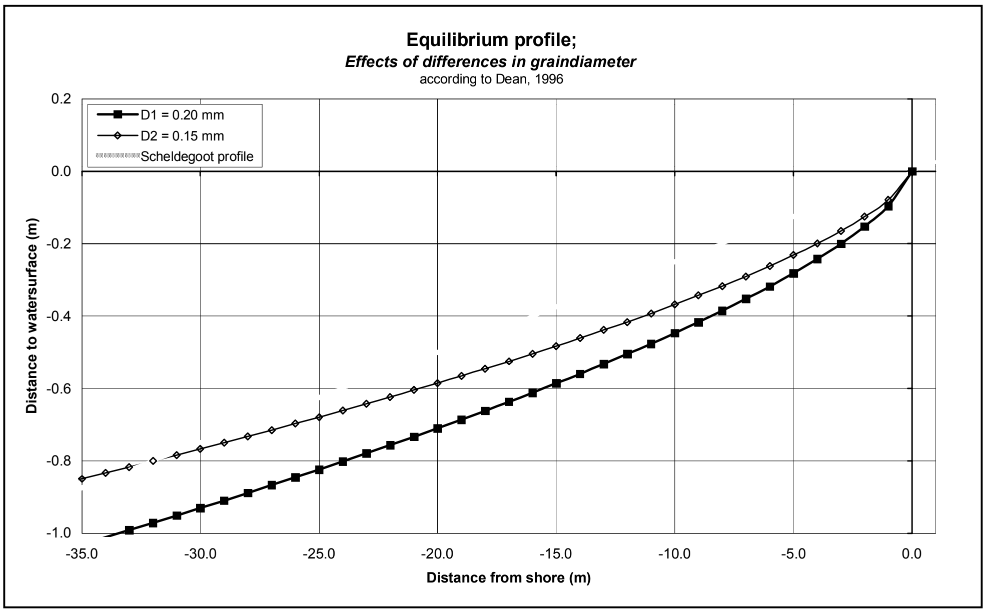


*Figure 2-2; Equilibrium beach profiles for different grain sizes, according to Dean and Moore*

In the figure, lines are plotted for two different median grain sizes as well as the initial profile of Scheldt-flume experiments. *(The latter is shown for referential purposes later on in this chapter and this document.)* The interpretation of Figure 2-2 together with equation (2-1) is that a particle of given size is characterised by an associated stability. Wave breaking results in mobilisation of the sediment particle with resulting offshore displacement and a milder beach slope.

Before calculating the profiles presented in Figure 2-2, the values for A were derived from the data analyses by Moore, presented in Figure 2-1.

Based on Figure 2-2, the conclusion can be drawn that a beach consisting of larger sediment particles will lead to steeper beach faces. It should be noted that this -empirical- theory is only valid for the area in which wave breaking occurs and for beaches consisting of quartz and quartz-like sediments. Differences in sediment density that may occur in the cross-shore profile are not implemented in this theory.

### 2.1.2 Profile response to beach nourishment

Dean includes in his theory on equilibrium beach profiles the effects that nourishments have on the "response" of the profile. The impact of differences in grain size between the native sediment and the borrow material can be significant.

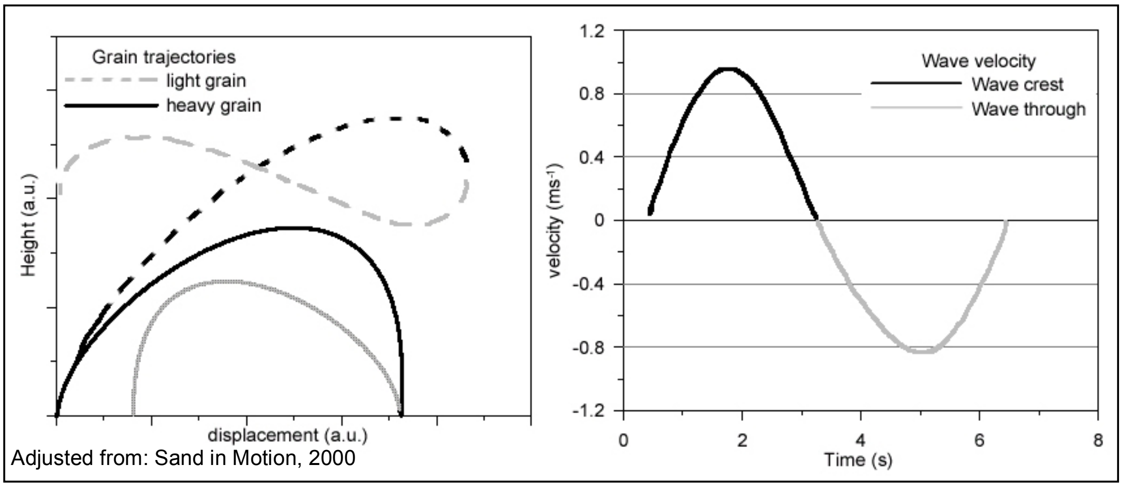
When a pilot on beach nourishments with smaller grains of larger density is set up, it is expected that this part of Dean's theory on equilibrium beach profiles will be very useful. It is therefore included in Appendix A.

## 2.2 Selective transport phenomena

Other researchers also investigated the influence of sediment density on transport processes. One of the theoretical models that was developed, is the grain-trajectory-model (Tánczos, 1996), which can describe why and how density affects the selectivity of transport. This selectivity of transport is a known phenomenon and it frequently occurs in nature.
Basically it means that sediment is transported in such a way that grains tend to settle in regions. In these regions you will mostly find grains which are hydraulically equivalent to each other. This can result in areas of large accumulance of heavy minerals for example.

### 2.2.1 Sorting and hydraulic equivalence of sediment particles.

Hydraulic equivalence explains why heavy minerals will be found in the lighter fractions of sediment. It is the mechanism that results in sorting of sediments. However, it does not mean that large quartz grains will be transported in the same way as hydraulic equivalent small heavy grains; it is the combination of a small diameter and a large density of heavy minerals that makes the difference. The difference in how a heavy mineral particle is transported under a single wave can be very different to that of a quartz particle. This is illustrated in Figure 2-3. The dashed line refers to light grain movement under a single wave and the differences in colour refer to the movement under wave crest or trough.



Adjusted from: Sand in Motion, 2000

*Figure 2-3; Grain trajectory differences between quartz and heavy mineral particle*

It is therefore important to realise that transport mode and non-linear effects may have a large influence on the transport rate.

The low transport rates for heavy minerals can not be accounted for by the tested quasi-steady models of Bailard (1981) and Ribberink (1993). Even corrections for hiding effects still resulted in over estimated rates by a factor 3 to 5. The quasi-unsteady model of Dibajnia and Watanabe (1992) showed better agreement with the measured transport rates by incorporating non-linear mechanisms in the suspended load transport.

### 2.2.2 Heavy mineral placers

Research conducted at Delft University of Technology in 1992 pointed out that it is impossible to **prevent** selective transport of different sediments in wave conditions. When a mixture of quartz and heavy minerals is used, some sorting will always occur.

Further research conducted in the Large Oscillating Wave Tunnel at WL Delft Hydraulics in 1994 points out that thin layers of heavy minerals (due to selective) transport act as armouring. This armouring effect was also studied in the research conducted by Tánczos.

Accumulations of heavy minerals occur because the small heavy grains are mostly transported close to the bottom and are therefore easily trapped. Since it is reasonable to assume that only the upper layer of sediment is involved in the transport process, it means that if light minerals are removed and mostly heavy minerals remain, this may act as a sort of armouring layer. The slow moving heavy minerals prohibit the underlying sediment from getting in suspension.
Due to this armouring effect, the influence of the presence of the heavy minerals on the sediment transport is bigger than was expected by means of the difference in fall velocity.

One striking observation on natural beaches is the following. It seems that accumulations of heavy minerals especially occur on eroding beaches. This is because high energy levels are needed for natural deposition on the shore face. This phenomenon adds to the ideas about selective transport.

### 2.2.3 Conclusions

From the research described above it is important to realise the following when considering further research in this area;

1. When an attempt to model the cross-shore profile and the influence of heavy minerals on it, is undertaken, it is important to realise that the armouring mechanism as described has a potential large influence.
2. When modelling the movement of heavy mineral particles, it is important to realise that these particles do not necessarily behave like their hydraulic equivalent counterparts. Possible difference in movement behaviour has to be implemented in the transport equations / transport rates.
3. If modifications to the transport equations are not possible, other ways to use this influence in an implicit manner should be investigated.

## 2.3 Effects of density and grain size

This paragraph deals with a detailed description of the experiments that were conducted in the Scheldt wave flume of WL Delft Hydraulics, as part of the research conducted by Koomans (2000) on the effects of density and grain size on the grading of sediments. His research was part of The European MAST-III project SAFE (performance of **S**oft beach systems **A**nd nourishment measures **F**or **E**uropean coasts) and parts of the text and illustrations in this paragraph originate from the PhD. thesis “Sand in Motion” (Koomans, 2000).

### 2.3.1 Objective of the research

The objective, of the part the research conducted in the Scheldt wave flume, was twofold:

- The generation of data on selective transport phenomena of density-graded sediments on a coastal profile (Koomans *et al.*, 1999)
- The generation of high-quality and high-resolution data on sediment transport on a “natural beach” under erosive conditions (Bosboom *et al.*, 1999)

The dimensions of the profile were 41 meters in length, a width of 1 meter and it had a water depth of 0.7 meter. This is illustrated in Figure 2-4, together with a scale impression of the significant wave that was used in the experiments.

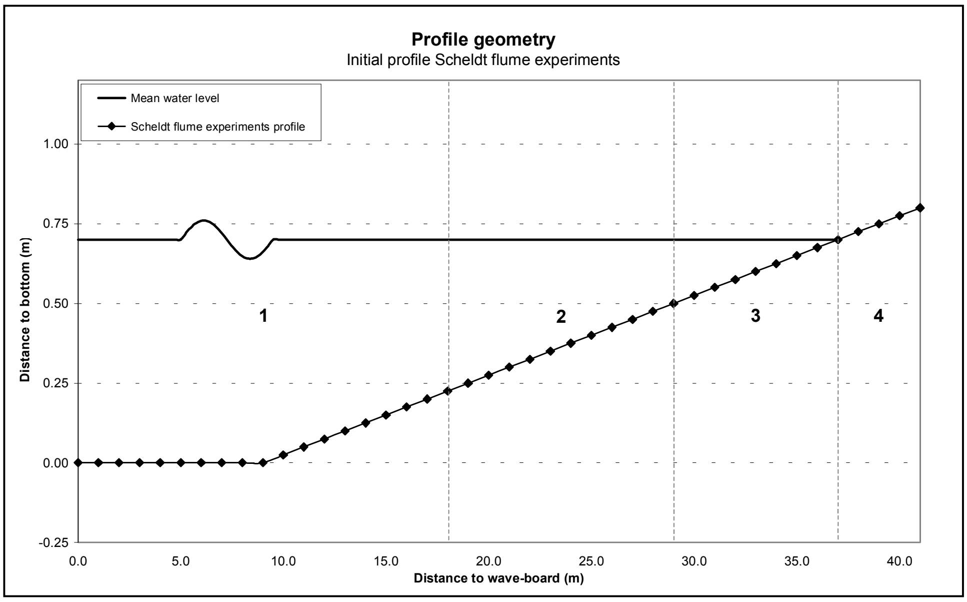


*Figure 2-4; Schematic set-up of the beach profile and wave conditions*

The numbers 1 to 4 in the figure mark the area’s in which the profile was devided for observations. These are respectively: the “outer surf zone”, the breaker zone”, the “inner surf zone” and the “dry beach”.

The experimental conditions and geometry were based on tests performed by Roelvink and Stive (1989). The generated random wave field consisted of waves with $H_{m0}$ = 0.17m and a wave period of $T_p$ = 2 sec. These are qualified as storm conditions and generated according to $2^{nd}$ order Stokes wave theory.

In the figure, the x-direction and the z-direction are drawn, the y-direction is parallel to the width of the flume.

### 2.3.2 Measurement program and data acquisition

The measurement program of Koomans' research consisted of four series, each divided into a number of consecutive runs. Of these four series only series A, B and C are of interest to the research undertaken in this thesis.
The properties and objective of each serie is presented in Table 2-1.

*Table 2-1; Properties of experiment series*

| **Series** | **Initial geometry** | **Sediment composition** | **Objective** |
|---|---|---|---|
| A | plane, 1:40 | quartz | reference test |
| B | final profile series A | quartz + zircon placers | effects of zircon placers on morphology |
| C | plane, 1:40 | 60% quartz, 40% zircon | effects of density gradation on morphology |

The properties of the sediment used in these series are presented in Table 2-2.

*Table 2-2; Sediment properties.*

| **Sediment** | **$d_{10}$ (μm)** | **$d_{50}$(μm)** | **$d_{90}$(μm)** | **$w_{s50}$ (mms$^{-1}$)** | **ρ (10$^{3}$ kgm$^{-3}$)** |
|---|---|---|---|---|---|
| quartz | 93 | 129 | 187 | 12 | 2.43 |
| zircon | 83 | 115 | 153 | 27 | 4.40 |

Finally, the cumulative times of profile evolution for these three series are summarised in Table 2-3.

*Table 2-3; Cumulative times of measured profile evolution*

| **Profile A-series** | **Profile B-series** | **Profile C-series** | **Time of profile evolution (hours)** |
|---|---|---|---|
| A106 | | | 4:00 |
| A207 | | | 8:00 |
| A309 | | | 13:30 |
| A407 | | | 17:30 |
| A607 | | | 22:30 |
| A707 | | | 26:30 |
| A904 | | | 29:30 |
| | B101 | | 0:30 |
| | B102 | | 1:30 |
| | B104 | | 3:30 |
| | | C101 | 0:30 |
| | | C201 | 1:30 |
| | | C302 | 7:00 |
| | | C402 | 11:30 |
| | | C404 | 14:30 |

### 2.3.3 Determining transport rates

The profile measurements that were performed can be used to calculate the time-averaged volumetric sediment-transport rate of the time interval between two measurements. To do this, equation (2-3) is used.

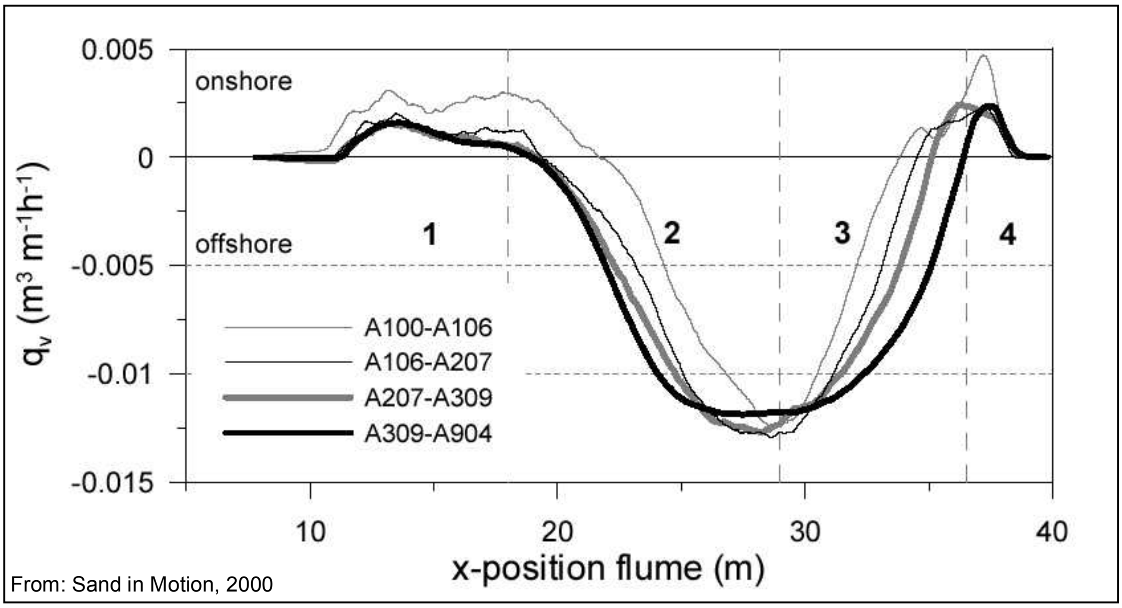
$$q_v(x_0) = \frac{1}{W\Delta t} \int_{offshore}^{x_0} -\Delta z(x)dx \qquad (2\text{-}3)$$

In which

| | | | |
|---|---|---|---|
| W | = | width over which the integration is performed | [m] |
| $\Delta$t | = | timestep between measurements | [hr] |
| $\Delta$z | = | measured bed height change | [m] |

It is, in fact, a volume-balance method and from profile measurements, such as illustrated in Figure B-1 of Appendix B-a, running averages of the changes in bed height for successive profiles are determined. An example of this is illustrated in Figure B-2 of the same appendix.

With these changes in bed height and equation (2-3), the time-averaged transport rates were determined. An example of this is illustrated in Figure 2-5.



From: Sand in Motion, 2000

*Figure 2-5; Time-averaged transport rates for succesive profile measurements of Serie A*

### 2.3.4 Findings Serie A

The observations that are made are summarised in Table 2-1 and illustrated in Appendix B-b and B-c. In these appendices, both profile evolution and sediment transport rates for successive time intervals of Serie A are presented.
The numbers 1-4 in the table correspond with the areas marked in Figure 2-4 and Figure 2-5.

*Table 2-4; Profile changes Serie A*

| **Series A; *reference test*** | |
|---|---|
| **Morphological zone:** | **Changes/ occurrence** |
| *1. The outer surf zone*<br>(x < 18m) | At the toe of the profile, the bed is eroded. This is due to asymmetric onshore sediment transport and to effects of transition of the bottom of the flume. Landward from this region of erosion, sediments are deposited. Accretion is small and decreases in shoreward direction |
| *2. The breaker zone*<br>(18 < x < 29m) | Sediments are deposited and the location of the maximum sediment deposition moves seaward *(from x = 24 m to x = 21 m)* through time. This deposition is more or less constant in magnitude. The magnitude of accretion on the landward side of the bar decreases with the evolution of the profile. |
| *3. The inner surf zone*<br>(29 < x < 37m) | In this zone, sediments are eroded. The location of maximum erosion migrates in time in the landward direction and increases. The amount of eroded sediment is largest in the landward part of the inner surf zone |
| *4. The "dry" beach*<br>(x > 37m) | Sediments are deposited as a swash bar. The rate of change in deposited sediments is equal for all time intervals |

For the experiments, an equilibrium profile of the beach was not reached. It is expected though, that sediment transport will decrease to zero after a period of time.

The most offshore point were sediment transport shifts from offshore to onshore moves offshore from the beginning of the time series and becomes fixed at x = 18 m. The onshore equivalent of this point keeps moving landwards. This results in a broadening of the image of transport rates (see Appendix B-c).

Transport rate gradients decrease a little with time. The point of maximum offshore transport moves in the seaward direction with time.

### 2.3.5 Findings Serie B

In Serie B, the influence of heavy mineral placers was investigated. These placers of pure zircon, were located on the final profile of Series A at I: 13 <x<14 m, II: 21<x<22 m and III: 34<x<35 m. This is illustrated in Figure 2-6.

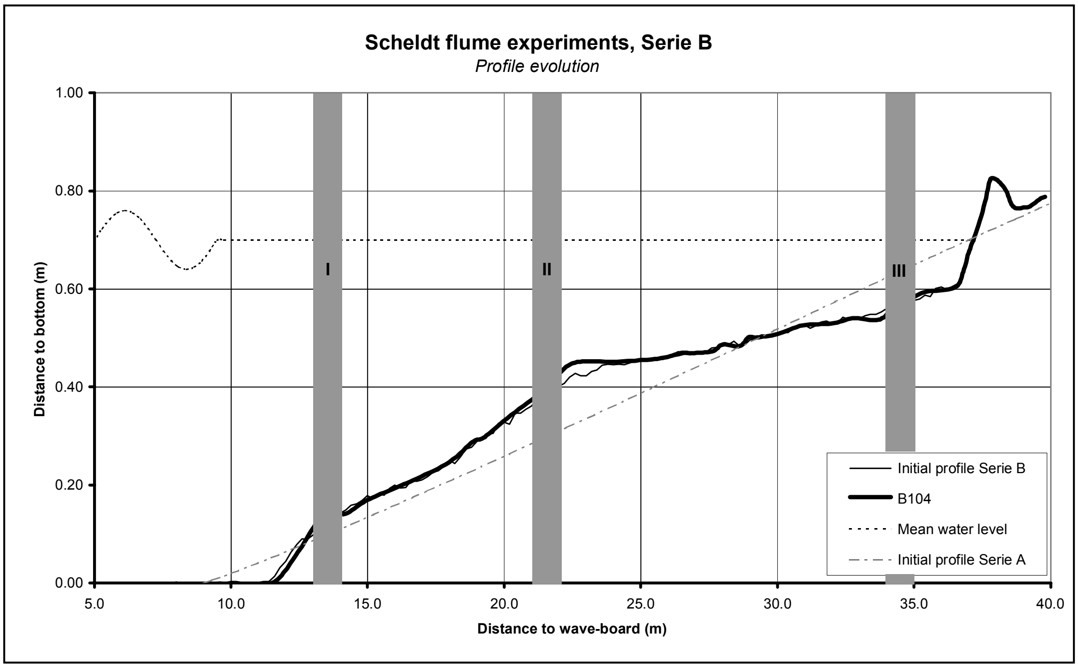


*Figure 2-6; Profile evolution for Serie B. The locations of the zircon placers are denoted by the vertical grey areas and the Roman numbers.*

Observations noted in Table 2-5, are also illustrated in the appendices.
Profile evolution is illustrated in Figure 2-6 and Appendix B-d. The volumetric sediment transport rates are presented in Appendix B-e, for two time-intervals of Serie B together with the last time-interval of Serie A.

*Table 2-5; Profile changes Serie B*

| **Series B; *zircon placers*** | |
|---|---|
| **Morphological zone:** | **Changes/ occurrence** |
| *1. The outer surf zone* (x < 18m) | Differences are small. Landwards of the first zircon placer, erosion occurs making it different from Series A. |
| *2. The breaker zone* (18 < x < 29m) | Clear differences occur in this region. As a result of the zircon placer, erosion occurs on the seaward side of the placer and accretion occurs on the landward side of it. In the subsequent time intervals, the erosion moves landward through the placer. |
| *3. The inner surf zone* (29 < x < 37m) | The effect of the placer resembles the one on the breaker bar. Furthermore, erosion increases and changes sharply were the placer is situated. The point of maximum erosion occurs more landward, but contrary to Series A, this point keeps fixed at x = 38m. through time. |
| *4. The "dry" beach* (x > 37m) | The maximum erosion, located in region 3 for Series A, is located on the beach for Series B. |

In general, the addition of zircon placers to the profile has an effect on profile evolution. The experiments indicate that the system reacts strongly on the artificial addition of a placer, by broadening it and covering it with quartz.
This redistribution of zircon can be considered to be the result diffusive processes.

In the sediment transport rate, changes (when compared to Serie A) can be seen in the whole area where the transport is directed offshore. The maximum transport gradients increase and so does the maximum offshore transport rate.

The most seaward point where direction changes from offshore to onshore is more or less unchanged. The landward equivalent of this point moves even more landward, a movement that was also noticed during the time intervals of Serie A.

The effect of the most landward placer of zircon seems to have the largest effect on the sediment transport rates. Over this placer, transport rates stay constant. Changes elsewhere can be considered small.

### 2.3.6 Findings Serie C

Again, observations that are made are illustrated in Appendix B-f and B-g. In these appendices, both profile evolution and sediment transport rates for successive time intervals of Serie C are presented.

*Table 2-6; Profile changes Serie C*

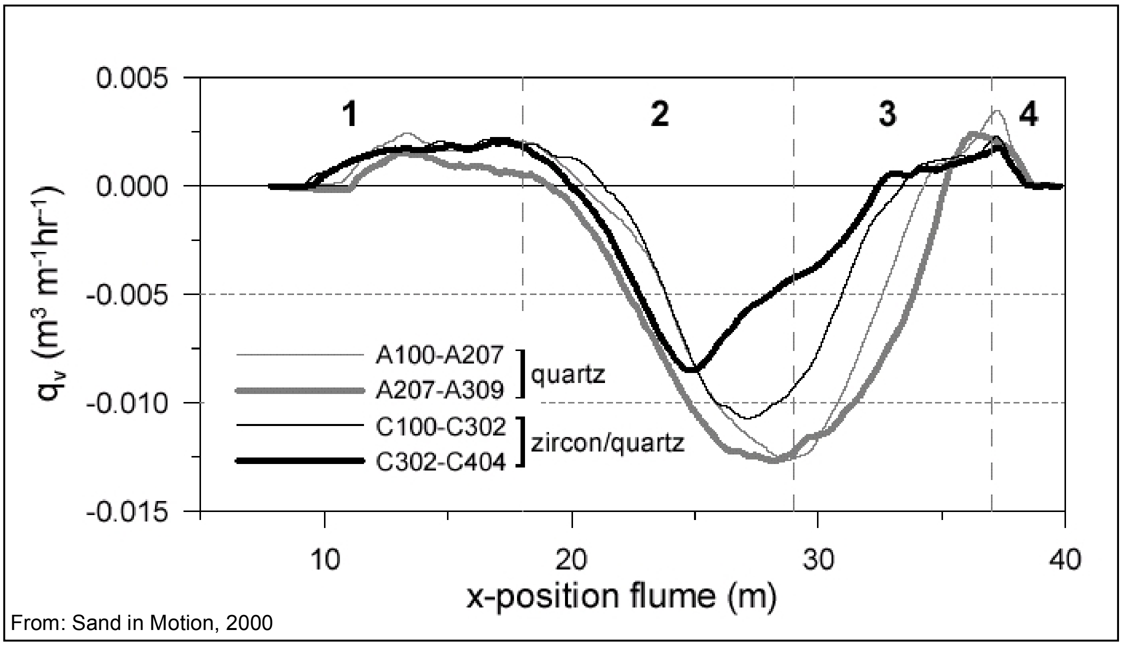
| **Series C; *uniform mixture quartz and zircon*** | |
|---|---|
| **Morphological zone:** | **Changes/ occurrence** |
| *1. The outer surf zone*<br>(x < 18m) | Changes in height are small, no particular erosion or accretion is apparent. |
| *2. The breaker zone*<br>(18 < x < 29m) | The variations in bed height show the offshore migration of the region of accretion (between x = 20m and x = 29m). With this migration, the magnitude of the maximum accretion changes in time; it becomes smaller. Furthermore, the breaker bar becomes smaller and is more pronounced |
| *3. The inner surf zone*<br>(29 < x < 37m) | The location of maximum erosion migrates in time and the magnitude of it decreases by about 25% between the first and the last time series. In the most onshore part of this region, the bed height does not change in time. This is very different from Series A, where maximum erosion occurs in the vicinity of the beach face. This is in sharp contrast to this Series, where maximum erosion occurs at the most seaward side of the inner surf zone. |
| *4. The "dry" beach*<br>(x > 37m) | Again, a swash bar is formed. The location and magnitude of (maximum) accretion in this region is constant in time. |

Large differences in magnitude, location and progression of erosion is observed for this Series when compared to Serie A. It contributes to the conclusion that the admixture of zircons to the sediment has an effect on the profile evolution and results in a considerable reduction of erosion between the crest of the breaker bar and the shoreface.

### 2.3.7 Assessment of findings

The experiments show that zircons are actively transported. Heavy mineral placers affect the total sediment transport rates and sediment transport gradients.

The admixture of heavy minerals to the sediment has an effect on the morphology; the breaker bar becomes smaller and more pronounced. (compare Appendices B-b and B-f)
Moreover, the erosion near the beach face is considerable reduced.
This is illustrated in Figure 2-7.



From: Sand in Motion, 2000

*Figure 2-7; Effects of heavy minerals on the transport rates*

Koomans concluded that the different sediment fractions do not behave independently. In the inner surf zone, sediment transport rates of the quartz fraction are reduced (armouring) to greater extent than can be expected from the availability[2] of quartz at the bed. It seems that, in order to reach this armouring effect, the zircon fraction in the bed has to be concentrated to a certain level.

### 2.3.8 Conclusions

1. As a result of interacting processes (the different fractions of sand do not behave independently) it is concluded that heavy minerals have a positive effect on erosion and this effect is larger than can be expected form the existing theories.
2. Experiments conducted in de Scheldt Flume shows that admixture of heavy minerals affects the time-averaged sediment transport in a way such that less sediment is transported.
3. The changes in the profile evolution and sediment transport rates can be divided in a number of trends. These trends (as described in paragraph 2.3.4 to 2.3.6) will serve as a qualitative reference, to interpret the findings of the Unibest-TC model calculations.

---

[2] *Based on "Bed-Availability-Model" (Reed* et al.*, 1999; van Rijn, 1998a)*

# 3 General introduction to Unibest-TC

[Parts of the text in this chapter originate from the Technical Reference Manual (Bosboom *et al.*,2000) and from the Unibest-TC userguide (Walstra, 2000).]

## 3.1 Introduction

Unibest-TC stands for “UNIform BEach Sediment Transport” - “Time-dependent Cross shore”. It is a process-based model developed by WL Delft Hydraulics, for transport on sandy beaches and shorefaces, like the Dutch coast. In its development no particular interest was given to differences in density and it is therefore not a user-defined property. Consequently, Unibest-TC lacks the ability to vary the density as a function of the cross-shore distance to the beachface. A great part of this research is therefore all about if and how it is possible to model heavy mineral presence in the beach profile with Unibest-TC.

When examining the problem analyses and the objective as stated in the introduction of this report, it becomes clear that in order to model the presence of heavy minerals on a beach in a correct and complete manner, not only heavy mineral specific properties have to be taken into account, but also their influence on transport processes. Therefore it are these transport processes which deserve a “closer look” and this chapter will deal with the ways in which sediment is transported in Unibest-TC.

## 3.2 Characteristics

Unibest-TC is a quasi-2D vertical model. The classification two-dimensional is given because of its ability to perform calculations in the x-direction (positive pointing shoreward) and the z-direction (positive pointing from bottom to the water surface). This coordinate system is illustrated in Figure 3-1.

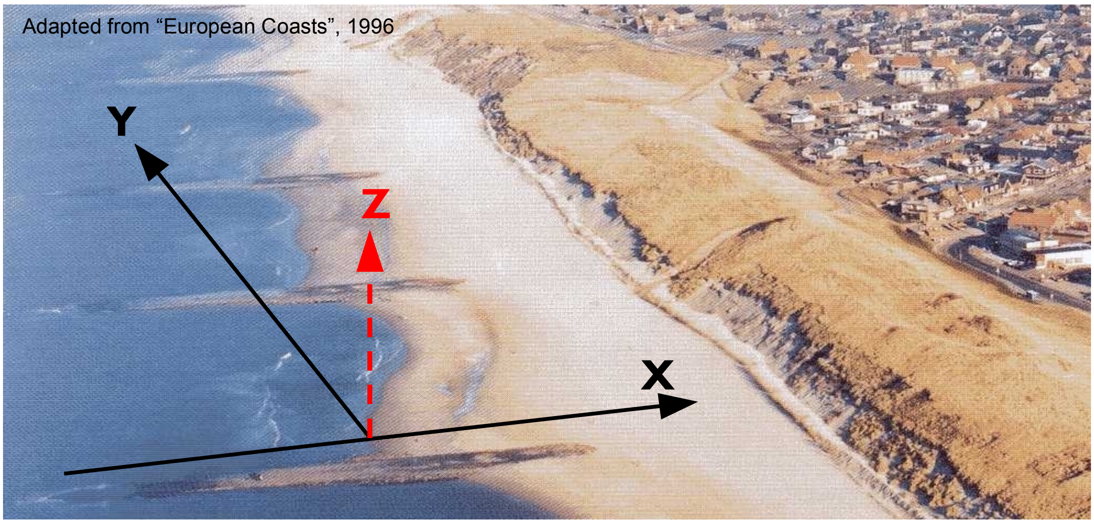

Adapted from “European Coasts”, 1996

*Figure 3-1; Coordinate system in Unibest-TC*

It is a quasi 2D model because the vertical is not completely modelled, only the horizontal velocities are taken into account and not the vertical velocities, for instance induced by turbulent eddies.

## 3.3 Grid schematisation

Unibest-TC can use a variable grid size. Generally speaking, grid sizes decrease with decreasing distance to the shoreline. The criterion with respect to the resolution of the grid is based on the desired accuracy towards representing the bottom profile and its details.

Furthermore, Unibest-TC uses a last "wet cell" and a last "dry cell". Processes that occur in the swash zone, where beach and sea meet, are poorly understood and not included in Unibest-TC. Therefore, it stops hydrodynamic calculations at a certain depth; the last "wet cell".

Unibest-TC uses a dimensionless parameter, TDRY, indicating the non-linearity of the wave field. This parameter is used to determine the minimum water depth and is defined as:

$$T_{DRY} = \frac{T_p}{\sqrt{g\ /h}} \qquad (3\text{-}1)$$

in which:

| | | | |
|---|---|---|---|
| $T_P$ | = | Peak period of the wave field | [s] |
| g | = | gravity | [$m/s^2$] |
| h | = | minimum water depth | [m] |

The user defines the value of TDRY. Computations are stopped when the right part of equation 3-1 equals the user-defined value of TDRY. In a normal profile, the value of TDRY is chosen such that computations are stopped at a water depth of about 0.5 m.

Unibest-TC then extrapolates the transports of this last "wet cell" linearly to zero for the last dry cell. It can extrapolate this vertically or horizontally to best fit local circumstances.

## 3.4 Overview of sub-models

Unibest-TC fully integrates the effects of waves, tidal and wind driven currents and sediment transport on the morphological profile development. It has been designed to simulate the morphodynamic behaviour of the nearshore coastal regions.

It consists of five sub-models, which deal with:

- wave propagation
- mean current profile
- wave orbital velocity
- bed load and suspended load sediment transport
- bed level change

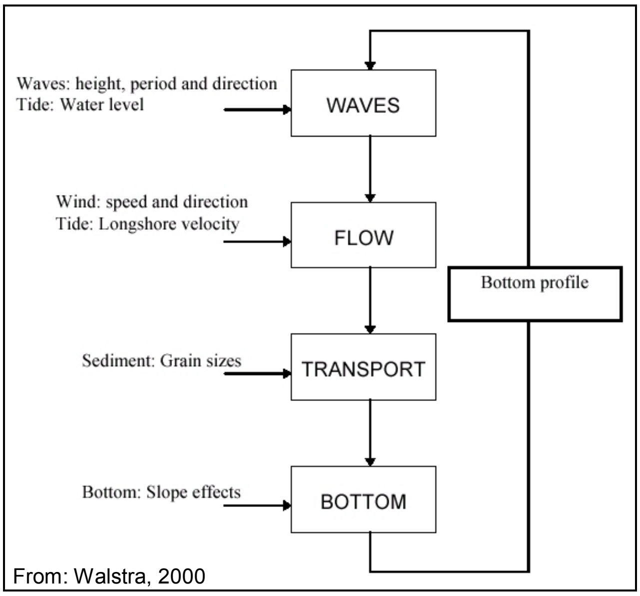


*Figure 3-2; Representation of process-based model calculations in Unibest-TC*

A simple schematic illustration of how these sub-models work is presented in Figure 3-2 and described partly below[1]. For a full description of all the sub-models, the reader is referred to the existing literature.

From boundary conditions and bed topography, wave propagation data is computed, including shoaling, refraction and energy dissipation. This is followed by computations for mean current profile and wave orbital velocity.

Now wave propagation and flow movements are known, computations on sediment transport can follow. In the sediment transport model one can distinguish between bed load and suspended load. The bed load and suspended load are treated fundamentally different. According to Van Rijn et al. (1995), it is reasonable to assume that bed-load transport reacts instantaneously to velocity fluctuations but this assumption can not be made towards the suspended load formulations. Therefore, it must be treated differently. A more detailed description of suspended and bed load formulations is given in the next paragraphs.

Finally, Unibest-TC uses the transport figures to compute a new bottom profile, which is used in the next time step.

### 3.4.1 Suspended sediment transport

Suspended sediment transport is that part of the sediment that is transported in a layer, beginning just above the bottom, reaching to the water surface.

Grains are brought into suspension due to stirring near the bottom. Due to fluid turbulence and mixing these grains are “transported” higher in the vertical.
The weight of the particles is balanced by an upward momentum transfer from fluid eddies. It can therefore be expected that concentrations of particles get smaller when the distance to the bottom increases. This results in a mean concentration profile of sediment particles in the vertical, which is plotted in Figure 3-3.

---

[1] *A full schematic overview of all the sub-models within Unibest-TC is presented in Appendix C*

The suspended sediment transport is dominated by the mean current. This mean current is the result from wave movement and has large variations across the entire cross-shore profile. The mean current can have a negative **and** a positive part (respectively offshore and onshore directed) in the vertical, or just a negative part. The positive part is also known as the velocity streaming effect. It is this streaming effect that can have significant impact on the mean current profile resulting in onshore-directed suspended sediment transport.

In Figure 3-3, a mean current profile is plotted (on a non-dimensional scale) at a location near the breaker bar and the velocity-streaming effect can be observed here. If a location is chosen closer to the beach, where waves are breaking massively, only negative values for the mean current are found and no streaming effect is present.

Combining the concentrations and the mean current, the suspended flux is computed as the product of these two. This is explained by equation 3-2.

$$q_s = \int_a^{h+\eta} VC\,dz \qquad (3\text{-}2)$$

in which:

$V$ = local fluid velocity at height z above the bed [m/s]
$C$ = local sediment concentration at height z above the bed [kg/m$^3$]
$h$ = water depth (to mean surface level), [m]
$\eta$ = water surface elevation [m]
$a$ = thickness of bed-load layer [m]

Computations result in a profile for the transport rates in the vertical, which is plotted in red in Figure 3-3.

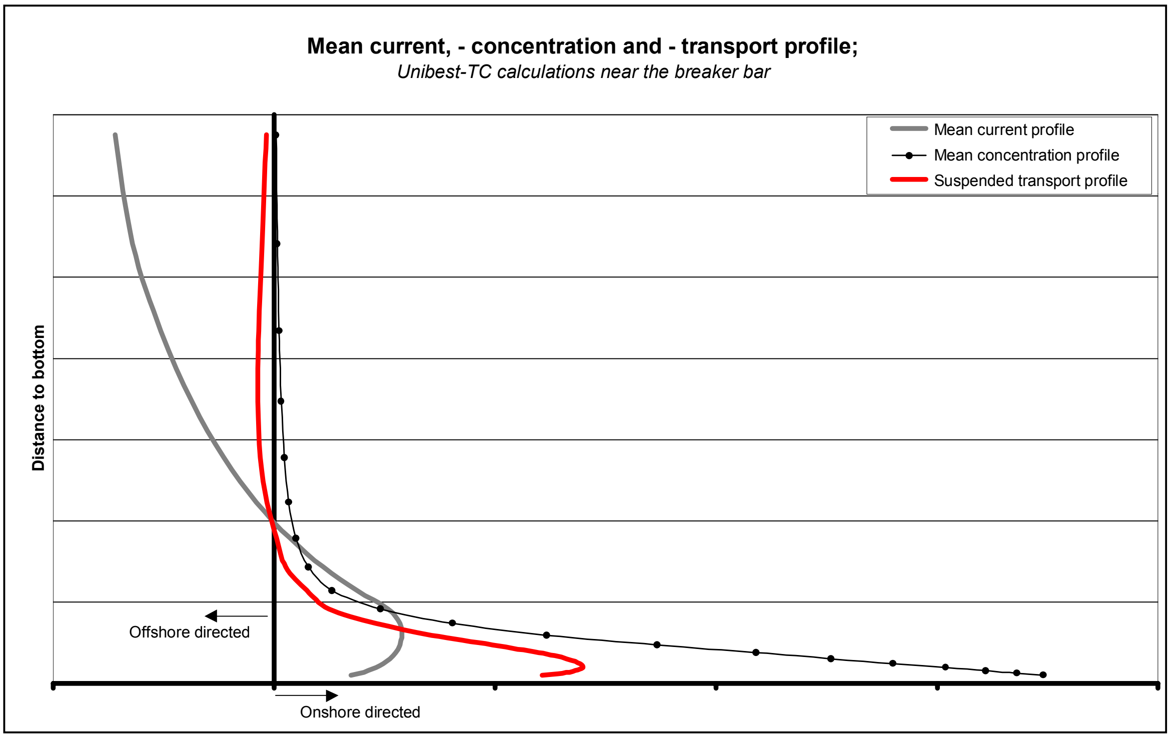


*Figure 3-3; Currents, concentration and the transport profile in a vertical near the breaker bar*

### 3.4.2 Bottom sediment transport

Bottom sediment transport is that part of the transport that occurs in a thin layer directly above the bottom. In Unibest-TC, the thickness of this layer can be defined by the user.

This part of the sediment transport is considered to be all the transport induced by rolling, saltating and collision of grains. It is based on the classical Shields "initiation of motion" curve as modelled by Van Rijn (1993)

At small shear stresses, the occurring transports represent the individual particles moving over the bed, while at higher values for the shear stress, the formulation represents the sheet flow phenomenon.

The non-dimensional instantaneous bed load transport vector $\Phi_{bd}$, defined as the ratio of bed load transport rate $q_b$ and the square root of a parameter representing the specific under water weight of sand grains, is given by:

$$\Phi_{bd}(t) = \frac{q_b(t)}{\sqrt{\Delta g d_{50}{}^3}} = 9.1 \frac{\beta_s}{(1-p)} \left\{ |\theta'(t)| - \theta_c \right\}^{1.8} \frac{\theta'(t)}{|\theta'(t)|} \tag{3-3}$$

in which:

$q_b$ = bed load transport rate [$m^2/s$]
$d_{50}$ = median grain size [m]
$\Delta$ = relative density = $(\rho_s-\rho)/\rho$ [-]
$\rho_s$ = density of sediment [$kg/m^3$]
$\rho$ = density of water [$kg/m^3$]
p = porosity of the sediment [-]
g = gravity acceleration [$m/s^2$]
$\theta$ = dim. less effective shear stress [-]
$\theta_c$ = dim. less critical shear stress [-]
$\beta_s$ = slope factor [-]

This semi-emperical relation has been fine-tuned for conditions in the field that can be found on Dutch beaches for example. This implicates that effects of heavy minerals are not accounted for.

It can be seen from equation 3-3 that, together with the shear stresses, the bottom slope factor, $\beta_s$, has an important impact on the magnitude of the bed load transport vector.
This parameter introduces the force of gravity on the grains and increases or decreases the transport rate in case of a sloping bed. It is defined as:

$$\beta_s = \frac{\tan\varphi}{\tan\varphi + \frac{dz_b}{ds}} \tag{3-4}$$

in which:

$\varphi$ = angle of repose and $dz_b/ds$ is the local slope angle.

The angle of repose may differ from the natural angle of repose and is a function of the cross-shore distance. It is specified by the user through two parameters; TANPHI I and TANPHI II. These parameters are used to define values of local angles of repose at two points in the cross-shore profile. Between these two points, XI and XII, the value of tan $\varphi$ is varied linearly.

### 3.4.3 Sediment properties

Unibest-TC uses three properties of the sediment. These are:

- $D_{50}$ = Median grain size
- $D_{90}$ = 90% grain size
- $D_{SS}$ = Suspended particle diameter

It is shown by Van Rijn (1987), that the diameter of the suspended particles lies between 60% and 100% of the value of $D_{50}$.

Furthermore, Unibest-TC has a limited ability to vary the sediment properties over the cross-shore profile. The user can define three water depths in the cross-shore profile and these water depths are accompanied by three multiplication factors. The user defined sediment properties $D_{50}$, $D_{90}$ and $D_{SS}$ are multiplied at these locations with the according factors.

As stated before, the density of the sediment normally can not be defined by the user. It is an integral part of the computer program and can only be altered in the source code of the program. Its default value is set to 2,650 kg/m$^3$.

# 4 Model Calculations and set-up

This chapter consists of two major parts. The first part (paragraph 4.1) is a sensitivity analysis and calibration of the Unibest-TC model set-up to the Scheldt flume experiments (Koomans and Bosboom, 2000).
A number of parameters, critical for modelling in Unibest-TC and for understanding the underlying processes are tested on their sensitivity in the model. The calibration was performed by means of an iterative process of simulations with Unibest-TC and comparing these simulations to the Scheldt flume experimental data[1].

After completing the calibration, the second part (paragraphs 4.2 to 4.4) describes the set-up for the final model calculations. The model settings are presented for modelling the Scheldt flume experiments' Series A to C with Unibest-TC.

## 4.1 Unibest-TC sensitivity analysis & calibration

Before correct modelling of the experiments as described in chapter 2, can commence, a sensitivity analysis of Unibest-TC was performed. This analysis comprehends the influences of profile geometry, particle size and roughness parameters. This analysis is followed by a calibration of the parameters to the results of the Scheldt flume experiments.
The different influences and their impacts are described in paragraphs 4.1.1 to 4.1.4.

### 4.1.1 Unibest-TC calculations for differences in grain size

As can be expected, the size of the grains has a major influence on the physical transport processes and the profile evolution (see also paragraph 2.1).
In Figure 4-1 the effects of grain size distribution on profile evolution in Unibest-TC are illustrated.

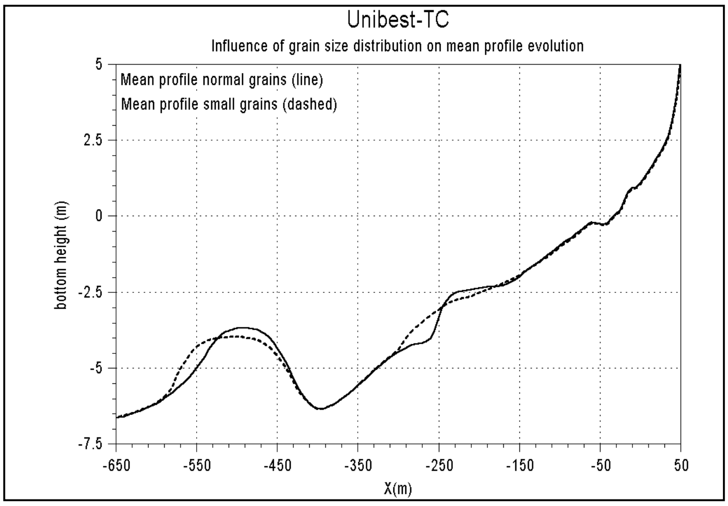


*Figure 4-1; Effects of different grain sizes on profile evolution in 5 days time*

In these simulations the effects of a 5-day storm on the cross-shore profile of Egmond was monitored. The time span of 5 days is chosen to make sure that impacts are clearly visible but that the time span is not to long.

---

[1] *This part has a major contribution in what is described as "Method and criteria" in paragraph 1.5.*

Although a new equilibrium profile is not yet reached, a striking difference between the two is clearly visible. When monitored closely (See appendix D-a) it becomes evident that the presence of such small grain sizes as in the Scheldt flume experiments, leads to large peaks in the suspended sediment transport. The fact that these peaks are approximately 4 times larger than the peaks in the bottom transport makes the suspended transport a major contribution to the overall image of the total transport.

Whether Unibest-TC predicts the effects of these smaller grains correctly is dealt with in the following manner.
The Scheldt flume experiments do not illustrate the effects of a difference in grain size diameter. Therefore, it can not form a basis to assess the impact of changes in grain size diameter when modelling it in Unibest-TC. The theory about equilibrium beach profiles (Dean, 1977-1991) however, can be used as a tool for this.

The impact of changes in grain size diameter according to Dean was already presented in chapter 2. The analyses in this paragraph and in chapter 2 can be interpreted such that the findings are in correspondence with the theory on equilibrium beach profiles (Dean, 1977-1991).

### 4.1.2 Influence of initial geometry on profile evolution

After a number of simulations it becomes clear that modelling of the Scheldt flume experiments' initial profile without modifications to the geometry, results in large and unrealistic erosion of the beach face. This is illustrated in Figure 4-2.

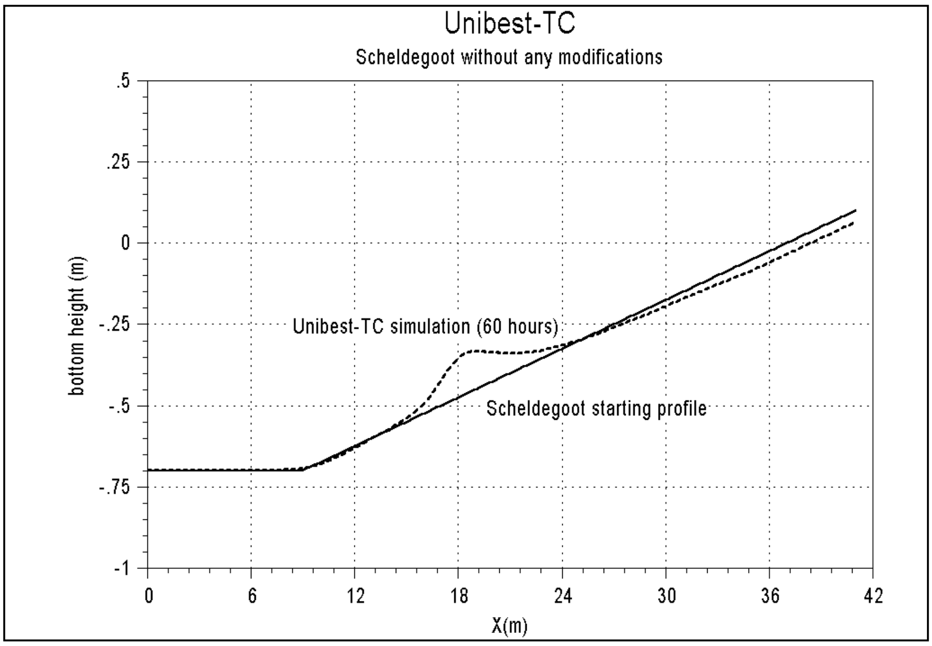


*Figure 4-2; Large drop of beach face without modifications*

When monitored closely this erosion is thought to be caused by a combination of two things. The first is a relatively large transport magnitude in the last computed wet grid cell, due to the presence of very small grains. The second is the fact that Unibest-TC extrapolates the value of this last **wet** grid cell to zero in the last grid cell of the entire profile.[2] When this value is negative it means that it will remain negative for the rest of the beach profile and sediment will continue to be eroded, also on the dry part of the profile and thus resulting in a drop of the beach face.

As can be seen in Appendix D-b, the way Unibest-TC extrapolates this last value (horizontally or vertically) matters in the sense of how the profile develops. However, both methods prove not to be sufficient when the profile is expected to remain more or less stable in the region of the beach face.

When a closer look is given to the experimental outcome of the Scheldt flume experiments it becomes clear that in the area of the beach face and the swash zone a very particular change in transports occurs: from offshore to onshore directed. This results in the formation of a swash bar. The processes that occur in the swash zone are still poorly understood and are not implemented in Unibest-TC. It is therefore unlikely that this formation of a swash bar can be simulated using Unibest-TC.

Another method of mimicking this specific phenomenon is to include it in the geometric profile by means of a fixed layer: a dune foot defence. This must ensure that the position where water meets land keeps fixated. It is constructed in the same form as the swash bar that was found in the Scheldt flume experiments. This will prevent Unibest-TC from completely eroding the beach because a negative value for the last computed sediment transport is of little impact on that part of the profile on which Unibest-TC performs no hydraulic computations

The new geometric set-up is plotted in Figure 4-3.

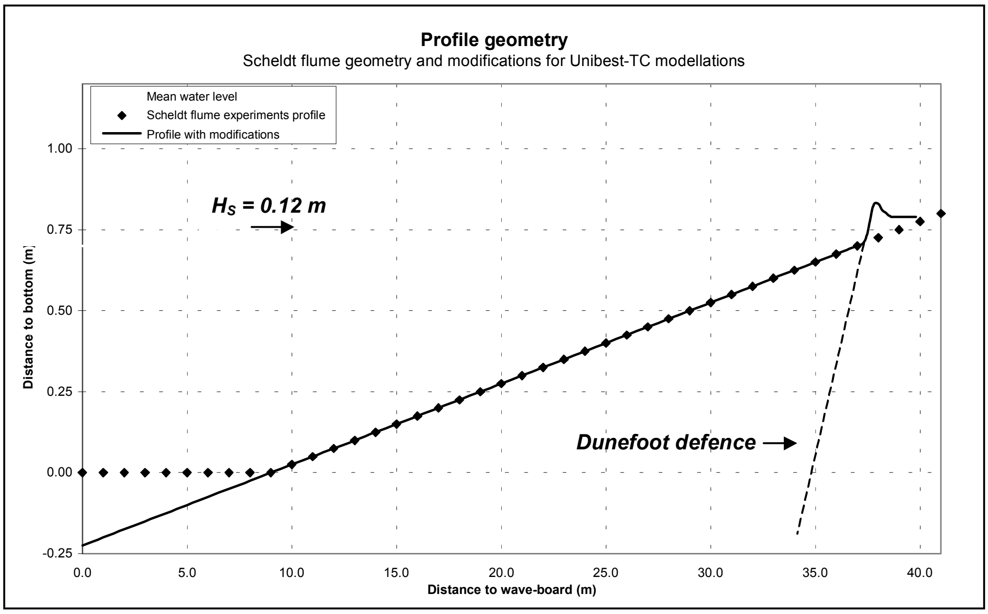


*Figure 4-3; Profile geometry and wave conditions*

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[2] *See also chapter 3 for a more detailed description of the extrapolation of transport over the dry part of the profile by Unibest-TC*

In Figure 4-3, the modifications to the beach profile and the swash bar are shown. Another modification that was made to the profile can be seen between the point X = 0 m and X = 9 m. Where the profile in the experiments was flat between these points, modifications were made to the initial profile used for the Unibest-TC calculations. This was done to meet a part of the objective that states that it is wishful to gain insight in modelling the cross-shore transport processes.

After examining calculations that were made without this modification, it became clear that specific transport processes that occur in this region were not fully developed. The geometric set-up has a major influence on the development of these transport processes, even beyond the point of X = 9 m. Therefore it was decided to modify the initial profile in the way that is illustrated above.
This implicates that results that are assessed in the most offshore part of the profile can not be compared directly or without any reservation to the results of the Scheldt flume experiments. This does not have to be a problem since Koomans (2000) states that it is not clear if the experimental results that are found in this particular region are genuine or a direct result of the abrupt bottom change at X = 9 m in the set-up of the experiments.

### 4.1.3 Influence of roughness parameters on sediment transport

Unibest-TC has three user-defined roughness parameters that need closer examination. These are presented in Table 4-1.

*Table 4-1; Relevant roughness parameters in Unibest-TC*

| Parameter | Significance | Range |
|---|---|---|
| RKVAL | Equals the Nikuradse roughness height. Indicates how far the roughness reaches into the boundary layer. It influences the (vertical) velocity profile | 0.0005m to 0.2m |
| RC | Current related roughness.<br>Affects the effective bed shear stress due to currents | 0.005m to 0.10m |
| RW | Wave related roughness<br>Affects the effective bed shear stress due to waves | 0.001m to 0.10m |

Detailed illustrations of simulations, performed with these parameters, are presented in Appendix D-c and partially in this paragraph. In Appendix D-c is also presented a plot of the wave height development over the profile. This plot is added to illustrate in which areas shoaling and wave-breaking occurs.
All the plots presented in Appendix D-c illustrate the individual effects of changes in one specific parameter, while others are held constant. Bottom changes were not calculated here.

### RKVAL

Although variations of RKVAL only have indirect effects on the sediment transport, it can be an important parameter since it directly affects the velocity profile[3]. The contribution of this streaming effect can make the difference in certain regions between offshore and onshore directed transports. This is illustrated in Figure 4-4[4].

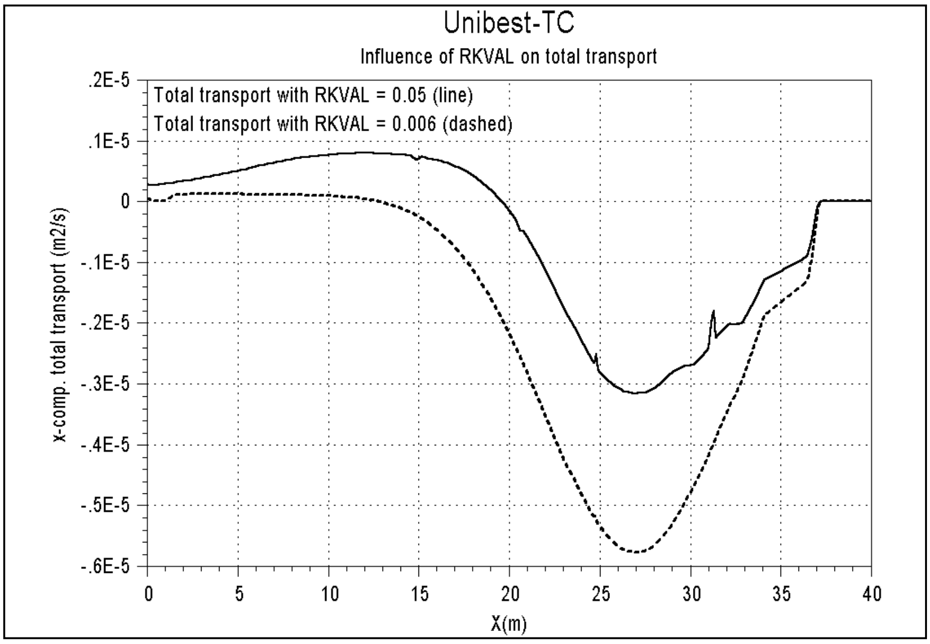

*Figure 4-4; Impact of changes in RKVAL on the total sediment transport*

Tuning the RKVAL parameter can result in onshore directed suspended sediment transport, on the seaside of the breaker bar ( X < 20 m). The magnitude of this change in suspended transport can be large enough to cause an onshore-directed total transport in this area, see Figure 4-4.

In the area landward of the breaker bar, suspended sediment will be transported in the offshore direction, caused by the return flow. The direction of the bottom transports in this area (between X = 20 m and X = 35 m) however can be both offshore and onshore. This largely depends on the value of RKVAL.

Resuming:

- RKVAL can be used to tune the direction of the suspended transport in the area seaward of the breaker bar.
- Landward of this breaker bar, RKVAL can change the direction and magnitude of the bottom transport from offshore to onshore.

---

[3] *See also chapter 3 for a more detailed explanation of velocity and concentration profiles in Unibest-TC*

[4] *For an explanation on how to interpret the transport figures presented here, the reader is referred to chapter 1.*

## RC

Varying the RC parameter changes the effective bed shear stress due to currents. It can have a significant influence on the suspended sediment transport. This is illustrated in Figure 12 of Appendix D.
The influence of this parameter to the bottom transport however is so small, that it is reasonable to conclude it has no tuning capabilities with respect to the bottom transport. The impact of RC on the total sediment transport across the profile is plotted in Figure 4-5.

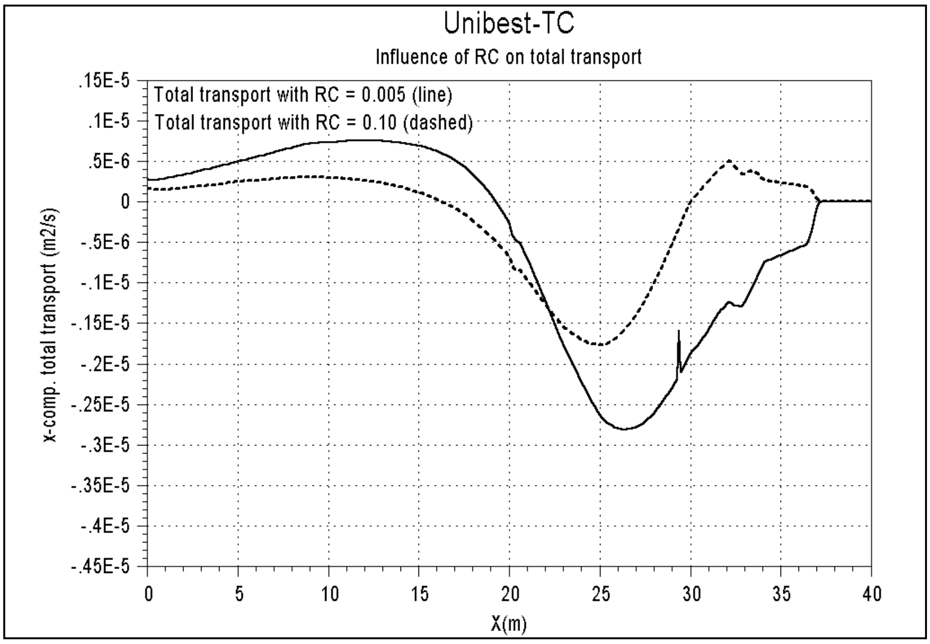

*Figure 4-5; Impact of changes in RC on the total sediment transport*

## RW

Varying the RW parameter changes the effective bed shear stress due to waves. A major difference when compared to the RC parameter lies in the way that RW is used in the different modules of Unibest-TC for suspended and bed-load transport. (*The user-defined value for RW is not used for determining the effective shear stress in the bed-load module. Instead, this stress is determined in another way, which will not be discussed here.*)

This implicates that changing the value of RW has no influence on the bottom sediment transport. Changes in RW only influence the suspended transport, which is illustrated in Appendix D-c. This influence is rather large when compared to the influence of RC on the suspended transport. Consequently, it has the same effect on the total transport, as can be seen in Figure 4-6.

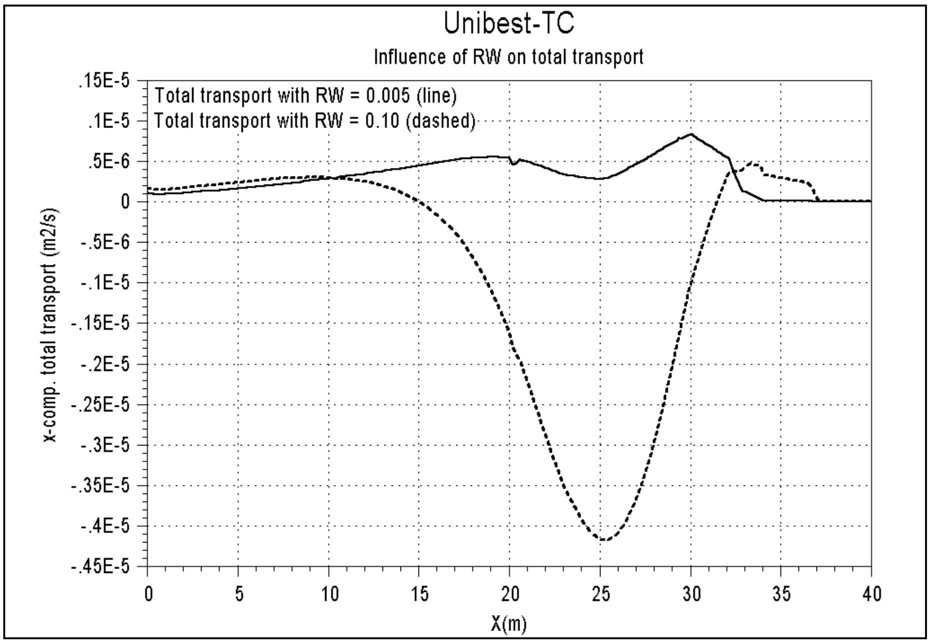

*Figure 4-6; Impact of changes in RW on the total sediment transport*

## Summary

In Table 4-2, a short summary is given of the different parameters and its influence on suspended and bottom sediment transport. It can be concluded that for tuning the bottom transport, RKVAL is the only contributor. For tuning of direction and magnitude all parameters have a contribution but it is expected that RKVAL and RW are best fitted to tune the suspended transport.

*Table 4-2; Impact of different parameters on the transports*

| **Parameter** | **Influence on:**<br>*Bottom transport* | <br>*Suspended transport* | **Determined “Best value”** |
|---|---|---|---|
| **RKVAL** | Significant in terms of direction and magnitude | Significant in terms of direction | 0.05m |
| **RC** | Little | Significant in terms of magnitude. | 0.03m |
| **RW** | No influence | Significant in terms of direction and magnitude | 0.05m |

The last column of this table represents the individual values of these parameters that are considered as best representation of the situation in the Scheldt flume experiments. This was concluded after an iterative process of testing and comparison. In these tests, parameter values were varied and the results were compared to total transport figures and profile development that were recorded in the Scheldt flume experiments.

### 4.1.4 Contribution of other user-defined parameters

*Table 4-3; Other important parameters*

| Parameter | Significance | Range | Determined "Best value" |
|---|---|---|---|
| TDRY | Non-linearity wave parameter. Determines at which depth calculations are stopped | 10 - 40 | 22 |
| K_IJL | Breaker delay switch | - | off |
| FCVISC | Depth averaged viscosity due to wave breaking | 0.05 – 0.10 | 0.05 |
| TANPHI | User defined angle of repose to adjust the Bagnold slope correction parameter | 0.02 – 0.6 | 1 and 0.4 |

**TDRY**

The parameter TDRY is a parameter that determines at which local water depth the calculations are stopped. This is already discussed in Chapter 3. The reason that it is briefly discussed here as well is due to the following.

When a typical value such as 35 was chosen for TDRY, it meant that in the case of a wave of 0.12 m with a peak period of $T_p$ = 2 sec. (The Scheldt Flume wave conditions), computations were stopped at a water depth of 3.2 cm's! While using a roughness parameter for wave or current induced shear stress of 5 cm's it meant that Unibest-TC was still trying to perform computations in an area in which the local roughness exceeded the local water depth. This is an unrealistic phenomenon and can be classified as being a scale problem. It limits the minimum local water depth to a certain value, which, after numerous tests was determined at 8.1 cm's, resulting in a value of 22 for TDRY.

**K_IJL**

> …The concept of breaker delay (Roelvink *et al*, 1995) was introduced based on field observations of breaking waves, which showed that waves – having inertia – need a distance of the order of one wave length to actually start or stop breaking. If breaker delay is used, it modifies the rate of wave breaking via a modification of the reference depth, which is used to determine the local maximum possible wave height….
>
> …It generally improves the results in swell-type conditions but in case of short waves the breaker delay tends to lead to an overprediction of the local wave heights…
>
> *From: - Aarninkhof (1998)*
> *- Walstra (2000)*

After testing the Scheldt flume set-up in Unibest-TC it appeared that the results without the application of the breaker delay concept are in better correspondence to the experimental results than is the case with the breaker delay.
Furthermore, application of the breaker delay is not expected to be a parameter that has a dependency to the presence of heavy minerals or other specific sediment properties and can perfectly well be used in cases of other geometric conditions.

### FCVISC

Extensive studies into the effects of FCVISC on the suspended sediment transport have been carried out. A recent study in the behaviour of Unibest-TC transport formulations (Sorgedrager, 2002) concluded that for larger values of FCVISC, the point of direction-change (suspended transport moves from onshore to offshore directed) shifts a little seaward. The value has little effect on the magnitude of the transports and is set to 0.05 for the modelling of the Scheldt flume experiments.

### TANPHI[5]

With this parameter, the user can quantify the effect of the Bagnold slope correction factor, $\beta$, which introduces the force of gravity on the particle movement in case of a sloping bed. It was introduced to prevent offshore migrating bar-systems in morphological long-term calculations. The general rule is that the two values of TANPHI, which must be entered by the user, should be decreasing in seaward direction.

When modelling the Scheldt flume experiments it became apparent that, maybe due to a rather steep profile, the effect of the gravitational force on the particles was highly overestimated. This results in large transport gradients and large offshore directed bottom sediment transport, presented in Figure 4-7. The values for TANPHI varied between 0.03 and 0.1.

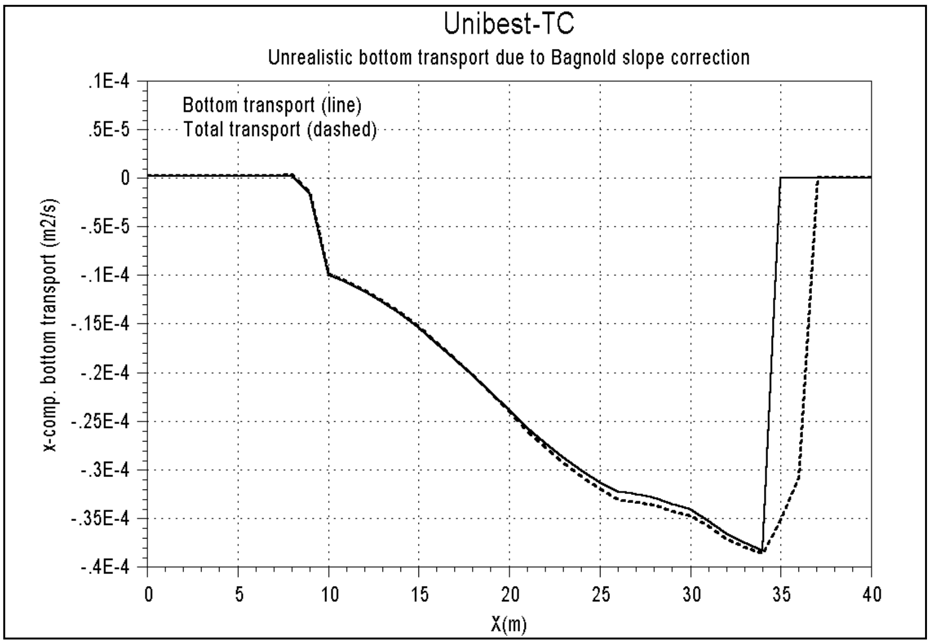

*Figure 4-7; Large bottom transports due to false Bagnold parameter*

It may be clear that the large transport gradients between X = 8m and X = 11m and the large bottom transport rate are very unlikely. This problem was handled by setting the parameters TANPHI to the value of 1000, which results in a value of nearly 1 [0.9999999 etc] for the slope correction factor $\beta$. This eliminates all slope effects and from here the values for TANPHI were adjusted to an acceptable level. This resulted in values of 1 and 0.4 for the respective values of TANPHI.
This means that some slope effects are taken into account and that the offshore migration of the breaker bar is damped to a level, which is in correspondence with the Scheldt flume experimental data.

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[5] *A detailed explanation on the effect of the two values of TANPHI-(I) and TANPHI-(II) is given in chapter 3*

## 4.2 Unibest-TC model set-up for Serie A

### 4.2.1 Wave conditions

The wave conditions, which will be similar for all series, are the following:

The $H_{m0}$ (energy spectrum based wave height) of the waves in the experiments was 0.17 meter. Unibest-TC however, requires a “root-mean-square” wave height, $H_{rms}$. In equation 4-1 the relation between $H_{mo}$ and $H_{rms}$ is given.

$$H_{rms} = \frac{H_{m0}}{\sqrt{2}} \qquad (4\text{-}1)$$

With this relation, the $H_{rms}$ is determined at 0.12 meter. The peak period, $T_P$, of this wave is 2 seconds.

### 4.2.2 Sediment properties

The sediment properties for this serie is exactly similar to that of the experimental Serie A. In Table 4-4, the geometric properties of this quartz sediment is presented as well as the fall velocities according to Van Rijn (1993).

*Table 4-4; Sediment properties for Serie A*

| Diameter range | Diameter | Fall velocity |
|---|---|---|
| $D_{50}$ | 129 μm | 10.9 mm/s |
| $D_{90}$ | 187 μm | 20.6 mm/s |
| $D_{SS}$ | 112 μm | 8.4 mm/s |

### 4.2.3 Time series

The original experiments for Serie A were carried out in 52 runs of approximately 30 minutes each. Every individual run started with five extra wave minutes, to allow all sediments to get in motion. All together, Serie A took 29 hours and 37 minutes.

Since Unibest-TC is not expected to reproduce the results exactly, calculations are carried out with a time-step of 0.0082 days or approximately 12 minutes. It is part of the objective to investigate if Unibest-TC can reproduce the trends in sediment transport development and profile evolution and therefore the choice is made to perform the following runs:

*Table 4-5; Time series for modelling Serie A*

| Number of run | Number of time steps | Total duration |
|---|---|---|
| UTC 101 | 20 | 4 hours |
| UTC 102 | 89 | 17.5 hours |
| UTC 103 | 152 | 29.5 hours |
| UTC 104 | 305 | 60 hours |
| UTC 105 | 610 | 120 hours |

Similar to the experiments, special attention will be paid to the development of suspended, bottom and total sediment transport figures, as well as the evolution of the profile.

## 4.3 Unibest-TC model set-up for Serie B

In this serie, special attention will be paid to the behaviour of the placers of “heavy minerals”. The results of the experiments have clearly pointed out how placers of heavy minerals behave and this model set-up is used for testing if Unibest-TC can reproduce these trends with hydraulic equivalent quartz grains.

### 4.3.1 Sediment properties

For modelling Serie B, the hydraulic equivalent counterparts of the heavy mineral particles are first calculated. This means that first the fall velocities of the heavy mineral particles were calculated. This was done with the theory of Van Rijn (equation 4-2), which was than used to determine the diameter of a quartz particle that has the exact same fall velocity. This is illustrated in Figure 4-8.

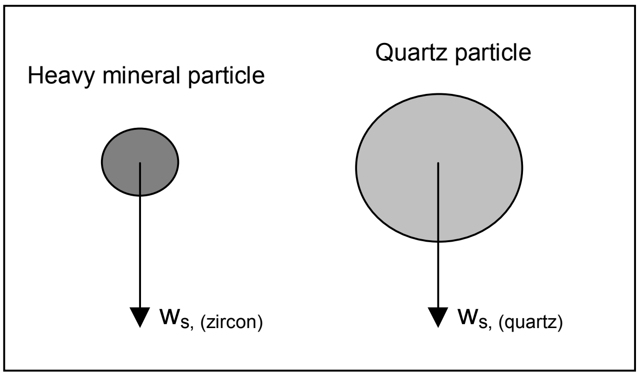

*Figure 4-8; Fall velocities for different sediment particles in water*

$$w_s = \begin{cases} \dfrac{(\Delta - 1) g D^2}{18\nu} & \text{for } 1 < D < 100\ \mu\text{m} \\ \dfrac{10\nu}{D}\left[\left(1+\dfrac{0.01(\Delta-1)gD^3}{\nu^2}\right)^{0.5} - 1\right] & \text{for } 100 < D < 1{,}000\mu\text{m} \end{cases} \qquad (4\text{-}2)$$

In which:

| | | | |
|---|---|---|---|
| $w_s$ | = | fall velocity | [m/s] |
| $\Delta$ | = | relative density = $(\rho_s-\rho)/\rho$ | [-] |
| $\rho_s$ | = | density of sediment | [kg/m$^3$] |
| $\rho$ | = | density of water | [kg/m$^3$] |
| D | = | particle diameter | [m] |
| $\nu$ | = | kinematic viscosity | [m$^2$/s] |

As is illustrated, there is a certain particle diameter for quartz, such that the fall velocity is equal to that of a smaller heavy mineral particle. This results in a range of new theoretical quartz particle diameters that have equal fall velocities when compared to their heavy mineral counterparts. The new range of grain diameters for Serie B is presented in Table 4-6.

*Table 4-6; New diameter for hydraulic equivalent particles*

| Heavy mineral diameter | → | Fall velocity | → Theoretical quartz diameter | |
|---|---|---|---|---|
| $D_{50}$ | 115 µm | 19.8 mm/s | $D_{50}$ | 183 µm |
| $D_{90}$ | 153 µm | 31.5 mm/s | $D_{90}$ | 250 µm |
| $D_{SS}$ | 90 µm | 11.3 mm/s | $D_{SS}$ | 132 µm |

In the model set-up for Serie B, these new diameters were used to simulate the presence of heavy minerals in the profile in certain area's known as placers.
In the experiments, heavy minerals were added to the final profile of Serie A and three placers of heavy minerals were created in this way. In these same area's, this was done for modelling Serie B, but this time with hydraulic equivalent quartz particles.

### 4.3.2 Limitations

From literature it is known that hydraulic equivalence is not limited to fall velocity. This is described in paragraph 2.3. In fact, it is known that the influence of grain size and shape can lead to major differences in the way grains are actively transported. These differences lead to selective transport phenomena. This selective transport can not be simulated in Unibest-TC, neither can armouring and/or hiding effects explicitly be taken into account for. This means that when simulating heavy mineral behaviour only by equivalence in fall velocity, possible significant, effects are being ignored.

In Appendix D-d and Figure 4-9, these differences are illustrated. Calculations were performed in Unibest-TC with heavy minerals of small diameter and with quartz with larger diameter (hydraulic equivalent according to Table 4-6).

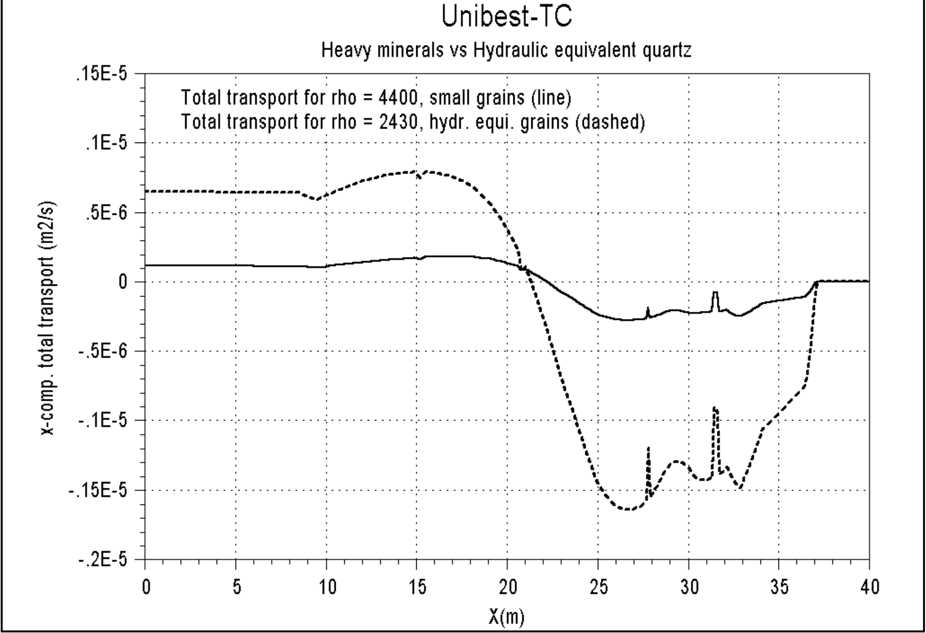

*Figure 4-9; Comparison total transport figures (H.M. vs. hydraulic equivalent quartz)*

From this figure, it becomes evident that differences in transport in Unibest-TC are dependant on more than just the fall velocity. The reason for this is that the particle sizes are used for more than just for computation of the fall velocities.

The particle size is, amongst others, also used to compute mixing coefficients in the time-averaged concentration profile, to compute the reference concentration near the bed and to compute the time-averaged critical shear stress.

Possible solutions to this problem are:

1. Tune transport figures with other user-defined variables like RKVAL and RC, to the level that transport figures are the same for heavy minerals and hydraulic equivalent quartz grains.
2. Change the way fall velocities are computed in Unibest-TC

From the figures that are presented in Appendix D-d, it can be expected that the first solution can work, but it is impossible to vary user-defined variables, like RKVAL, with the cross-shore distance. This solution can therefore not deal with the concept of heavy mineral placers.

It is expected that the same is true for the second option. Moreover, it means that the empirical theory about fall velocities of sediment needs to be changed in the computer model. This is expected to result in unrealistic behaviour, not corresponding with actual physical behaviour of sediment and is not in accordance with the objective of this research.

The motivation to perform the simulation of Series B, based on the singularity in fall velocity, is the following:
It still is thought to be interesting to see how Unibest-TC results compare to the experimental results. It is accepted that the conclusion might be that simulating it in this manner with this computer model might prove not to work at all.
On the other hand it is known that the effects, that can not be modelled, only have positive effects[6] regarding erosion and profile evolution, which may be accounted for with efficiency factors. These simulations may point out that this is possible.

From this point forward, the term “heavy mineral placer” will be used when reference is made to the placer of hydraulic equivalent quartz grains that is placed on the profile in Series B of the Unibest-TC model calculations.

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[6] *Positive from a coastal engineering point of view, in which a reduction of erosion can be considered as a positive one.*

### 4.3.3 Profile geometry

The initial profile for these simulations is taken from the experimental data.
Similar to the experiments, the initial profile for Series B is based on the final profile of Serie A in the Scheldt flume experiments. This profile is derived from the available experimental data and again, the swash bar and beachface are fixed similar to the previous simulations.

Similar to the initial profile of Serie A, the most offshore part of the profile was set to a slope of 1 on 40. This illustrated in Figure 4-10.

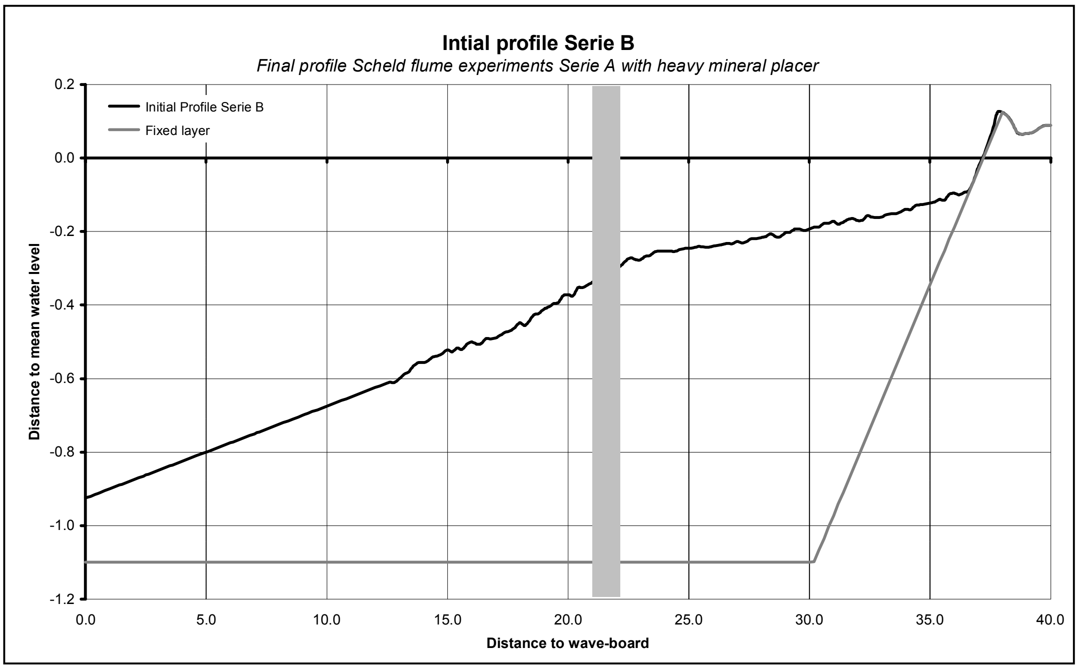

*Figure 4-10; Initial profile Serie B*

In the experiments, three placers of heavy minerals were placed on the initial profile. However, the possibilities in Unibest-TC are limited to simulating just one placer of sediment with larger diameter.[7] This placer will be located between X = 21 m and X = 22 m and is similar to placer II in the Scheldt flume experiments.
It is marked with the grey area in Figure 4-10.

---

[7] *See also chapter 3 for a more detailed description on this topic.*

### 4.3.4 Time series

Again, a number of runs will be performed in Unibest-TC with different total time spans. The time series are summarised in Table 4-7.

The first two of these runs (201 and 202) can be compared to the experimental results. Also, a reference run (204) for these runs is made. This run has the same model set-up as UTC 202, but no heavy mineral placer is present. The goal is to investigate how Unibest-TC responds to the “placer” on this particular initial profile.

*Table 4-7; Time series for modelling Serie B*

| Number of run | Number of time steps | Total duration | Objective |
|---|---|---|---|
| UTC 201 | 8 | 1.5 hours | Comparison to experimental data; B102 |
| UTC 202 | 18 | 3.5 hours | Comparison to experimental data; B104 |
| UTC 203 | 75 | 15 hours | Effects in Unibest-TC on morphology |
| UTC 204 | 18 | 3.5 hours | Reference run (without placer) for UTC 202 |
| UTC 205 | 75 | 15 hours | Reference run (without placer) for UTC 203 |

Run UTC 203 can be used to investigate what the effect is in Unibest-TC of a longer run[8]. Also for this run, a reference run (205) is made, again for the same time window but without a placer of heavy minerals.

---

[8] *In this case, not very long runs are chosen to perform because the location of the placer is connected to the water depth in Unibest-TC, instead of a horizontal coordinate in the cross-shore profile. Morphology will therefore have a significant influence on the location of the placer. It is unlikely that this is realistic.*

## 4.4 Unibest-TC model set-up for Serie C

### 4.4.1 Sediment properties

In Koomans' Serie C, experiments are conducted with a uniform quartz and zircon sediment mixture. The top layer (about 10 centimetres thick) of the profile consists of a mixture with 60% quartz and 40% zircon *(percentages of mass).*
The specific individual properties are presented in Table 4-8.

A problem arises when using Unibest-TC and trying to model a mix of sediments. Unibest-TC is only capable of dealing with one kind of sediment density and has limited abilities of varying the grain sizes as a function of the cross-shore distance to the shoreface. Therefore in Table 4-8 the theoretical properties of a mix of 60 - 40 percent quartz and zircon is also presented. This "mix" is used when attempting to reproduce experiments of Serie C.

*Table 4-8; Sediment properties*

| **Diameter** | **Quartz**<br>($\rho$ = 2,430 kg/m$^3$) | **Zircon**<br>($\rho$ = 4,400 kg/m$^3$) | **Mix**<br>($\rho$ = 3,220 kg/m$^3$) |
|---|---|---|---|
| $D_{50}$ | 129 $\mu$m | 115 $\mu$m | 125 $\mu$m |
| $D_{90}$ | 187 $\mu$m | 153 $\mu$m | 178 $\mu$m |
| $D_{SS}$ | 112 $\mu$m | 90 $\mu$m | 106 $\mu$m |

The new density is based on the 60 - 40 mass percentage ratio, resulting in a new mean density of 3,220 kg/m$^3$. In calculating the new grain size distribution, the 60 - 40 mass percentage ration is transformed into a volume ratio. In this new ratio, for calculating the new grain sizes, the density is taken into account resulting in a 73,5 - 26,5 volume percentage ratio between quartz and zircon. With this ratio, the new grain size distribution for the mix is calculated. Before using this in Unibest-TC, the sediment density in the transport formulations was changed to the new density of 3,220 kg/m$^3$.

**Note**:
Since the diameter of the suspended zircon was not measured, it has been determined by application of Van Rijn (1987), which states that the diameter of the suspended diameter lies between 60% and 100% of the median grain size, $D_{50}$. From this diameter and the $D_{SS}$ (the measured diameter of the suspended sediment) in Serie A, the new theoretical diameter of the suspended sediment was derived. Since the diameter of the suspended diameter is of significant influence in the model calculations of Unibest-TC, calculations have also been performed with a $D_{SS}$ of 112 $\mu$m to investigate the magnitude of this change in Unibest-TC. This is based on the hypothesis that in a mixture of quartz and zircon, the quartz will have a greater contribution to the number of suspended particles than the zircon. This will lead to a mean suspended particle diameter that lies closer to that of the quartz than that of the zircon.

### 4.4.2 Time series

The time series for modelling Serie C are presented in Table 4-9. Again, two runs (301 and 302) can be compared to the experimental data, where the other runs can not, since the experiments in Serie C were stopped after 14.5 hours.

*Table 4-9; Time series for modelling Serie C*

| **Number of run** | **Number of time steps** | **Total duration** |
|---|---:|---:|
| 301 | 36 | 7 hours |
| 302 | 74 | 14.5 hours |
| 303 | 152 | 29.5 hours |
| 304 | 305 | 60 hours |
| 305 | 610 | 120 hours |

The other runs are to investigate if the trends that have been recorded can also be found if longer runs are performed. An attempt will be made to explain the behaviour of the model when longer runs are made, with aid of the theoretical background.

# 5 Validation and findings

Morphodynamic calculations have been performed in Unibest-TC, based on experiments conducted in The Scheldt wave flume. (Koomans and Bosboom, 2000) These calculations were carried out with specific interest towards sediment transport rates, profile evolution and the influence of heavy minerals on these processes.

Results will be presented for each individual serie in paragraphs 5.2 to 5.4.
Each paragraph consists of a validation and a summary of the Unibest-TC model results.

These paragraphs begin with a comparison of the Unibest-TC calculations to the data of the Scheldt flume experiments. The objective is to validate the Unibest-TC results to the experimental results.

The validation is followed by a summary of results for the particular Unibest-TC serie. Observations with regard to profile evolution, time-mean sediment transport rates and gradients of transport are summarised. Differences between the subsequent time-intervals will be presented.

In the last paragraph the results will be assessed so that valid conclusions, with regard to the problem analysis and the objective of this research, can be drawn. These conclusions as well as recommendations will be given in chapter 6.

## 5.1 Serie A: validation and results

### 5.1.1 Validation

The results of UTC103 are compared to run A904 from the experiments. Both runs were completed in 29.5 hours.

While observing profile development and sediment transport rates, it becomes apparent that the model results show quite a number of similarities to run A904. This is illustrated in Appendix E-g. The profile development is also illustrated in Figure 5-1.

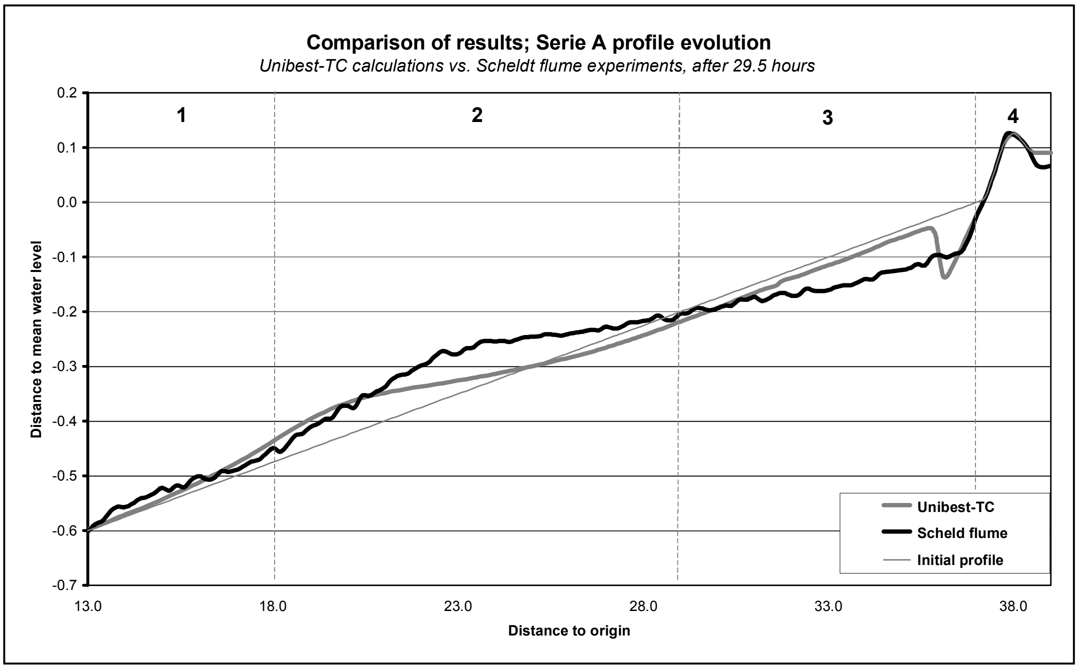

*Figure 5-1; Comparing Unibest-TC and Scheldt flume experiments, Series A*

Both transports and profiles show similar development and comparable magnitudes. Unibest-TC underestimates the transport rates a little bit, but gradients of transport seem to be in correspondence to the experimental data. Only the transport rates near the beach face are predicted very differently by Unibest-TC when compared to the experimental data.

The locations for all major trends are predicted a little bit too far offshore in Unibest-TC when compared to the experimental data.

### 5.1.2 Findings Unibest-TC

The findings are divided into three areas with respect to the location in the profile. The area X < 18 m, marked with the number 1 in Figure 5-2, will be referred to as the "outer surf zone". The "breaker zone" is the area between X = 18 m and X = 29 m. The last wet part of the profile is known as the inner surf zone; X = 29 m to X = 37 m. In Figure 5-2 is also shown a fourth region; X > 37 m. This is the "dry beach" where the sediment transport rate of the last computed wet cell is extrapolated over the dry beach.

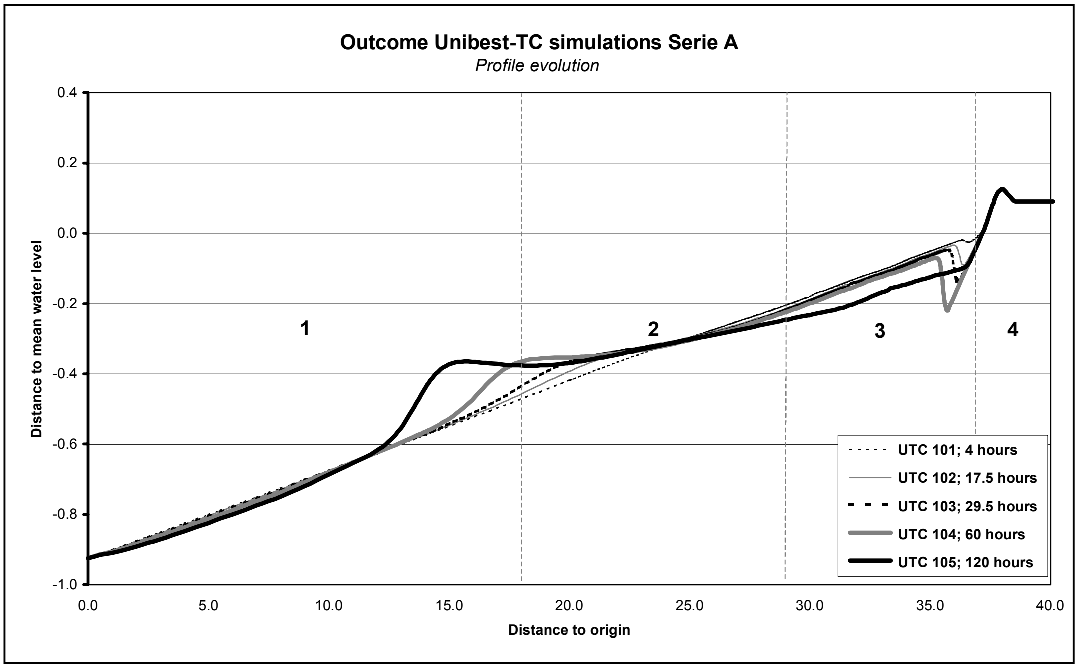

*Figure 5-2; Profile evolution for successive time-intervals of Serie A*

**Observations of profile change**

The observations below are illustrated in figure E-1 of Appendix E-a. The profile changes are also illustrated in Figure 5-2.

1. **The outer surf zone**
   In the most offshore part of this area, little changes are observed. A little erosion occurs, but it has very small impact on the geometry. However, in the most onshore part of this area, changes are significant.
   From the beginning of the time series, the geometry is changing. The formation of the breaker bar is such that it migrates offshore in time. This offshore migration of the breaker bar however, is decreasing by more than square.

2. **The breaker zone**
   In this area, energy dissipation due to wave breaking becomes significant.
   The profile changes gradually little in time and even after longer time spans (UTC 105), changes between time series are small. It can be seen from appendix E-d that the suspended sediment transport for this area is negative but decreasing in time. The bottom transport is onshore directed and small changes occur near the top of the breaker bar.

3. **The inner surf zone**
   This area combines positive transport gradients with offshore-directed transport of sediment. This means that the bed is eroded and that the eroded material moves seaward. In the beginning of the time series, the bed erodes rapidly at the beach, forming a sand erosion pit with very steep slopes.
   When given enough time, these large slopes disappear and the erosion pit is filled up again. This phenomenon is accompanied with positive and increasing bottom transports. (see Appendix E-d)

### Observations of sediment transport rates

In the development of the time-mean total sediment transport, a number of trends can be observed. This is illustrated in figure Figure 5-3. A larger copy of this is illustrated in figure 2 of Appendix E.
The development of bottom and suspended transport is presented in Appendix E-d.

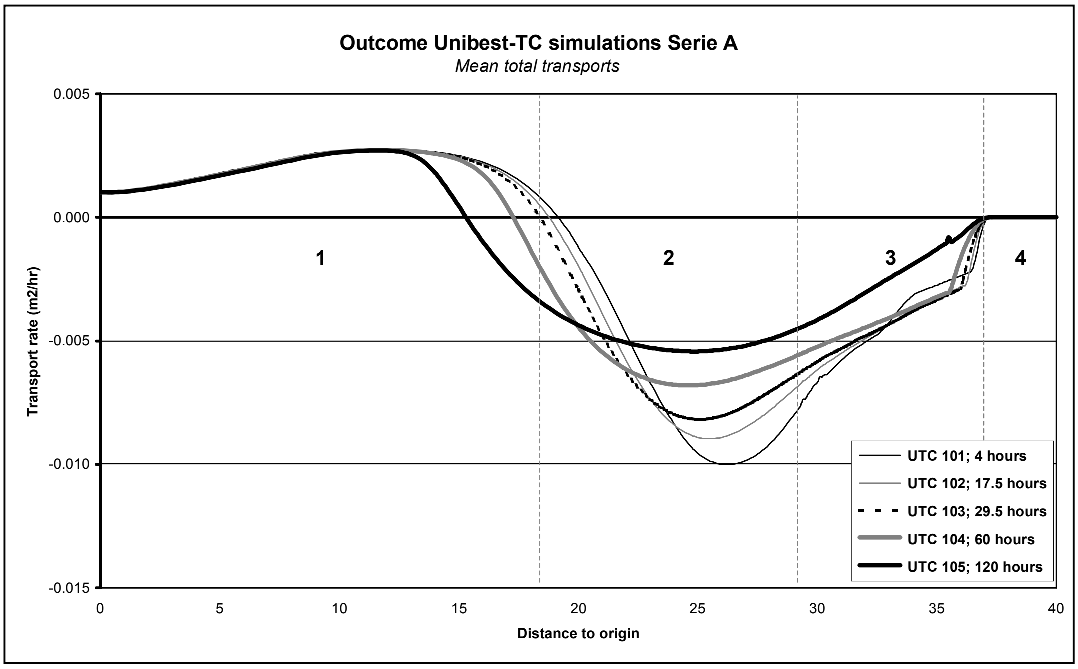

*Figure 5-3; Mean transport rates for succesive time intervals of Serie A*

At three locations in the profile zero gradients in transport rate occur. Two of them are located in a morphological area. These two locations shift in an offshore direction through time. This means that the locations were transport changes from erosion to accretion migrate seawards. No indication is apparent from these observations that a 100% equilibrium state will be reached. However, the profile appears not to migrate endlessly since the migration decreases by more than square.

The area of maximum erosion (near X = 29 m) shows a decrease of the transport gradient with passing time. The area of maximum accretion however migrates strongly in an offshore direction. It is located at about X = 24 meters for UTC 101 (after 4 hours) and after 120 hours it is located at about X = 15 meters.

## 5.2 Serie B: validation and results

### 5.2.1 Validation

For validation of Serie B, the results of UTC204 are compared to run B104 from the experiments. Both runs were completed in 3.5 hours.
In these observations, attention must be paid to the breaker zone. This is where the placer is located for the Unibest-TC runs, in contrast to run B104, which has three heavy mineral placers in the entire profile.

Results are illustrated in Appendix E-h and the profile development is also illustrated in Figure 5-4.

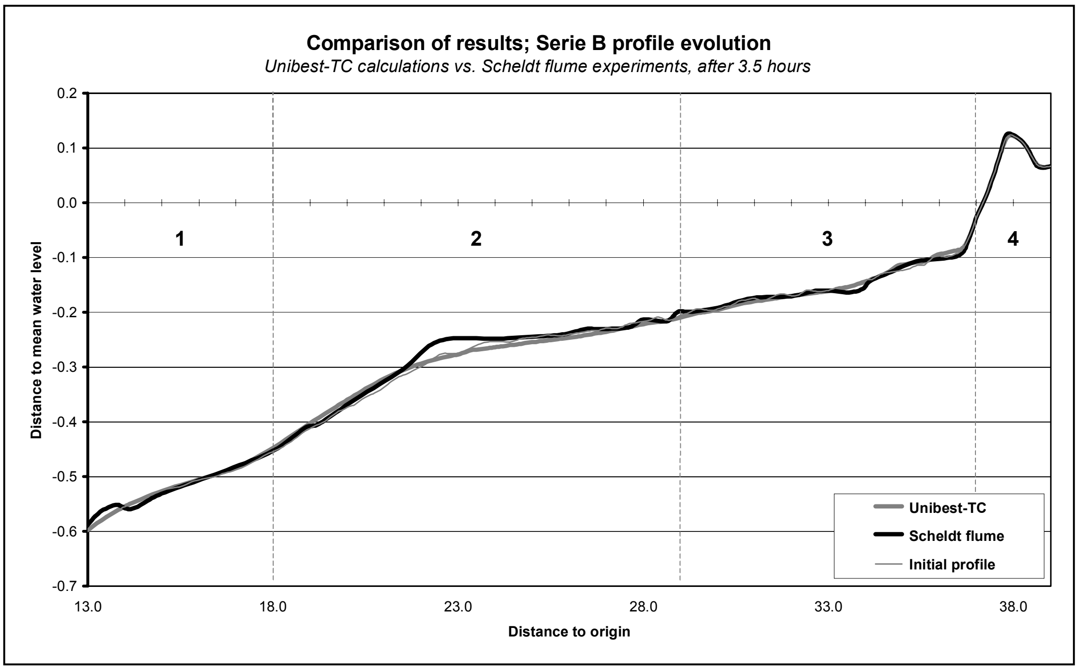

*Figure 5-4; Comparing Unibest-TC and Scheldt flume experiments, Series B*

From the figures presented, it can be observed that Unibest-TC has difficulties with modelling the impact of the heavy mineral placer correctly. The profile development shows little correspondence to that of the experiments. In the very short time period that was used, Unibest-TC predicts too small bottom changes when compared to the Scheldt flume data.

In picture 16 of Appendix E, transport rates for UTC204 and B104 are illustrated. The peaks in offshore transport rates of these series show some similarity in magnitude, but large differences in form, locations of zero-crossings and maximum gradients.

Also, the transport rates in the more shoreward part of the profile are very different from each other and even opposite in direction. This however must be evaluated with caution, since run B104 of the experiments has a placer located in the inner surf zone. It is known that this placer has influence on the sediment transport behaviour, but it was not modelled in Unibest-TC.

### 5.2.2 Findings Unibest-TC

The “input beach profile” for these runs was taken from the final profile that developed in the Scheldt flume experiments. This is why this serie has a very different behaviour from Series A and C in terms of morphology and can not be compared to the other Series.

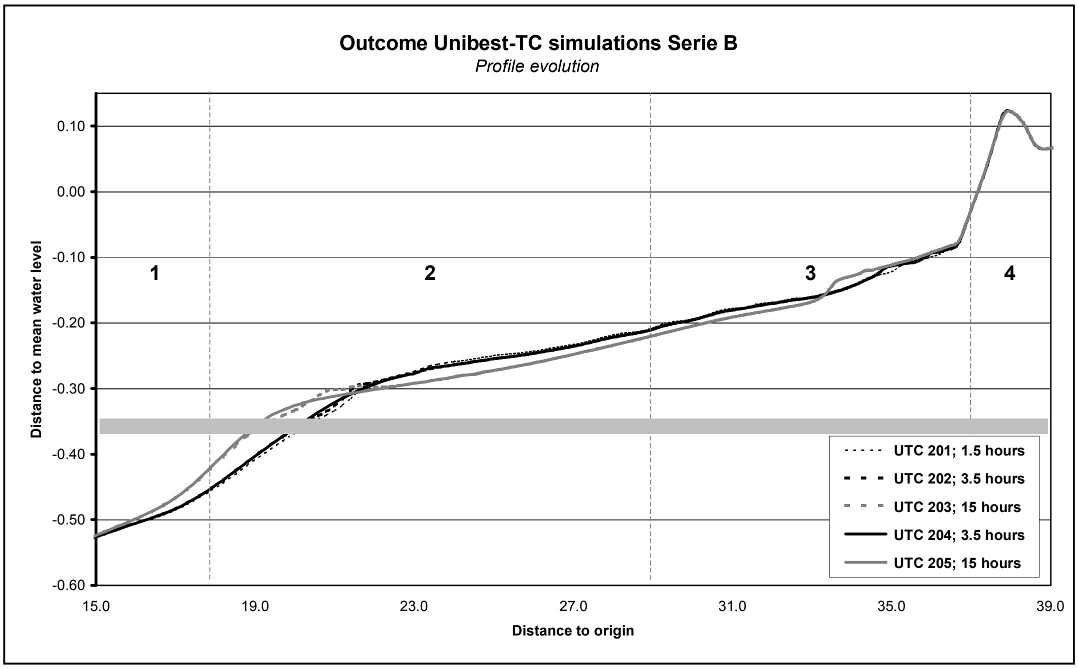

*Figure 5-5; Profile evolution for successive time-intervals of Serie B*

In Figure 5-5 are illustrated the profile changes and the effects of the heavy mineral placer on these changes. Runs 201 to 203 are performed with the heavy mineral placer. This placer is defined horizontally, in terms of the water depth. This is illustrated with the grey area in the figure. At the beginning, this placer is located between X = 21 and X = 22 m.

Runs 204 and 205 are reference runs to respectively 202 and 203. These reference runs don’t have a placer of heavy minerals present and are used to illustrate the impacts of a placer of heavy minerals to the profile evolution. They are plotted with solid lines in the figure, in contrast to the runs **with** a placer of heavy minerals. They are plotted with dashed lines.

**Observations of profile change**
An enlarged figure of the profile development is illustrated in Figure 5-5 and in Appendix E-b. This enlargement is concentrated on the areas where changes occur.

1. **The outer surf zone**
   Again, changes to the profile are very small in the most offshore part of the outer surf zone. For the small time intervals, changes are almost nil. After a longer period of time it can be seen that the breaker bar becomes broader and also the impact of the heavy mineral placer becomes visible. Sediments are deposited at the seaward side of the initial breaker bar. When the placer is present, the breaker bar is a bit narrower and more pronounced.
   This is clearly visible in the figure when comparing UTC 203 and UTC 205.

2. **The breaker zone**
   Changes in this area, although hard to observe in the pictures, are dominated by the length of the time intervals only. Little or no changes are observed for all the short time series (201, 202 and 204), independent from the presence of a heavy mineral placer. Only for longer time series (203 and 205), erosion of this part of the profile is observed. Sediments are eroded and transported offshore.

3. **The inner surf zone**
   A similar behaviour to that of the breaker zone area is observed here. The transport is mostly erosive but directed onshore. Therefor, the profile builds up towards the beach.

### Observations of sediment transport rates

In the development of the time-mean total sediment transport, a number of trends can be observed. This is illustrated in figure Figure 5-6. A larger copy is illustrated in figure 4 of Appendix E.
The development of bottom and suspended transport is presented in Appendix E-e.

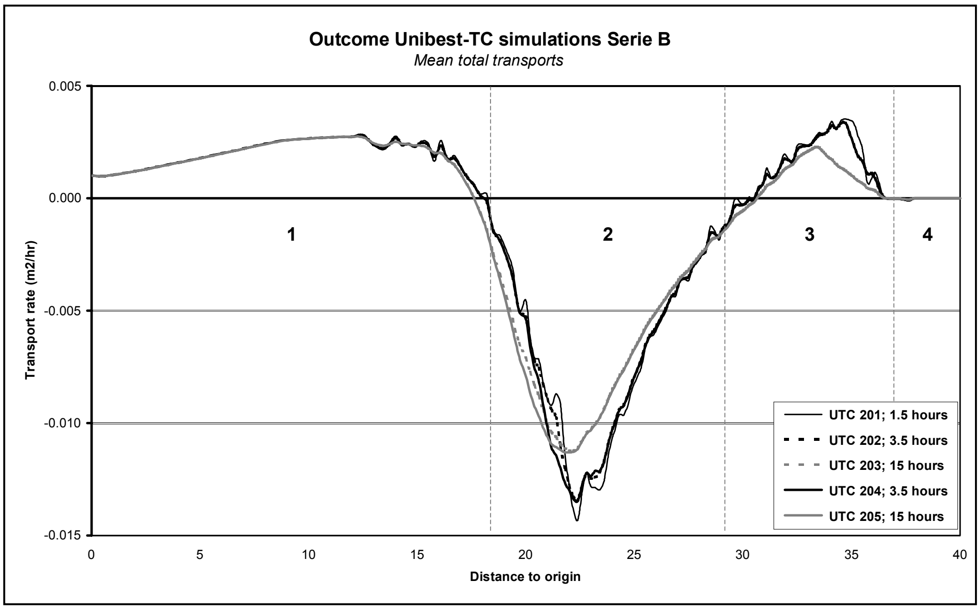

*Figure 5-6; Mean transport rates for successive time-intervals of Serie B*

Three locations of zero transport gradients can be found, each lying in a different zone. All three of them move offshore with time. However, the two locations where transport rates shift from negative to positive respond differently. The one located in the outer surf zone moves offshore with time and the other one, located in the inner surf zone moves in the opposite direction. This causes a broadening of the entire transport profile and consequently decreases gradients at other locations.
Together with the image of profile evolution when the heavy mineral placer is present, this suggests that an equilibrium will be reached for longer time series. This could not be investigated since the morphology causes the placer to migrate offshore, limiting the time span of the series.

As can be seen in Figure E-9 of Appendix E-e, the influence of the heavy mineral placer on both the bottom and the suspended transport is apparent where the placer is situated. The placer causes small decreases of both bottom and suspended transport. Remarkable is the fact that it decreases the local bottom transport with such magnitude that the transport even becomes a little negative.

## 5.3 Serie C: validation and results

### 5.3.1 Validation

For this evaluation, the results of UTC302 and UTC304 are compared to run C404 from the experiments. When looked at the model results, it can be observed that changes in bathymetry are very small for small time-intervals.
Therefore, the choice was made to compare two model runs with run C404 of the Scheldt flume experiments.
This is to illustrate the hypothesis that Unibest-TC underestimates the development of transport rates and profile evolution in time. When comparison is made between run UTC304 and run C404, a comparison is actually made between 60 hours in computer simulation and 14.5 hours in experimental runs.

Results for profile evolution and sediment transport rates are presented in Appendix E-i. The profile development is also illustrated in Figure 5-7

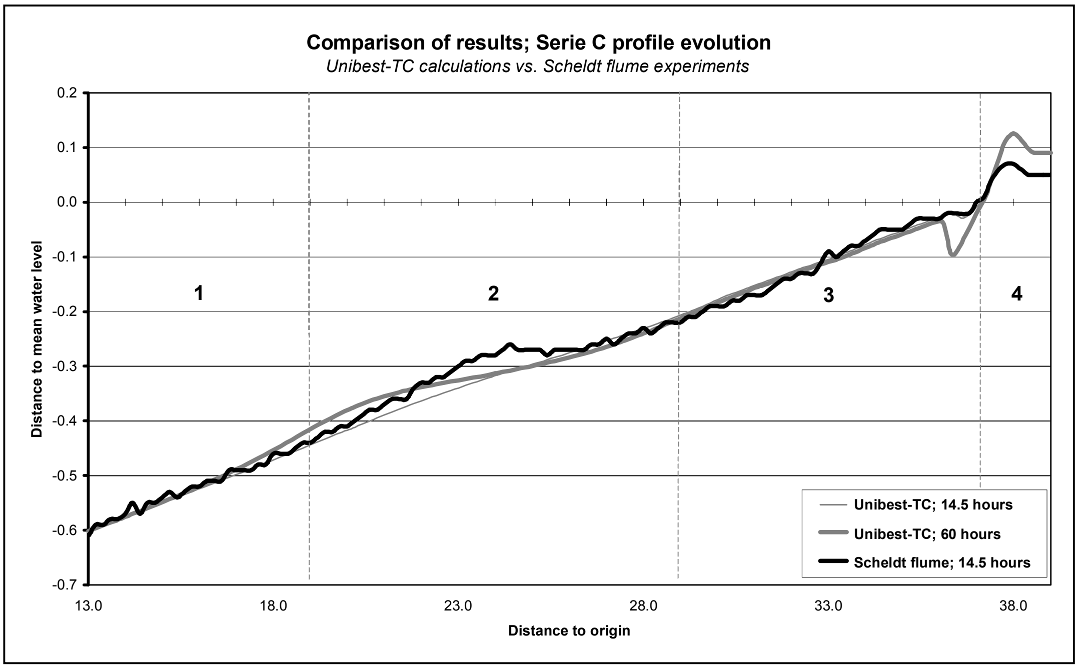

*Figure 5-7; Comparing Unibest-TC and Scheldt flume experiments, Series C*

From observations in profile evolution and the development of sediment transport rates can be concluded that Unibest-TC underestimates transport rates. This becomes also apparent when looked at the profile development.

Transport rates, illustrated in figure 18 of Appendix E, are underestimated in magnitude. However, the development seems to be in correspondence to the experimental data. Zero crossings of transport and the development of maximum gradients show similarities to what was observed in the comparison between Series A, as made in paragraph 5.1.1.

It must be noted however, that the locations of the trends in sediment transport are in good correspondence to the experimental results. This was not entirely the case for Serie A.

### 5.3.2 Findings Unibest-TC

Again, results are presented in the Appendices as well as in this paragraph. Serie C is a simulation for the behaviour in Unibest-TC of a uniform mix of heavy minerals and quartz. The mix is based on a 60-40 mass percentage ratio for respectively quartz and zircon. Specific details of this can be found in Chapter 4.

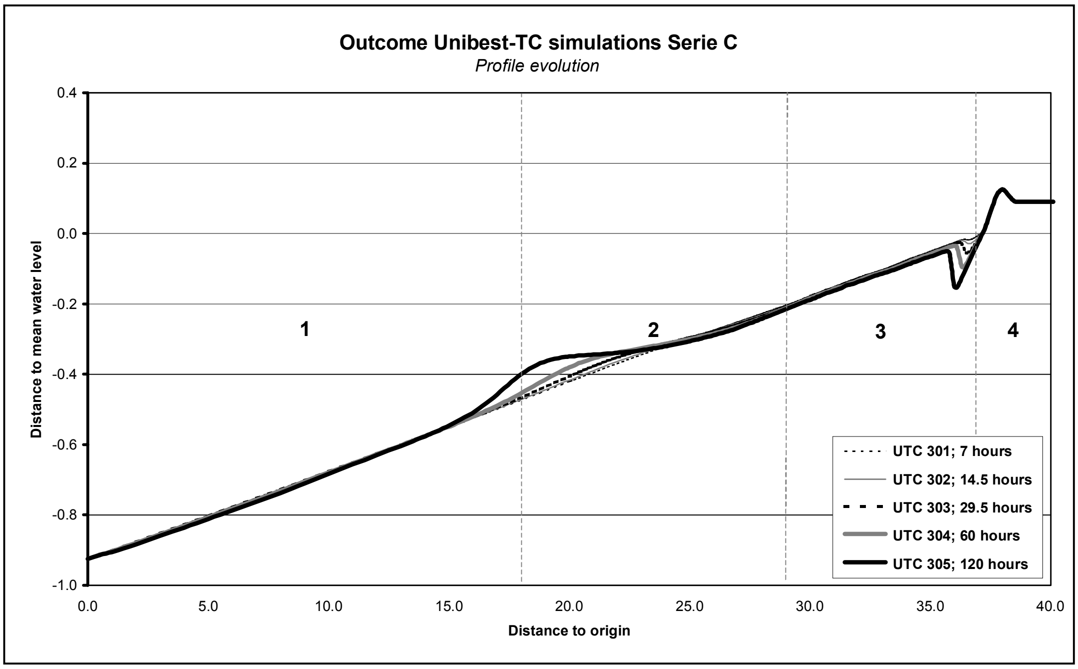

*Figure 5-8; Profile evolution for successive time-intervals of Serie C*

**Observations of profile change**

The observations below are illustrated in figure E-5 of Appendix E-c. Profile changes are also illustrated in Figure 5-8. It can be seen that Serie C shows great similarities to Serie A, but it needs greater time spans to build up to the same level. In other words: for similar hydraulic conditions, sediments are less easily transported.

1. **The outer surf zone**

   The difference between this area and the same area in Serie A is significant. Changes to the profile are very small, only becoming significant for the longer time series and in the most onshore part of this area. A little sediment is eroded and transported onshore. It settles on the seaward side of the breaker bar.

2. **The breaker zone**

   A breaker bar is formed but at a lower rate when compared to Series A. Less sediment is eroded in the same time spans, indicating that the beach profile has become more resistant to energy dissipation due to wave action. The breaker bar also migrates offshore like it does in Series A, but again it takes more time to build up to the same level and to migrate the same distance offshore. When looked upon in detail, the runs UTC103 and UTC104 show similar development of profile to run UTC305.

### 3. The inner surf zone

A similar behaviour to that of Series A can also be observed here. Again, a sand erosion pit with rather large slopes is formed in the swash zone. It is expected that, when given enough time, the large slopes will disappear and the sediment gets evenly redistributed in this part of the profile.

### Observations of sediment transport rates

A significant difference between the transport rates of Series C and A is observed. This difference lies in the magnitude of the transport rates. Multiplying the density of the sediment with a factor 1.3 decreases the transports with more than a factor 2. This can be observed when comparing runs UTC105 and UTC305. The latter is illustrated in Figure 5-9.
Development of bottom and suspended transport is presented in Appendix E-f.

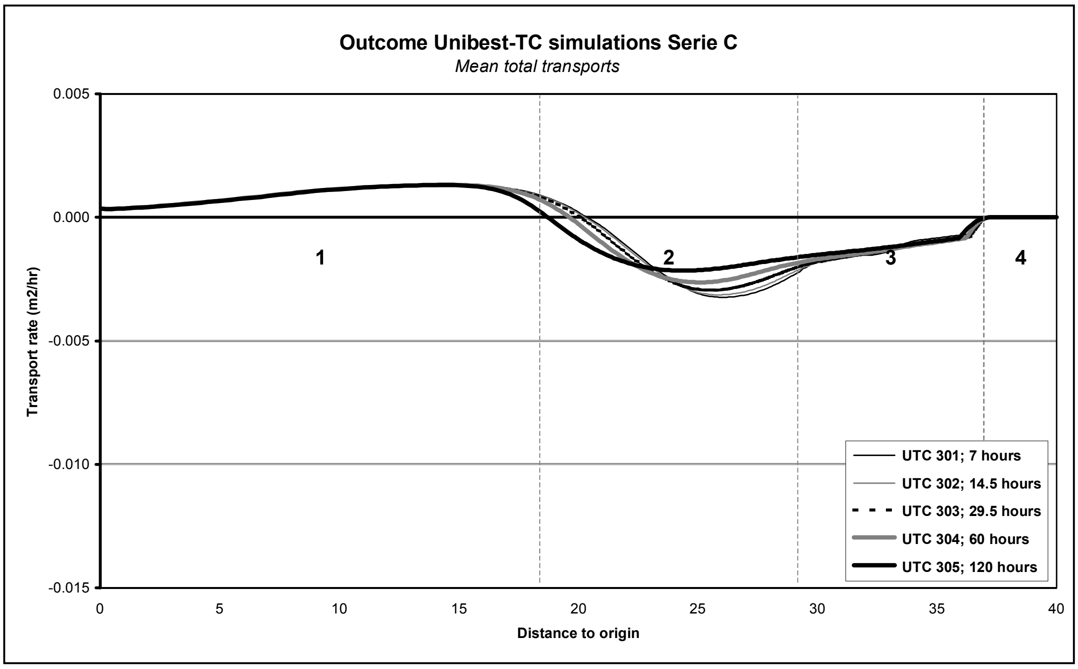

*Figure 5-9; Mean transport rates for successive time-intervals of Serie C*

The locations in the breaker zone where the gradients are zero, for successive time interval of Series C, are more or less the same for Series A. Maximum gradients of transport are smaller for Serie C but show similar development to their counterparts of Series A.

It should be noted that the area in which the total transport is onshore directed, is larger for Series C, stretching from X = 0 m to X = 19 m after 120 hours.
(The positive sediment transport for Series A after the same time span reaches up to X = 15 m.) The explanation for this is that due to the difference in density, less sediment gets into suspension. In Appendix E-f it can be seen that both suspended and bottom transport rates decrease. The bottom transport however decreases to a lesser extend than the suspended transport.
This gives the positive bottom transport a relatively larger contribution to the total transport in Serie C.

## 5.4 Assessment

In this paragraph, the results as stated in this chapter will be assessed shortly so that they can serve as an instrument for making conclusions and recommendations.

### 5.4.1 Modelling of a quartz and heavy mineral mixture

In the results, a number of things become apparent, which are in good correspondence to the experimental results. These lead to understanding of how heavy mineral mixtures can be modelled successfully. However, a number of unrealistic phenomena also appeared. Both are described here.

**Heavy minerals in Unibest-TC**

1. When a larger sediment density is introduced in Unibest-TC, the sediment transport responds to this. This response is in good correspondence with the experimental results and to what can be expected.
   This is illustrated in Figure 5-10.

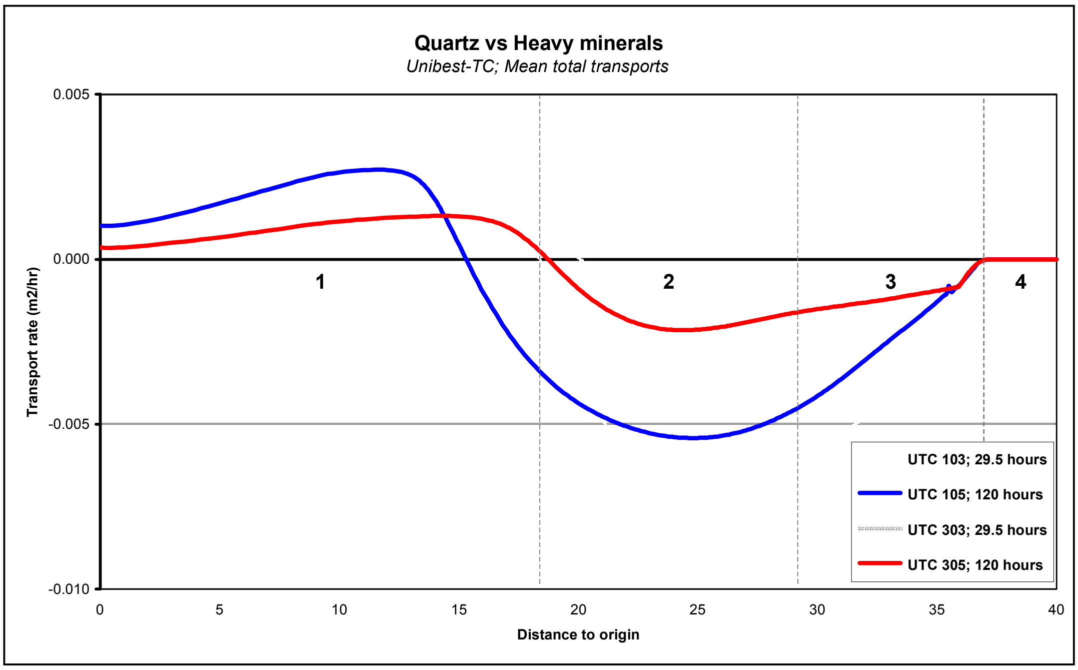

*Figure 5-10; Impact of heavy minerals on sediment transport*

Less sediment gets suspended in the water column and bottom transport becomes more important. Its contribution to the total transport is such that over a larger area in the more offshore parts of the profile, sediment is transported in a shoreward direction. This can be considered as a large advantage of using heavy minerals for beach protection.

2. Introducing a mix of heavy minerals by means as suggested in this research can be considered successful. Transport rates in general decrease, leading to a more durable state of the beach. For the outer surf zone and the breaker zone this leads to good results. However, two things remain.

   The first is the fine-tuning of the composition of the sediment mixture. This is thought to be important because the transport rates seem to be under-estimated. This results in slower changing profiles than can be expected from the Scheldt flume experiments.
   The second are specific hiding and sorting effects of heavy mineral grains amongst the generally larger quartz grains. These effects should be included somehow, when long-term morphological simulations are desirable.

**Unrealistic phenomena**

1. In the model results of Series A and C, the development of a sand erosion pit can be observed. It is unlikely that this phenomenon is realistic and a hypothesis is made in relation to this.

   Due to offshore directed transport in the last computed wet cell of the profile, transports will be directed offshore over the entire last part of the profile.
   Only when water depths just in front of this pit become large enough, the last computed wet cell shifts more shoreward. When it does, positive bottom transport contributes a great deal to the total transport in this area, which in the end leads to a filling up of the erosion pit. (The latter can be observed in Appendix E-a)
   This behaviour is due to a combination of scale problems and the non-linearity wave parameter in Unibest-TC.

2. The influence of gravity on the transport of sediment on a sloping beach was altered significantly. With the chosen set-up, profile development seems in good correspondence to the experiments when the breaker bar location is considered. For the more onshore part of the profile however, this may lead to local beach slopes, which become too steep.

### 5.4.2 Modelling of heavy mineral placers

Modelling the presence of a heavy mineral placer is not without problems. As noted in chapter four, hydraulic equivalence is not limited to singularity in fall velocity. Therefore, attempting to model the presence of a heavy mineral placer in Unibest-TC implies a lot of simplifications.

It is clear that:

- Modelling a placer in the way that has been performed does lead to a more pronounced breaker bar, similar to what may be expected.
- Specific behaviour of heavy minerals, other than fall velocity, can not be modelled in Unibest-TC at this time.
- Implementing heavy mineral behaviour (such as hiding effects and sorting) in Unibest-TC will be a difficult job, but will help to create better understanding of the transport of sand in general.
- A lot of parameters can not be varied with the cross-shore distance to the shoreline. This is considered to be unrealistic. Moreover it is expected that a lot of parameters can be considered to be a function of this distance.
- The fact that the cross-shore variation of grain sizes is fixed to a water depth instead of an X-location in the profile, makes it impossible to perform long term morphodynamic calculations for placers of heavy minerals.

Unclear however is:

- ..if the experimental data used to compare and test the model results can be described as sufficient. The runs only took 3.5 hours, which seems to be a bit short when compared to the other model results.
- ..if it is just the simplifications of modelling a placer of heavy minerals, that causes the differences in results.

# 6 Conclusions and recommendations

## 6.1 Conclusions

This chapter will look back to what was achieved and how this can answer to the objective of this research.

The objective was to create better understanding of cross-shore transport processes in relation to the presence of heavy minerals in the sediment. In earlier performed studies, effects of density gradation have been concentrated on the selective transport phenomena and other heavy mineral specific behaviour.
This research focussed on the existing possibilities in Unibest-TC to simulate heavy mineral behaviour.

It is possible to alter the density in the program code itself, enabling the user to perform calculations on short-term morphodynamics with mixtures of quartz and heavy mineral sediments. A new mean density can be used to model a mixture of sediments with a certain mass-percentage ratio. This will lead to representative[1] transports for the outer surf zone as well as the breaker zone. For more shallow parts of the beach profile, extensive tuning is needed to assure good results.

Comparing the differences in bottom and suspended sediment transport is very useful to investigate how sand mixtures of different densities are treated differently in Unibest-TC from quartz sediment, uniform in density.

It can be concluded that Unibest-TC is not very well prepared to simulate narrow placers of sediment, consisting of different density and/or grain size.
Furthermore, it is not expected that this can easily be overcome.

It can also be concluded that Unibest-TC can deal with a mixture of heavy minerals, but long-term morphodynamic calculations are not possible yet. This is caused by poorly understood sediment transport processes. This makes it hard to model these processes correctly in the existing computer models.

Towards using heavy minerals in beach protection, it is expected to be a very attractive and innovative engineering possibility for sandy beaches, which suffer from erosion.

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[1] *With respect to the outcome of the Scheldt flume experiments (Koomans and Bosboom, 2000)*

## 6.2 Recommendations

- If heavy minerals are considered for use in beach protection, an economic feasibility study should be carried out. This study should not only concentrate on the economics of getting concentrations of heavy minerals, high enough that it can be used in beach nourishment for example.
  It should also concentrate on expectations of what research budgets are required for further research[2] into this topic.

- If a beach nourishment with sediment, enriched with heavy minerals, is found to be a possible economic alternative, it is recommended that a full-scale field test is performed. With the data that can be gathered in such a field test, good calibration of models can be achieved.

- It is recommended that for the shallow water area such as the swash zone, alternative models are used to predict sediment transport rates. These rates can be used as input for Unibest-TC at this boundary. Implementation in Unibest-TC of such models, however wishful, is not a first priority.

- Priority should be given to investigate new possibilities in Unibest-TC to vary roughness and other parameters with the cross-shore distance.
  It is expected that this will lead to better understanding as well as better representation of actual physical processes in the model.

- If modelling of placers of sand, whether different in density or not, becomes wishful, it is recommended that a possibility is created to define the location of the placer(s) at a horizontal position in the cross-shore profile.

- If modelling of sand mixtures with differences is density will continue on a regular basis, it is recommended that the sediment density becomes a user-defined parameter in Unibest-TC. It is also recommended that this parameter becomes a function of the cross-shore distance.

- Before further modelling is undertaken of sediments with differences in density, it is recommended that the Bagnold slope correction parameter (β) is subject of investigation. This parameter has a large influence on the bottom transport and it needs validation in case of sediments with differences in density.

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[2] *Research into long-term morphological modelling for example.*

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# Appendices

# Appendix A; Equilibrium beach profiles

Three different types of profiles can occur after beach nourishment. These generic types are intersecting, non-intersecting and submerged. These types are presented in Figures A-1 to A-3.

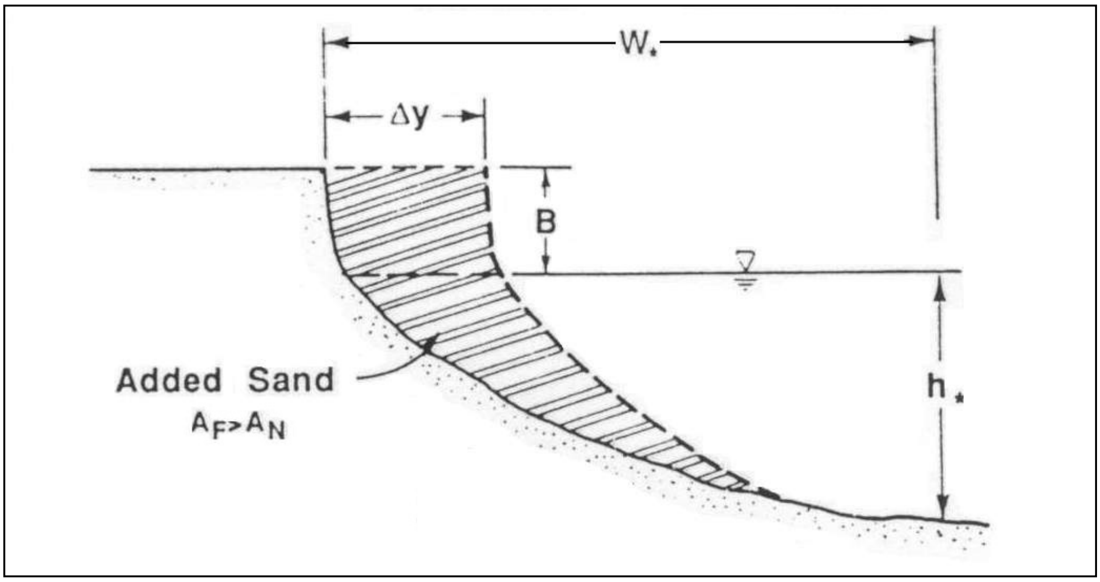

Figure A – 1; Intersecting profile

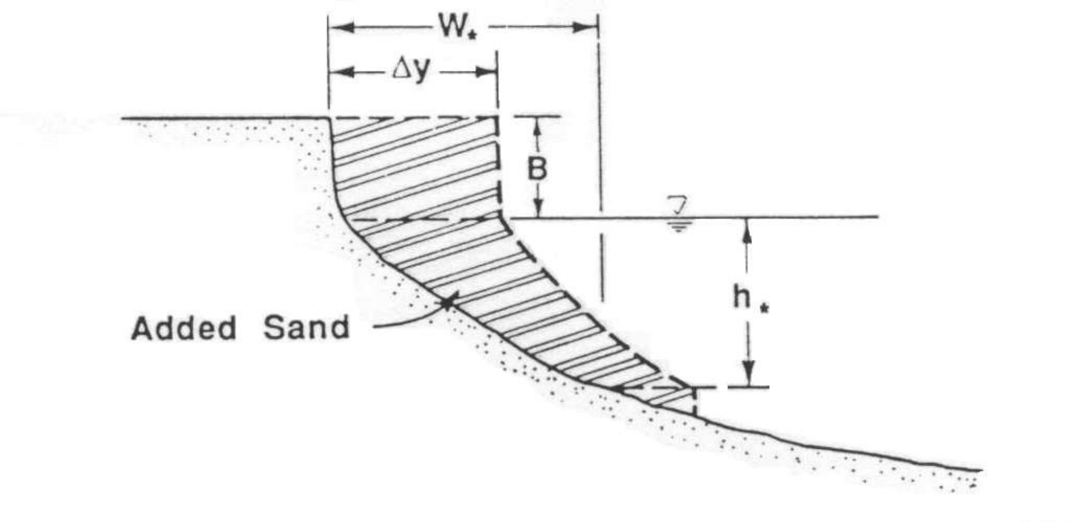

Figure A – 2; Non-intersecting profile

…. A necessary but insufficient requirement for profiles to intersect is that the placed material be coarser that the native. Similarly, non-intersecting or submerged profiles will always occur if the placed sediment is the same size as or finer than the native. However, non-intersecting profiles can occur if the placed sediment is coarser that the native. For submerged profiles to occur, the placed material must be finer than the native………

*From: -Dean (1991)*

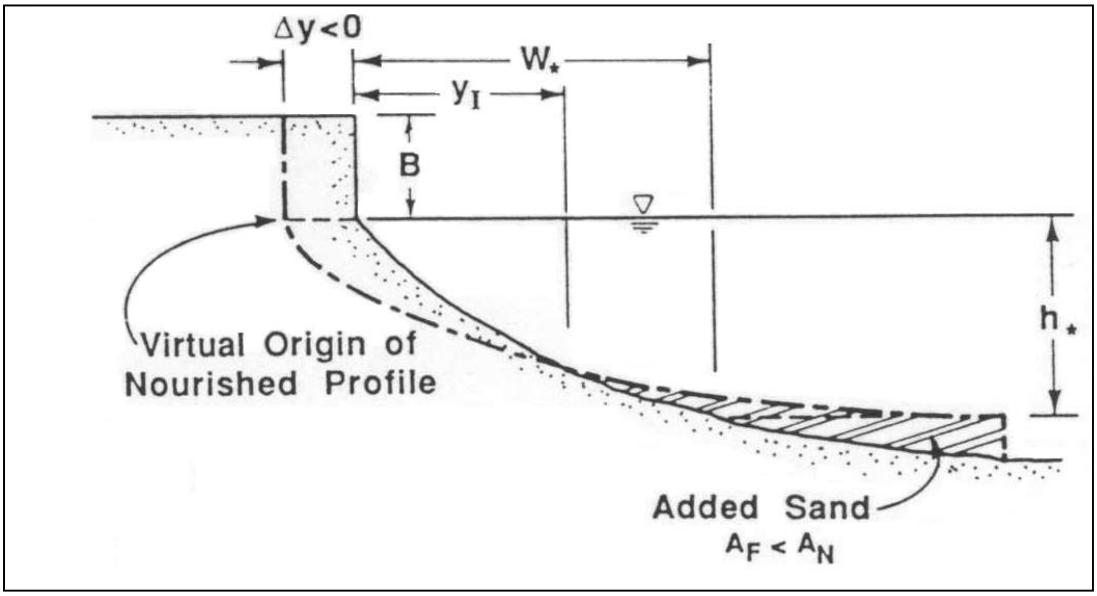

Figure A – 3; Submerged profile

The requirement for profiles to intersect is described with a dimensionless parameter:

$$\Delta y' + \left(\frac{A_N}{A_F}\right)^{3/2} - 1 \rightarrow \begin{cases} < 0; \text{ Intersecting profile} \\ > 0; \text{ Non-intersecting profile} \end{cases} \tag{A-1}$$

An explanation of terms used here is illustrated in Figure A-4.
The parameters in this equation are:

$$\Delta y' = \frac{\Delta y}{W_*} \tag{A-2}$$

$A_N$ = Scale parameter[1] for the native sediment [$m^{1/3}$]
$A_F$ = Scale parameter for the fill sediment. [$m^{1/3}$]

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[1] *See Chapter 2 for a more detailed explanation on this parameter*

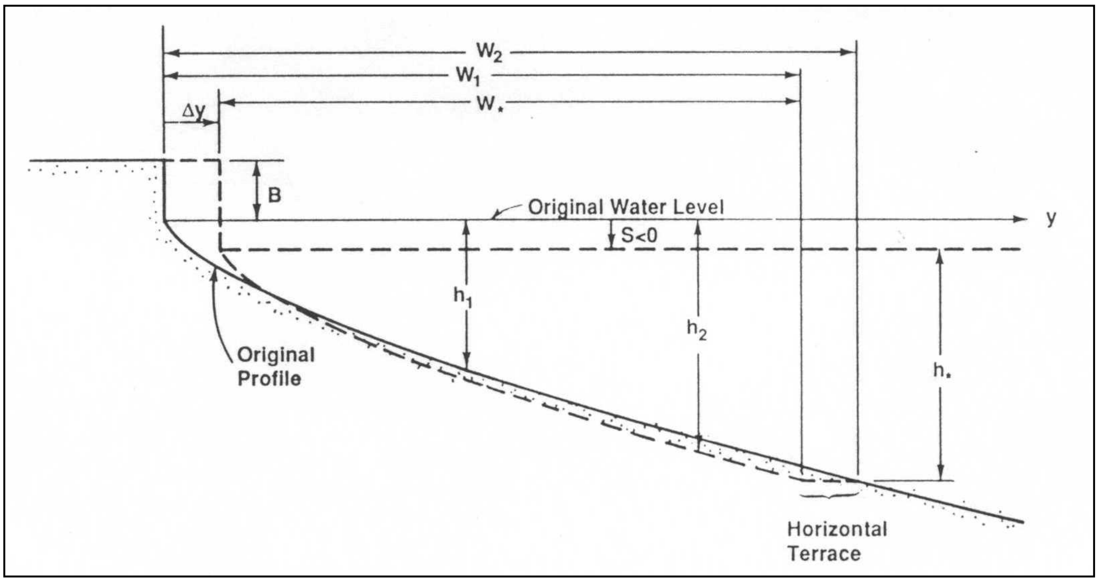


Figure A – 4; Profile geometry and notation

The volume of feed material placed per unit shore length becomes:

$$V_1 = V_1' \cdot \mathrm{BW}_* \tag{A-3}$$

In which:

$$W_* = \left( \frac{h_*}{A_N} \right)^{3/2} \tag{A-4}$$

$$V_1' = \Delta y' + \frac{\frac{3}{5\mathrm{B}} (\Delta y')^{5/3}}{\left[ 1 - \left( \frac{A_N}{A_F} \right)^{3/2} \right]^{2/3}} \tag{A-5}$$

For more detail on the subject of beach nourishment and the effects of the nourishment on the beach profile, the reader is referred to R. Dean, 1991.

# Appendix B; Experimental data; Effects of density and grain size

*Some figures in this appendix originate from: “Sand in motion, effects of density and grain size”, R.L. Koomans, 2000.*

# Appendix B-a; *Determining transport rates*

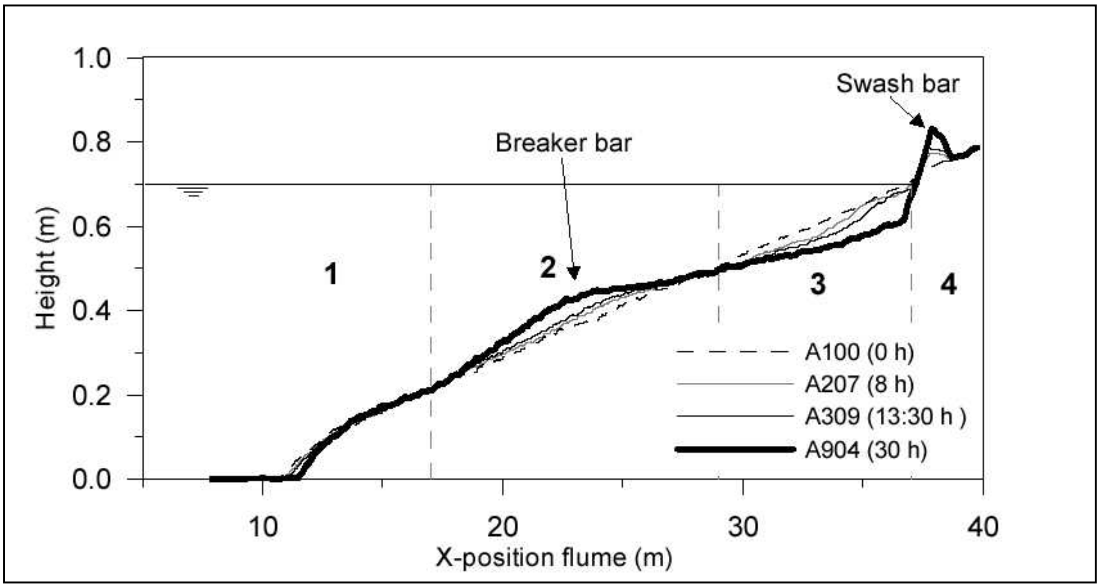


Figure B – 1; Example of bed height measurements

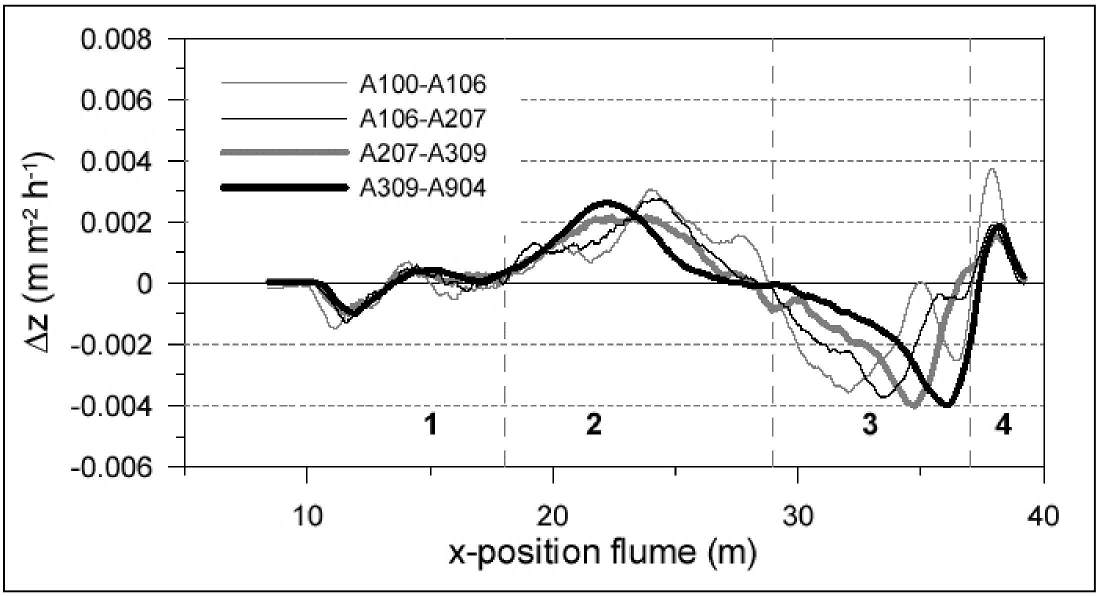


Figure B – 2; Example of running averages of the changes in bed height for the succesive profiles in Figure B - 1

# Appendix B-b; *Profile evolution Serie A*

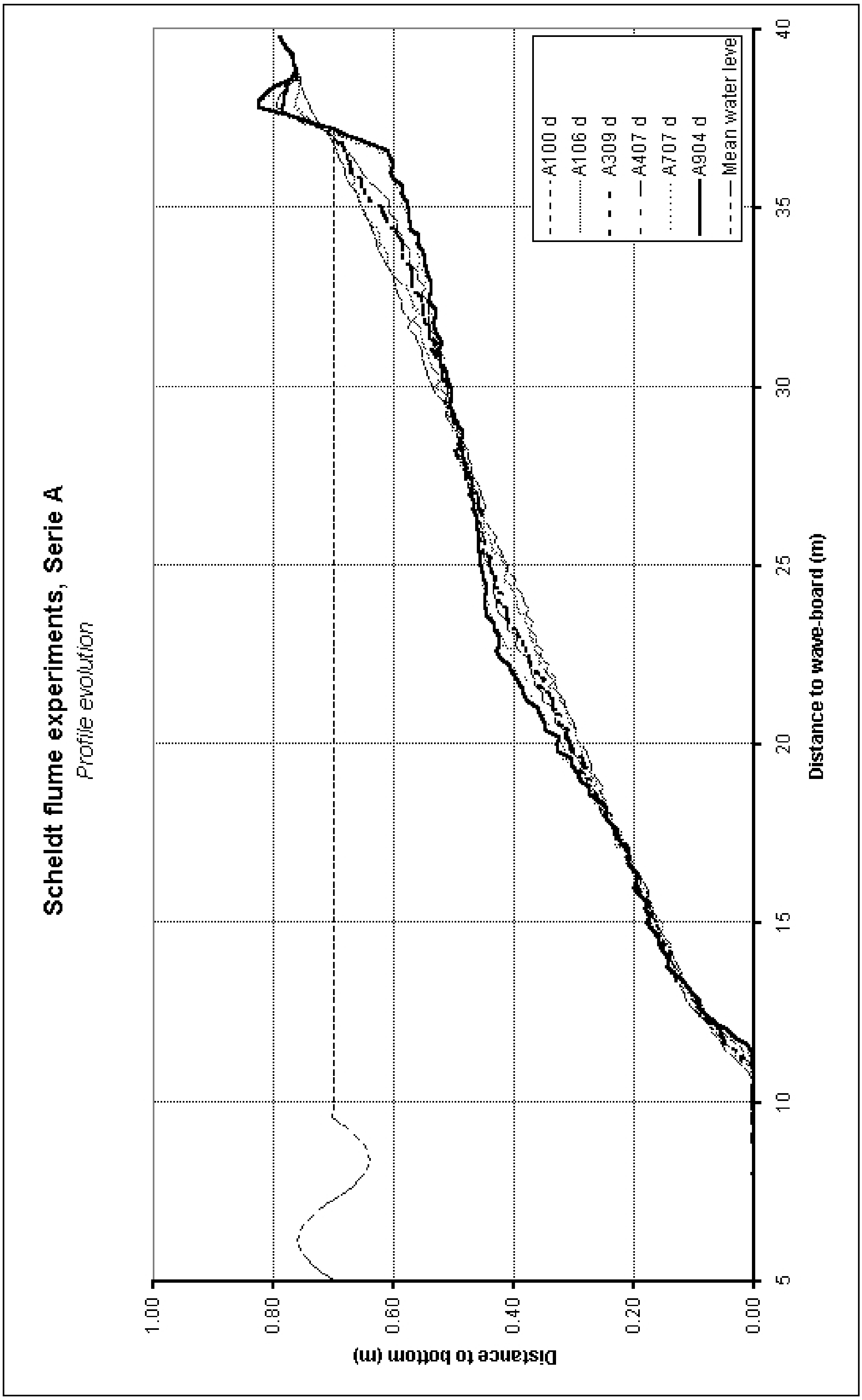


Figure B – 3; Bed height measurements for different profiles of Series A

# Appendix B-c; *Sediment transport rates Serie A*

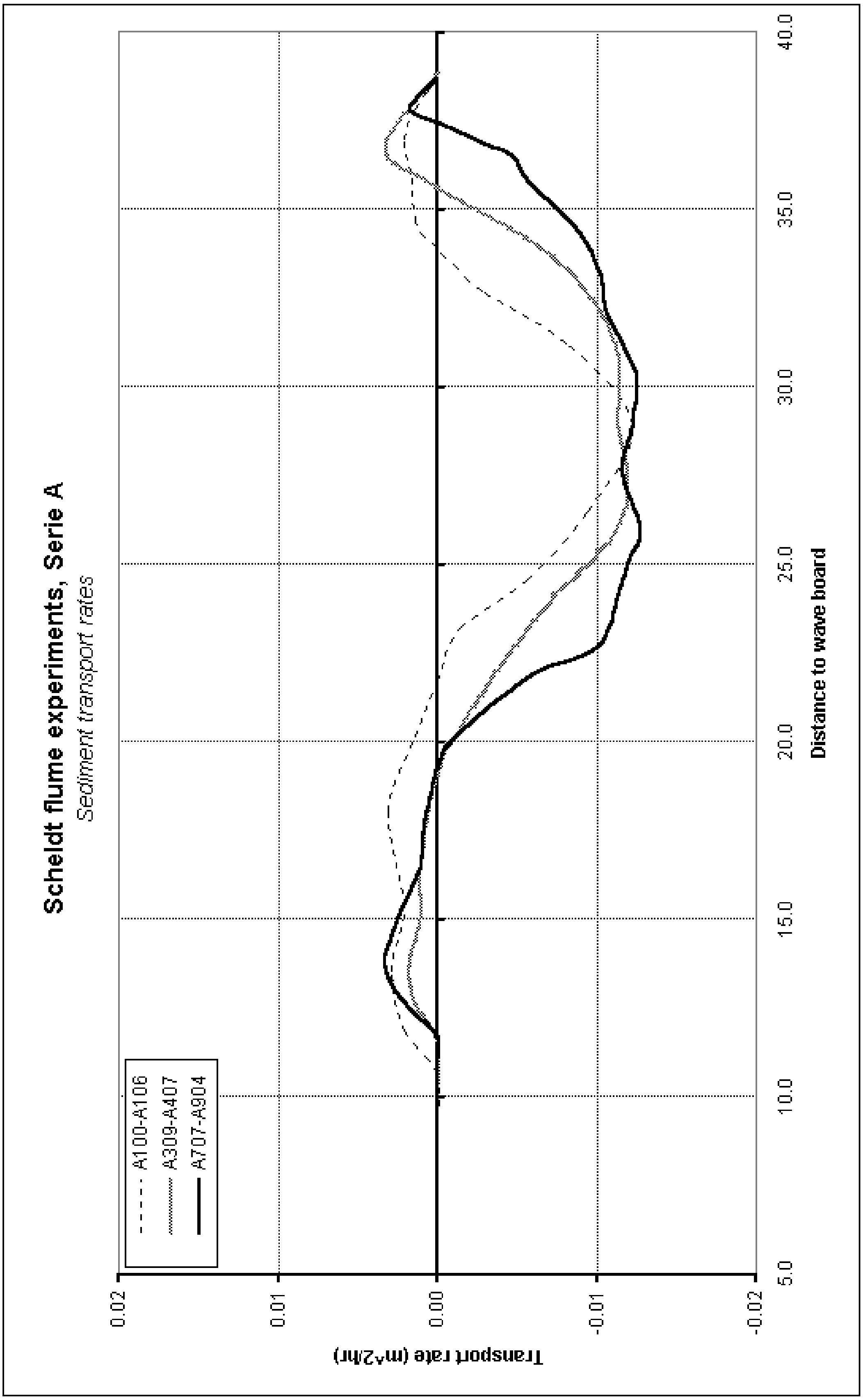


Figure B – 4; Sediment transport rates for successive profiles for Series A

# Appendix B-d; *Profile evolution Serie B*

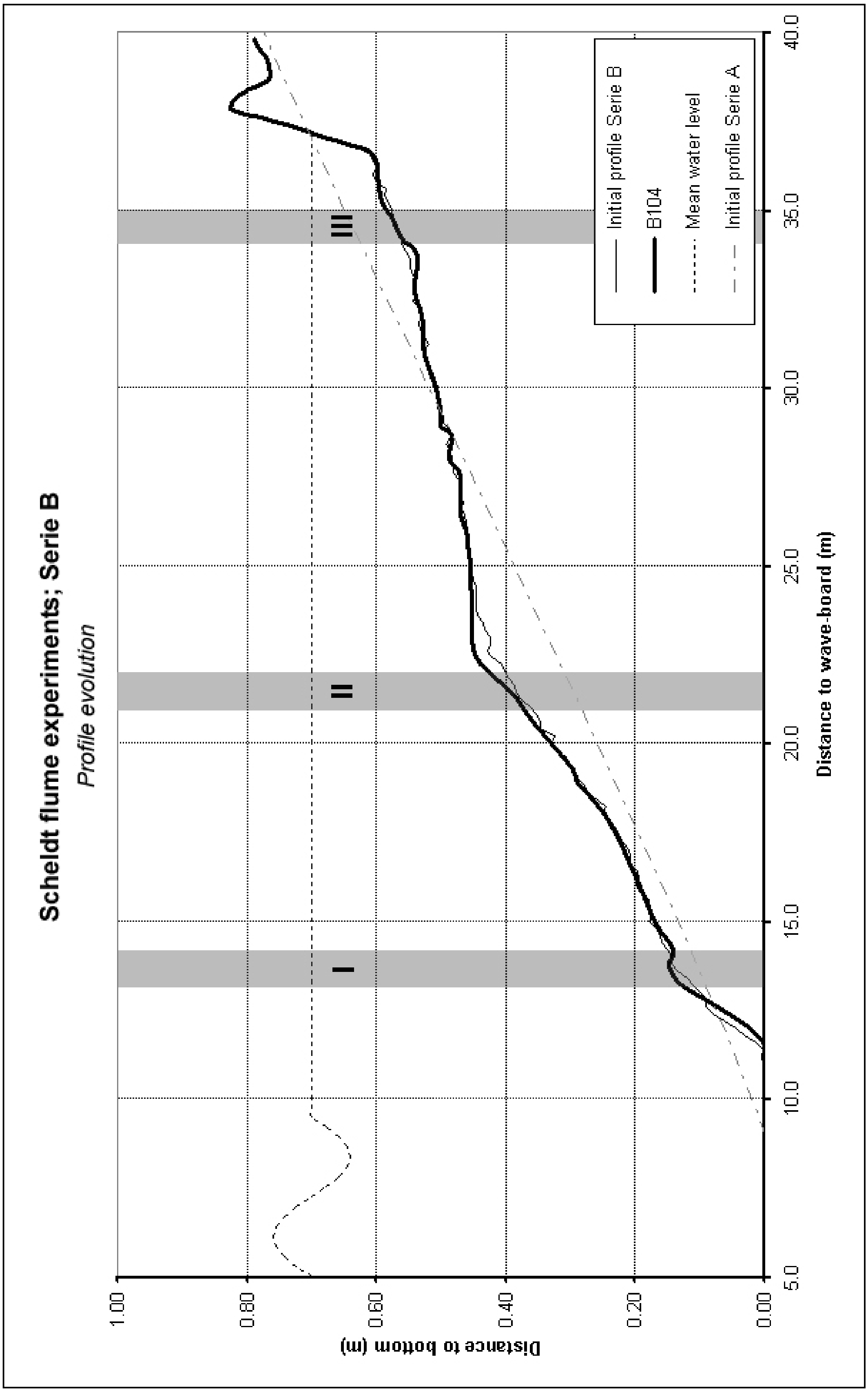


Figure B – 5; Bed height measurements for different profiles of Series B

# Appendix B-e; *Sediment transport rates Serie B*

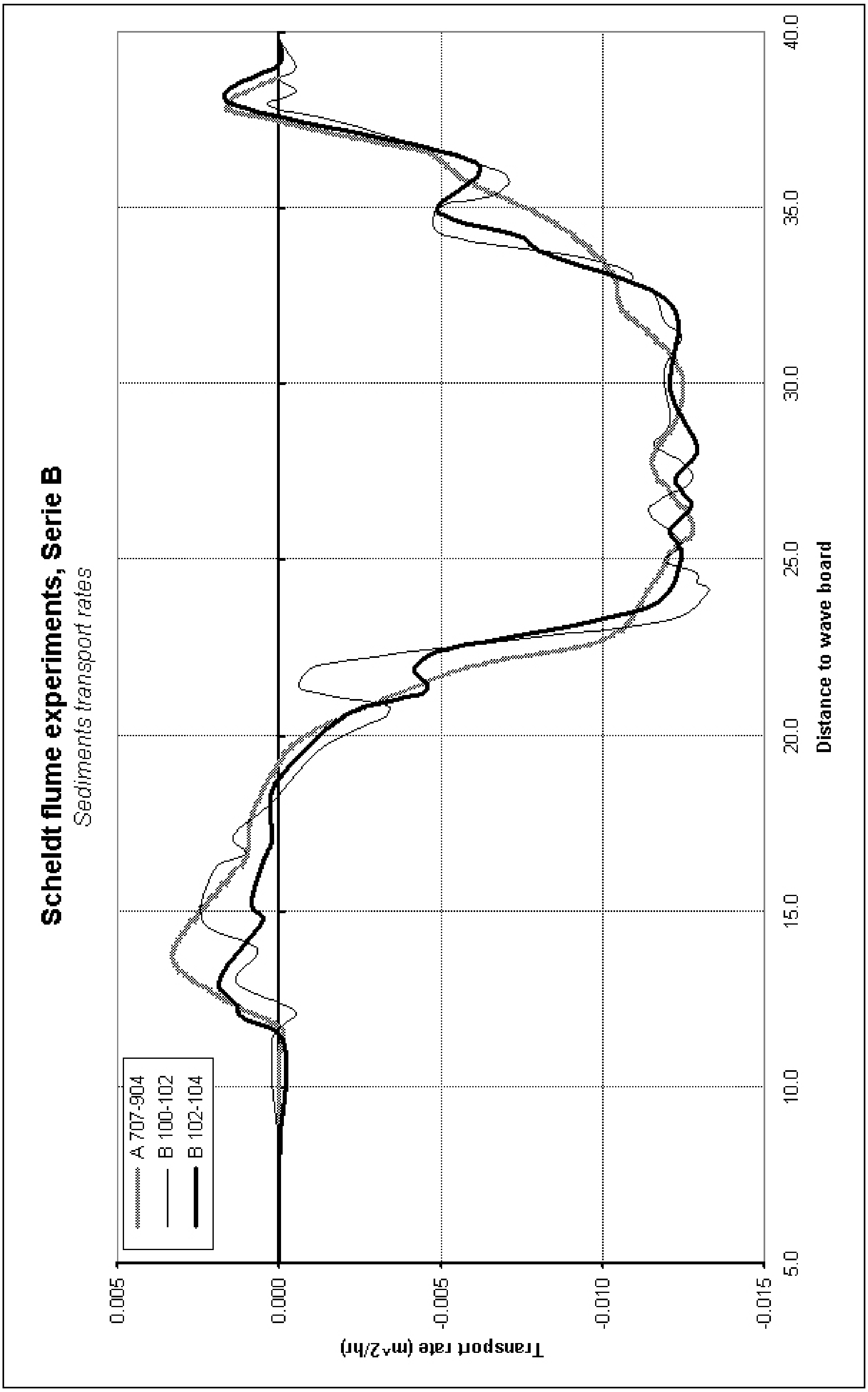


Figure B – 6; Sediment transport rates for successive profiles for Series B

# Appendix B-f; *Profile evolution Serie C*

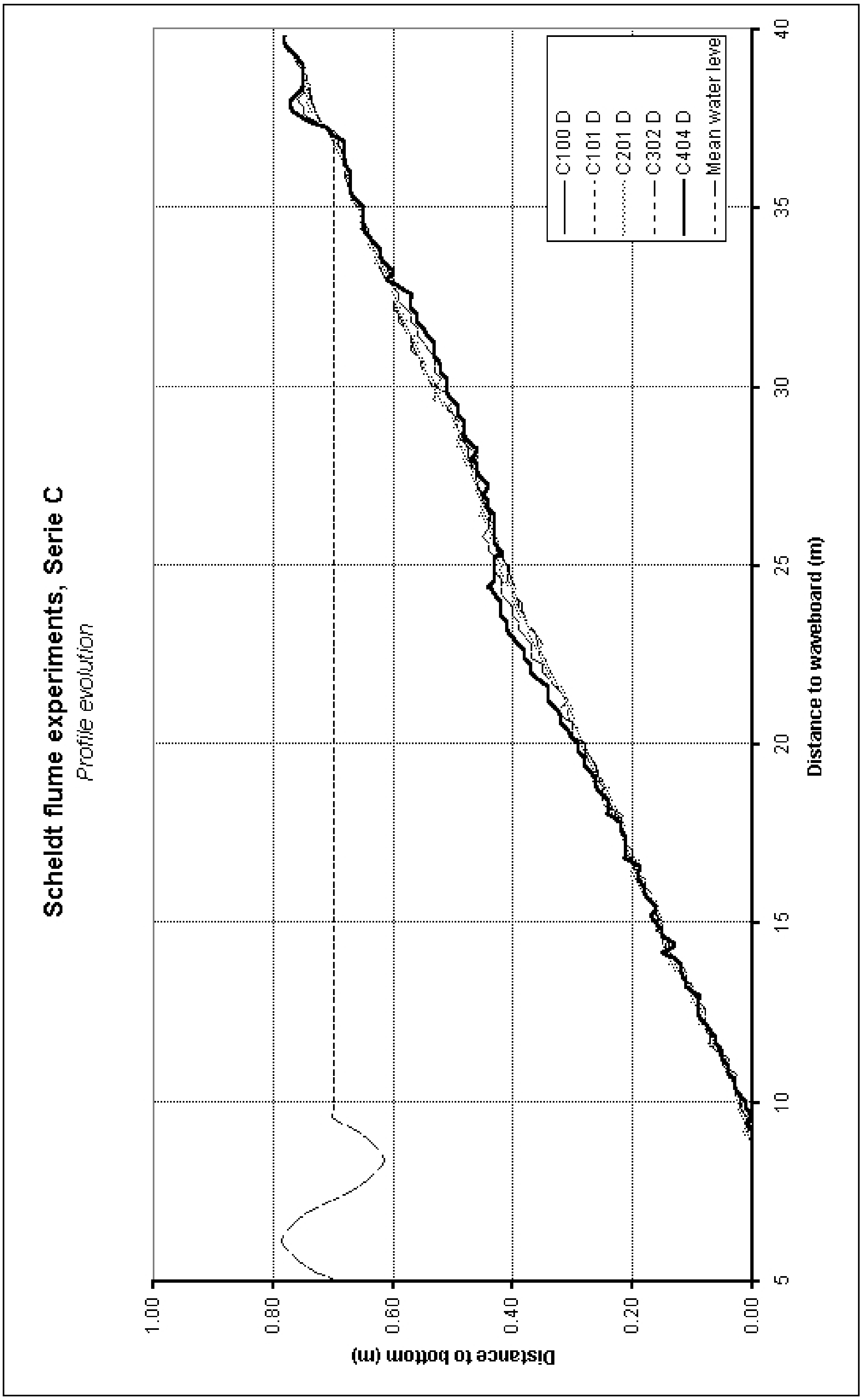


Figure B – 7; Bed height measurements for different profiles of Series C

# Appendix B-g; *Sediment transport rates Serie C*

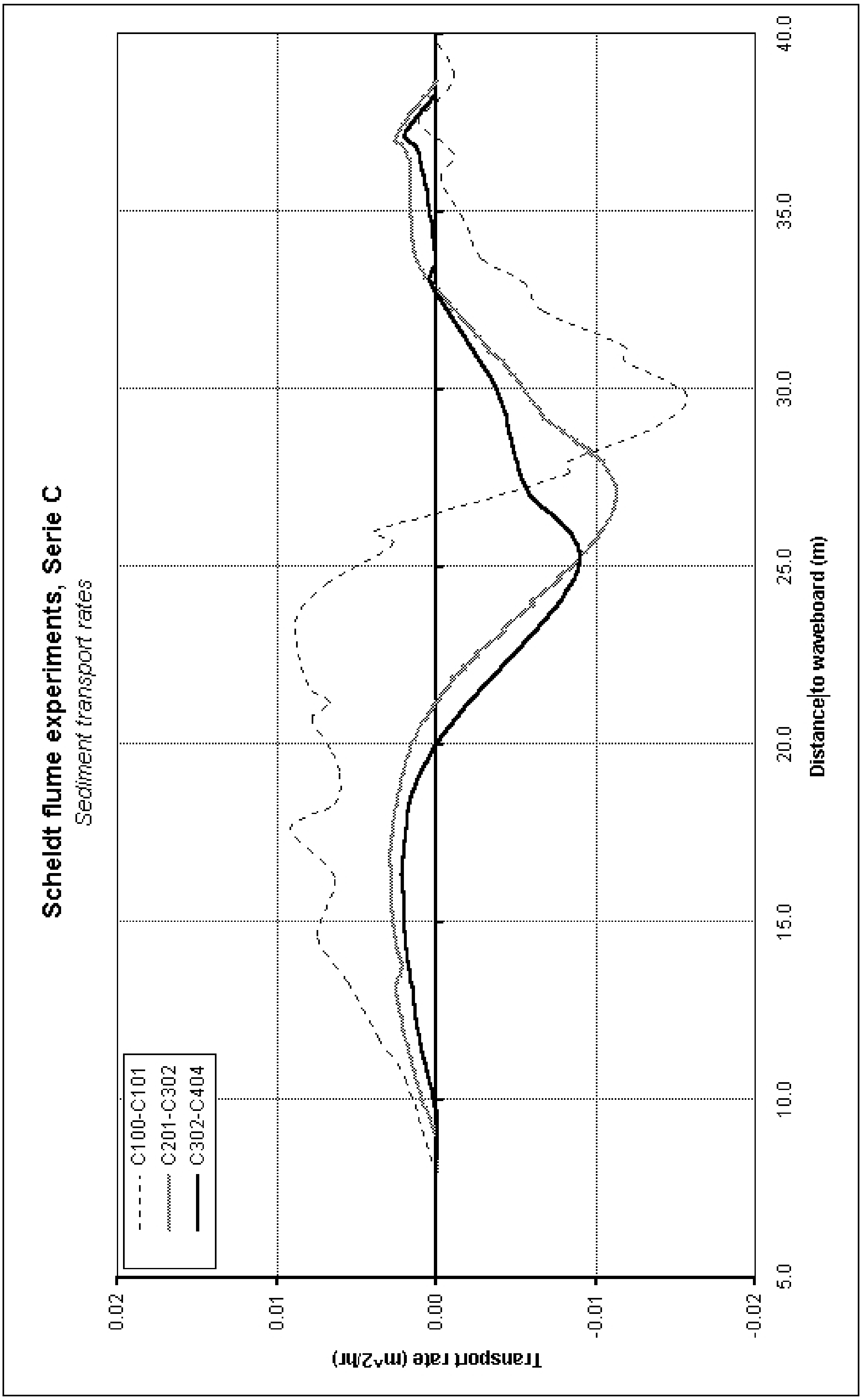
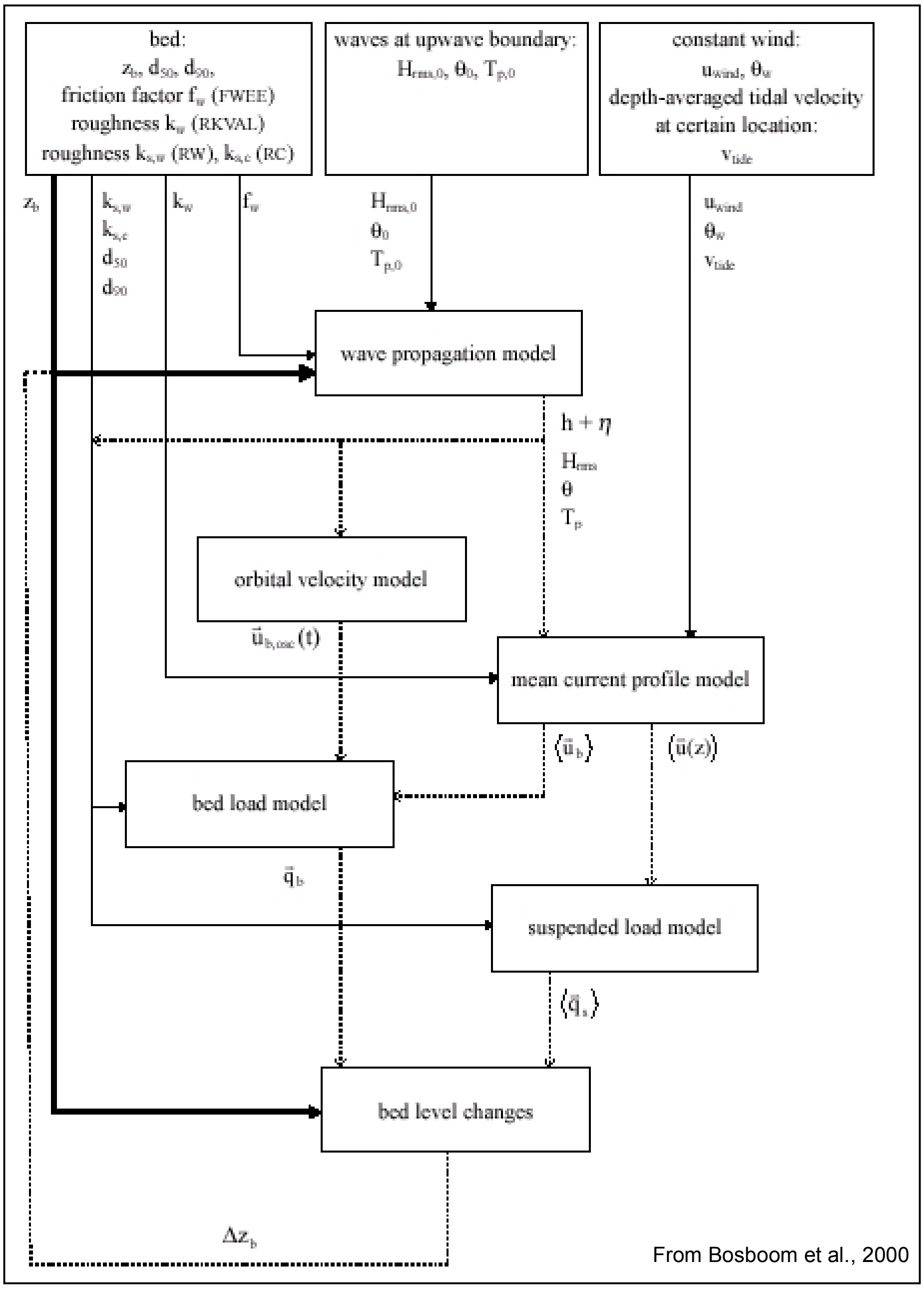


Figure B – 8; Mean transport rates for successive time-intervals of Serie C

# Appendix C; Unibest-TC sub-model overview



From Bosboom et al., 2000

# Appendix D; Unibest-TC sensitivity to user-defined conditions and parameters

# Appendix D-a; *Grain size distribution vs transport and profile evolution*

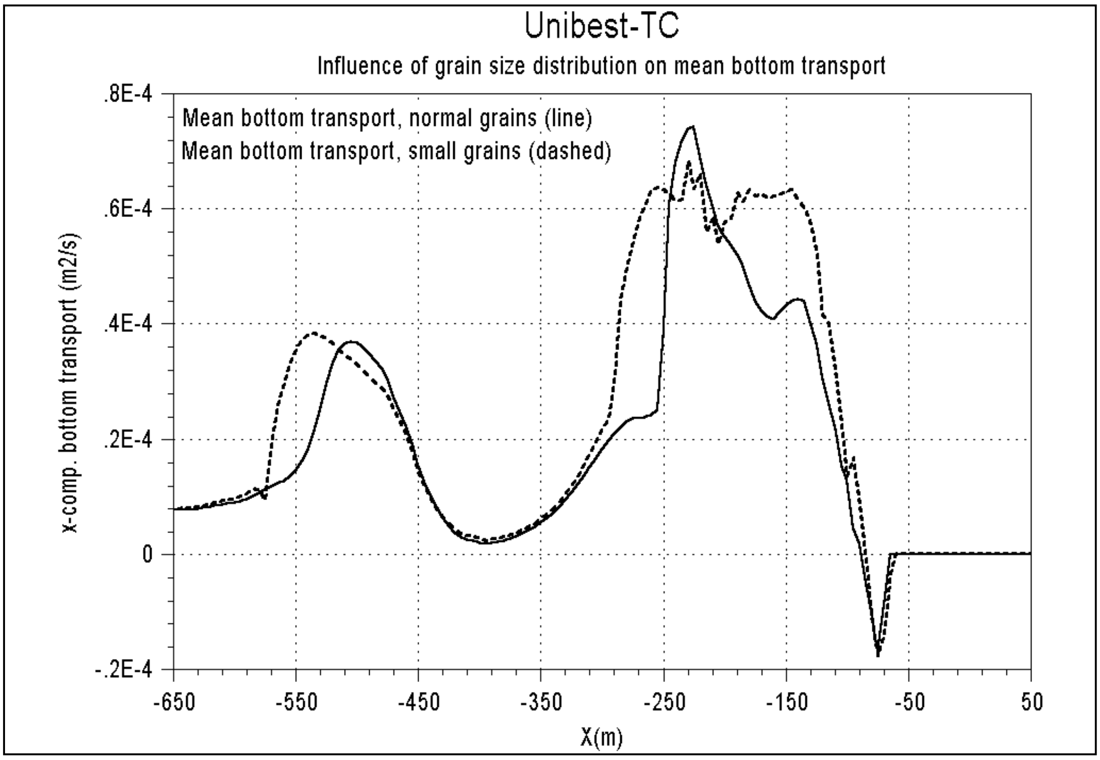


Figure D – 1; Mean bottom transports

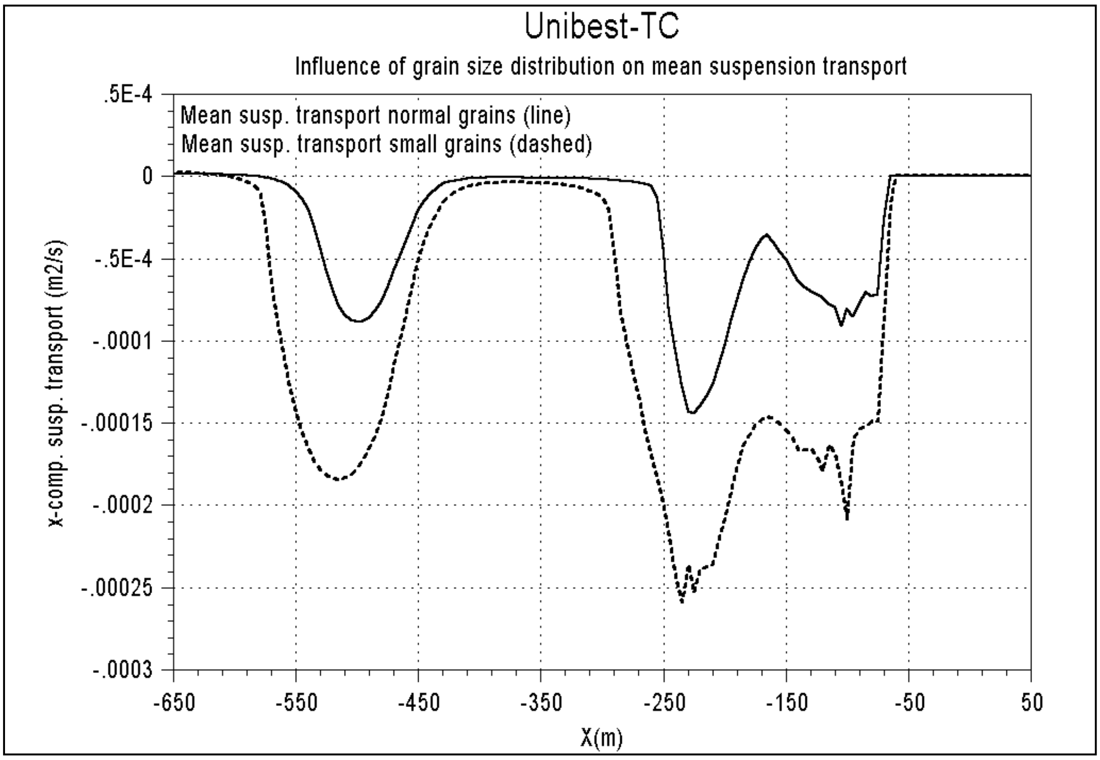


Figure D – 2; Mean suspended transports

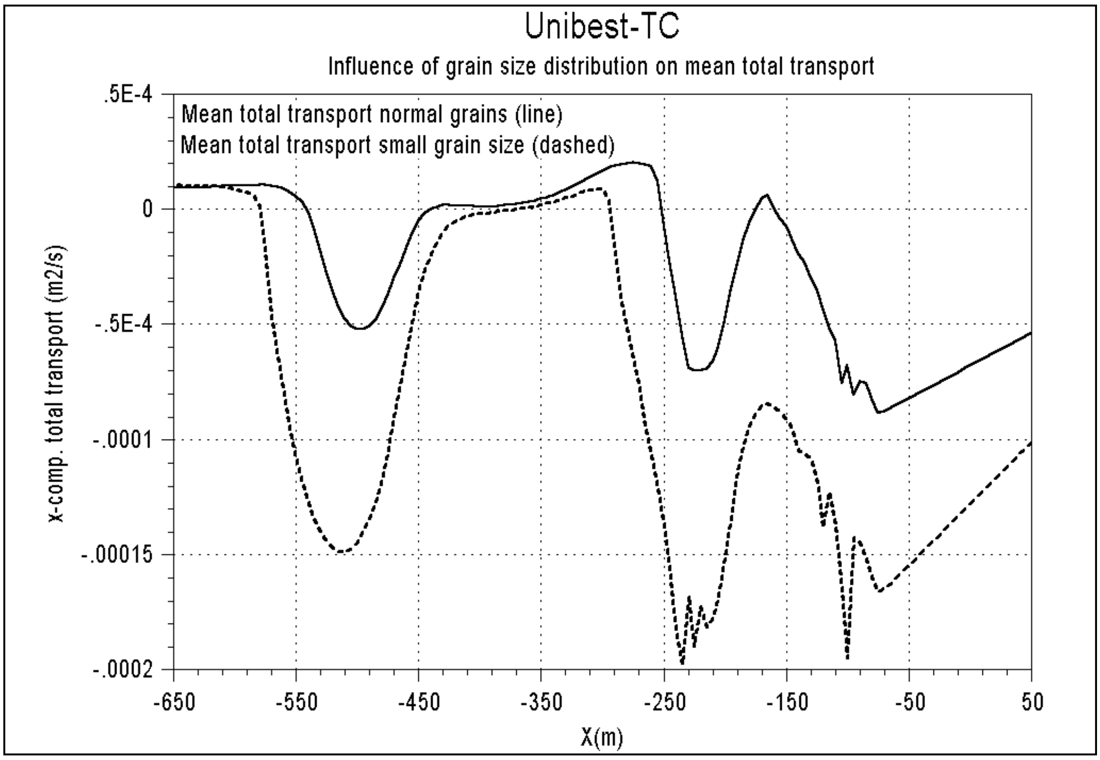


Figure D – 3; Mean total transports

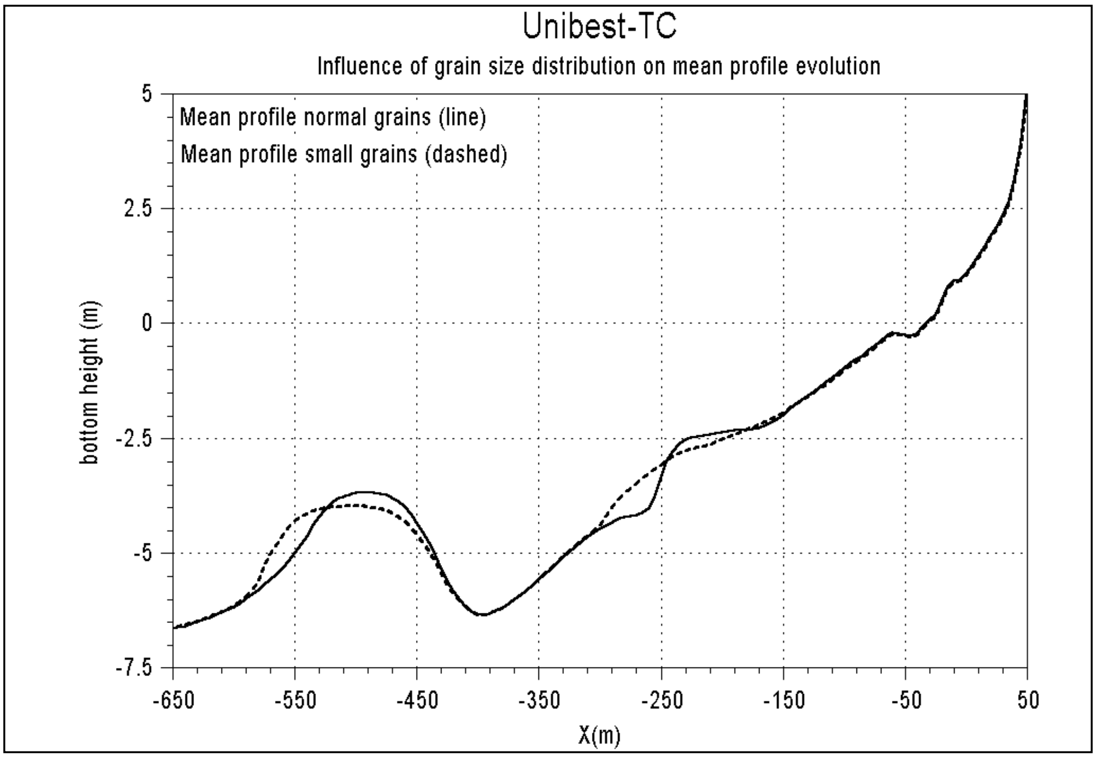


Figure D – 4; Mean profile development

# Appendix D-b; *Impact of geometric set-up on beach face profile evolution*

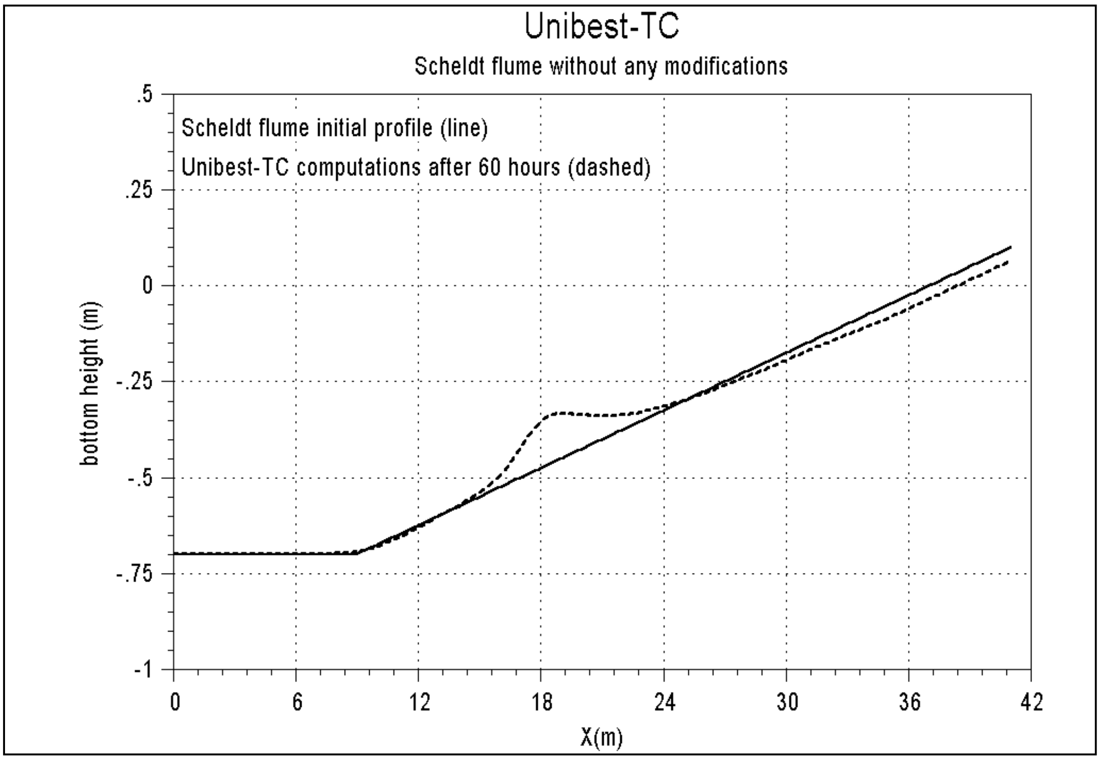


Figure D – 5; Profile evolution with horizontal extrapolation

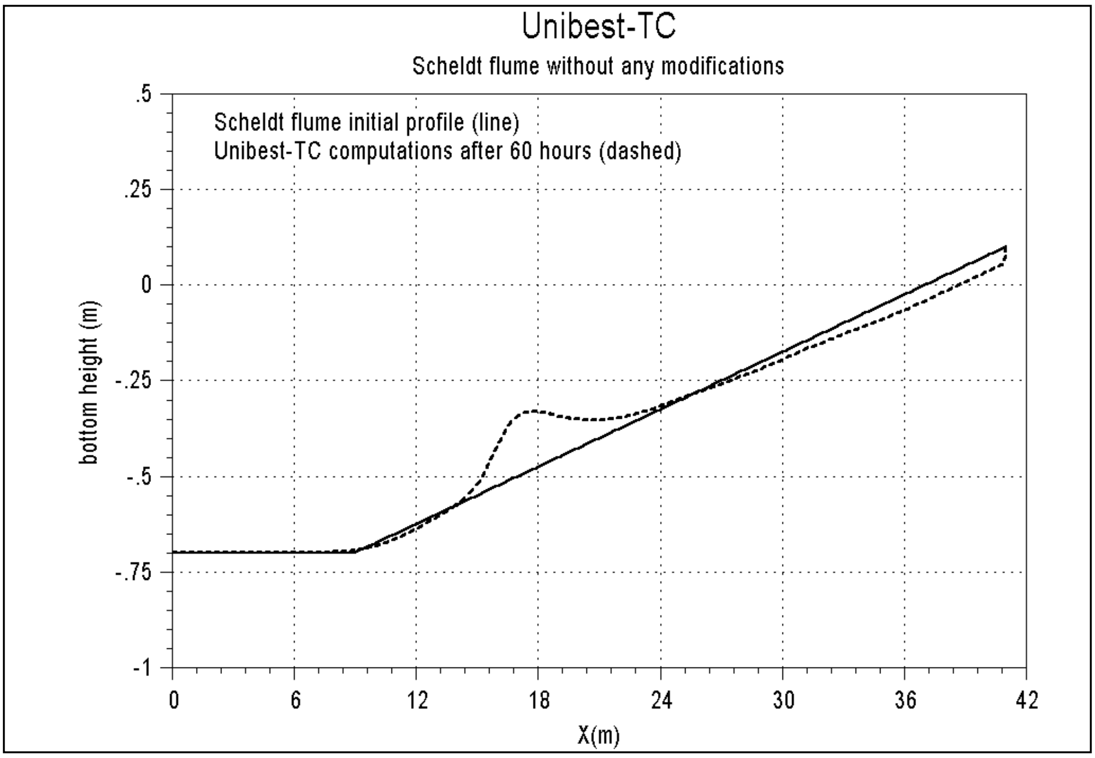


Figure D –6; Profile evolution with vertical extrapolation

## Appendix D-c; *Impact of RKVAL, RC and RW on transport processes*

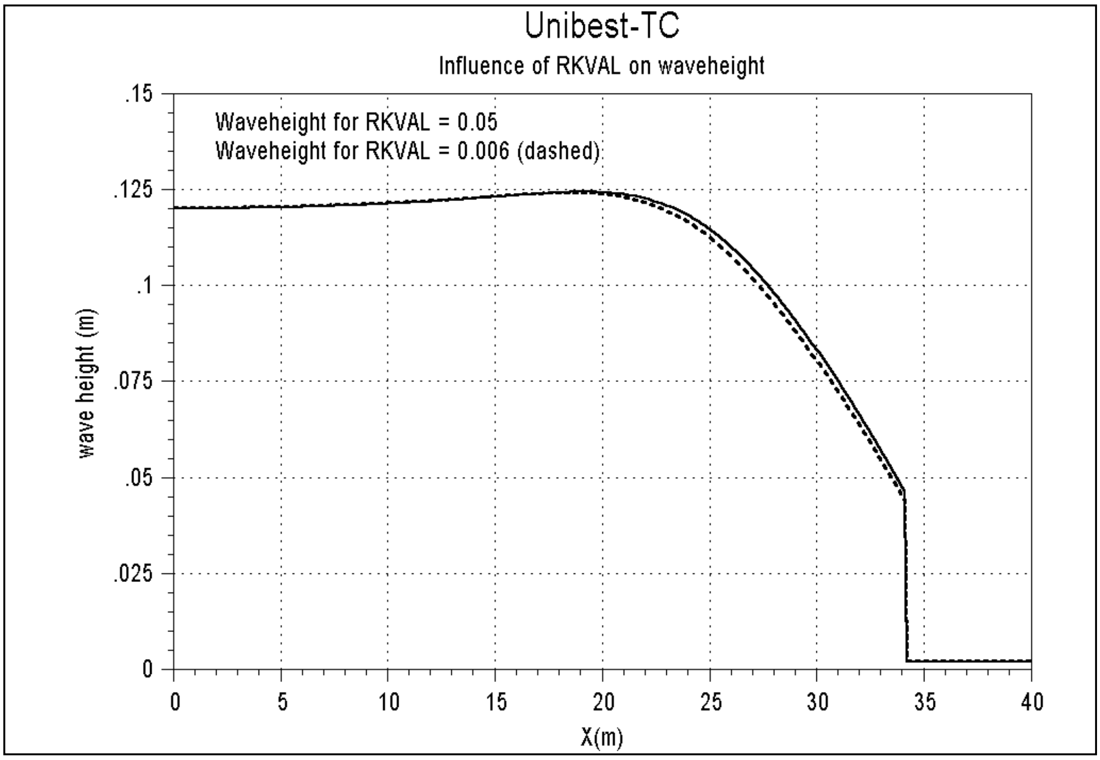


Figure D – 7; Wave height evolution on the profile

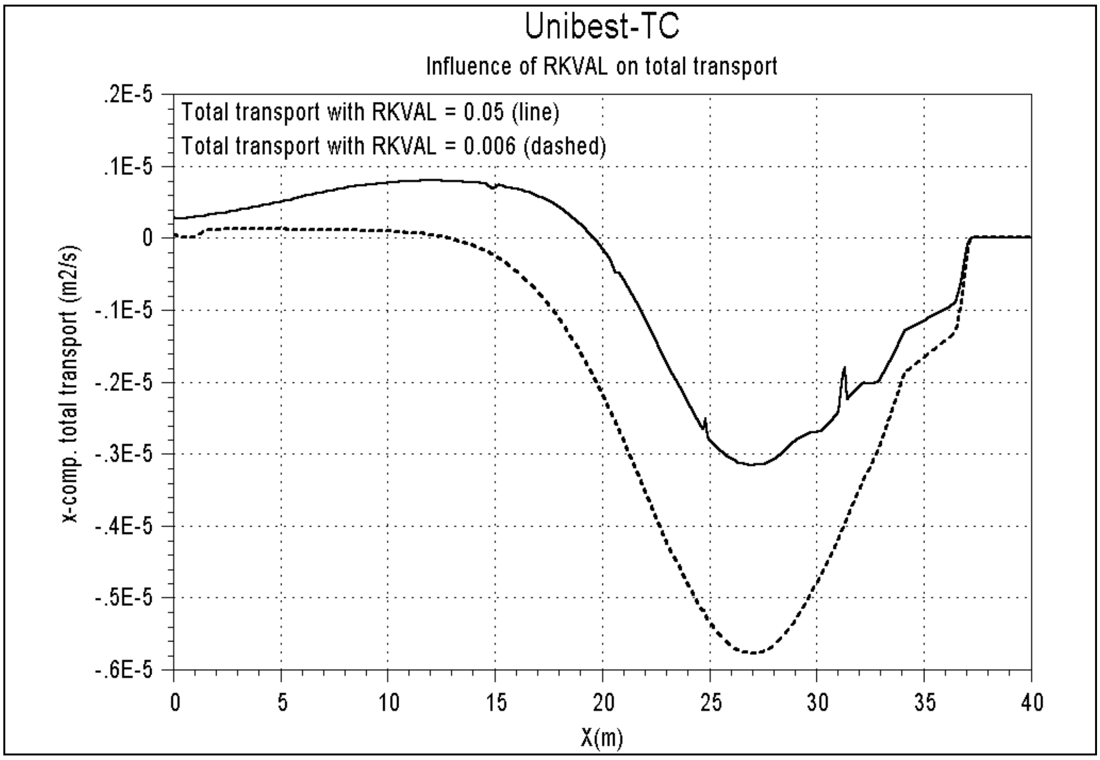


Figure D –8; Influence of RKVAL on the total sediment transport

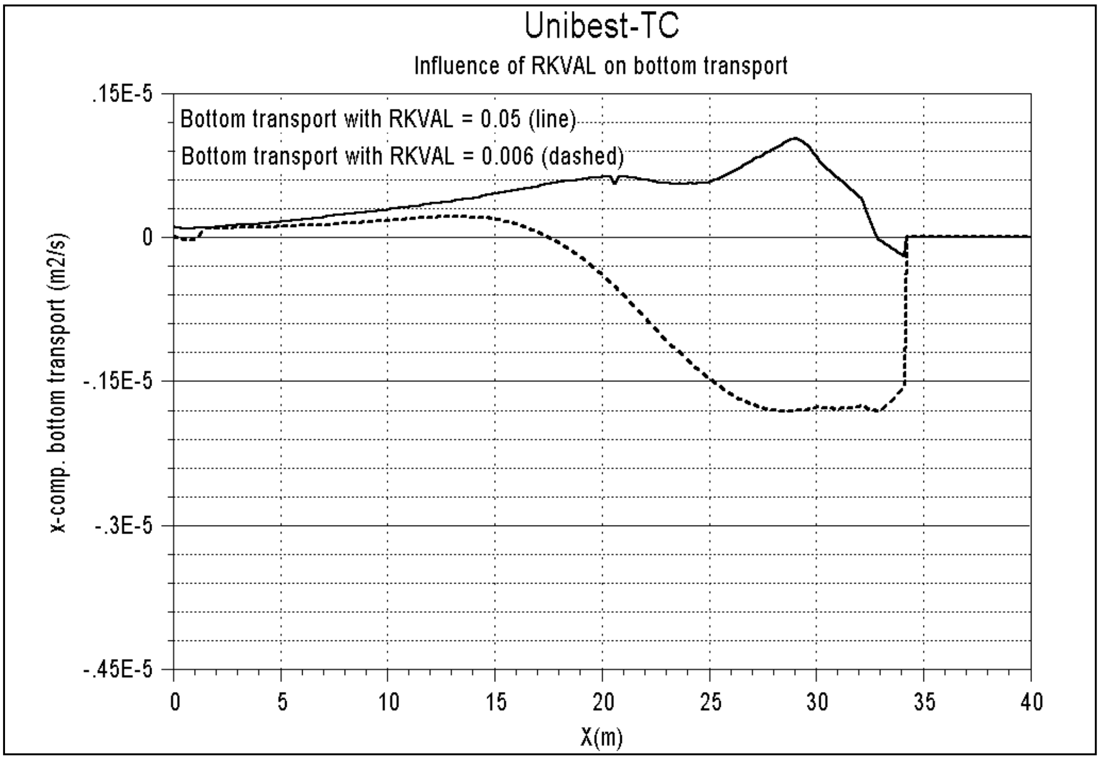


Figure D – 9; Influence of RKVAL on the bottom sediment transport

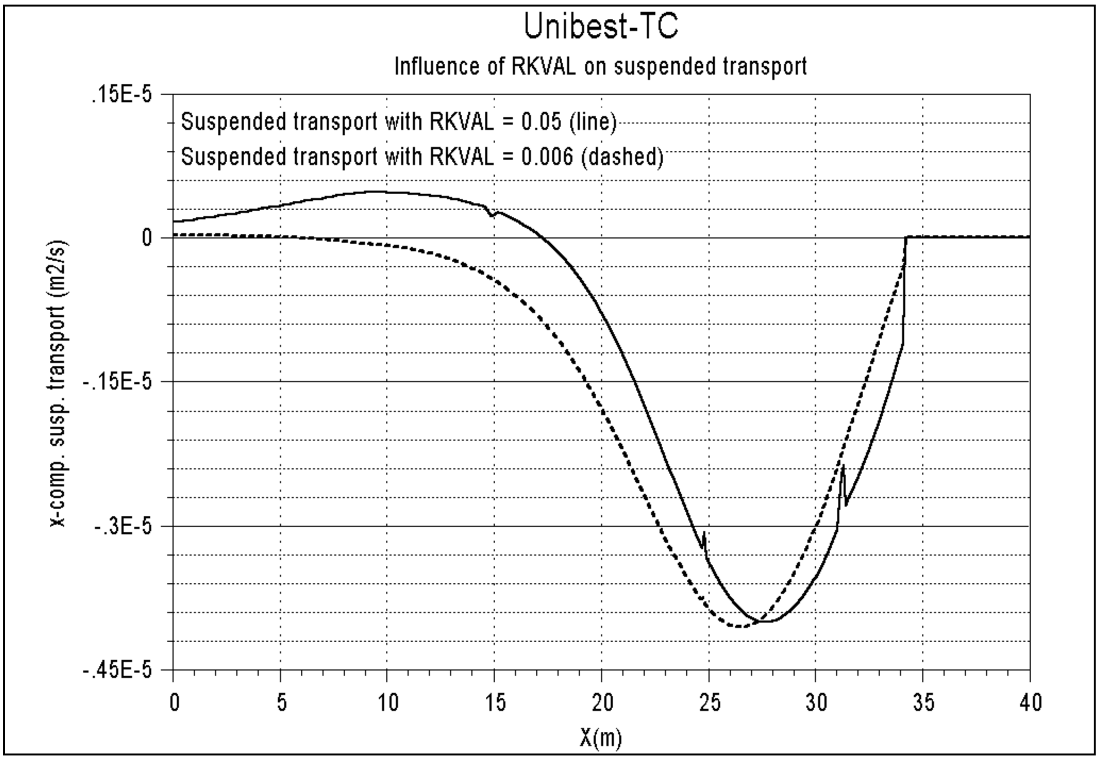


Figure D – 10; Influence of RKVAL on the suspended sediment transport

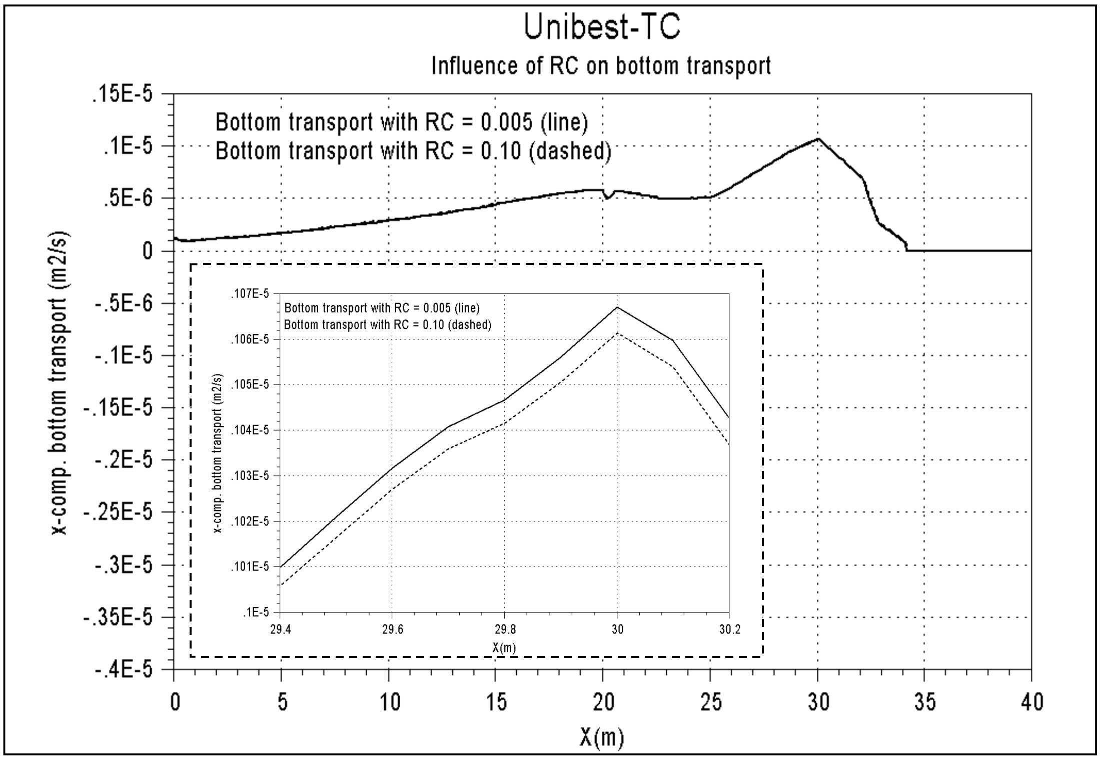


Figure D – 11; Influence of RC on the bottom transport with detail-window

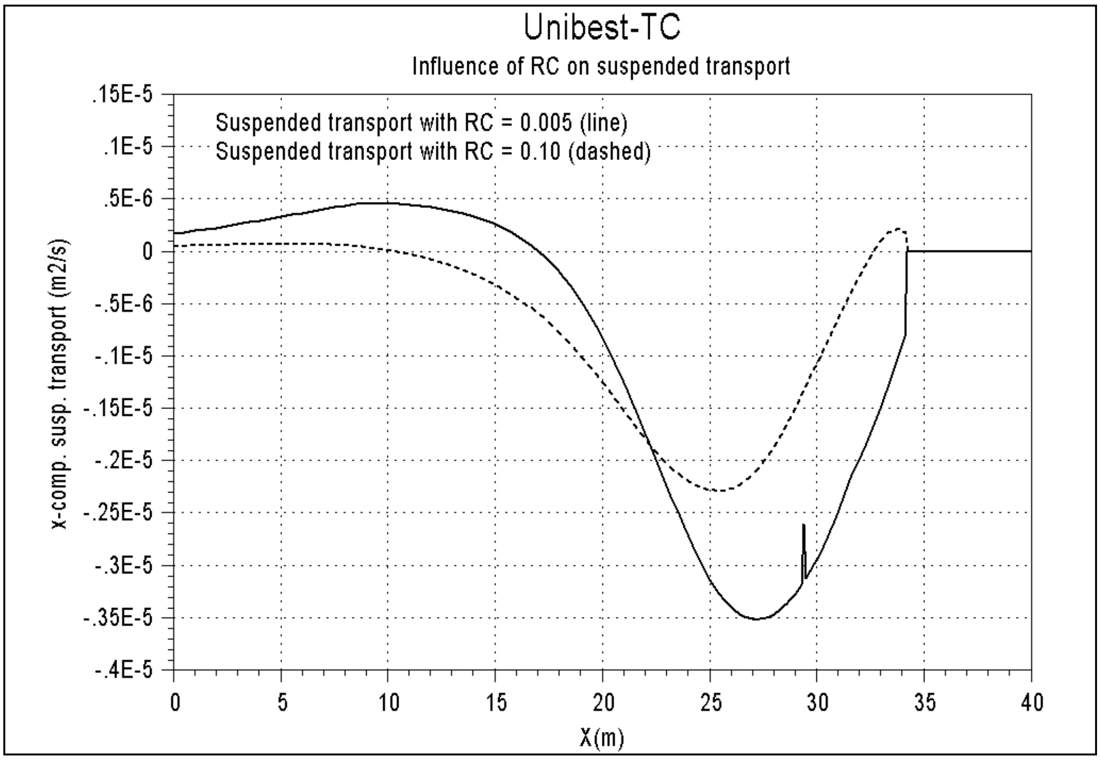


Figure D –12; Influence of RC on the suspended sediment transport

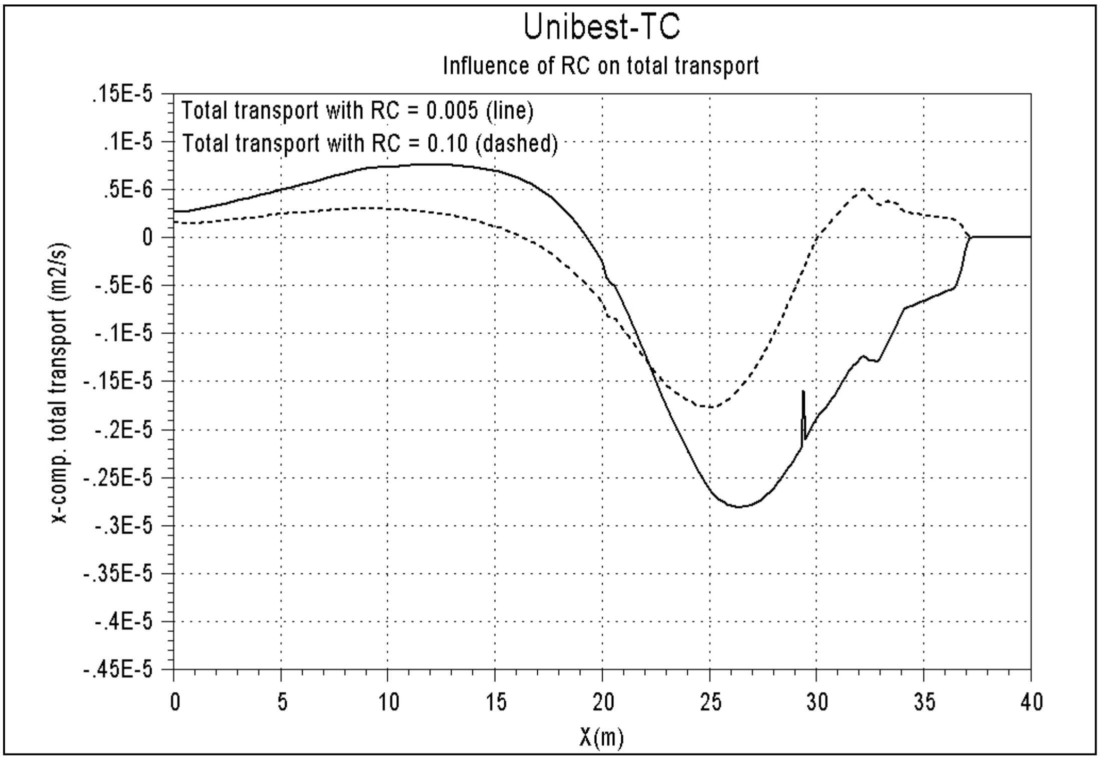


Figure D – 13; Influence of RC on the total sediment transport

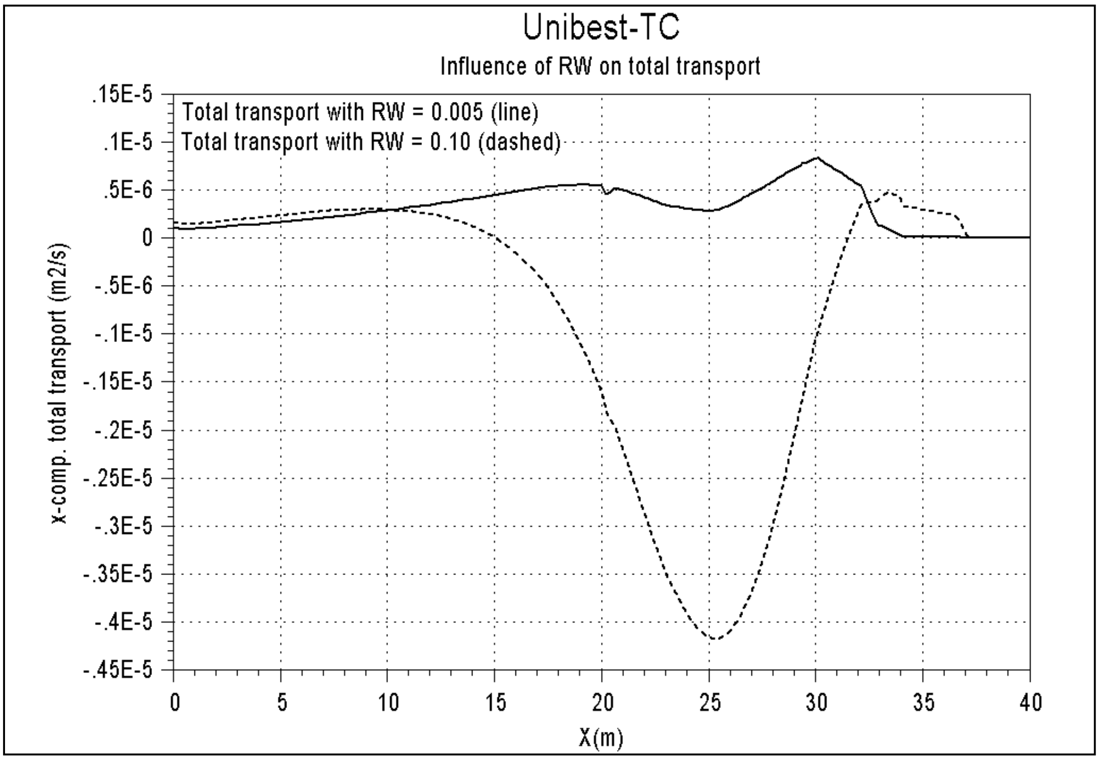


Figure D –14; Influence of RW on the total sediment transport

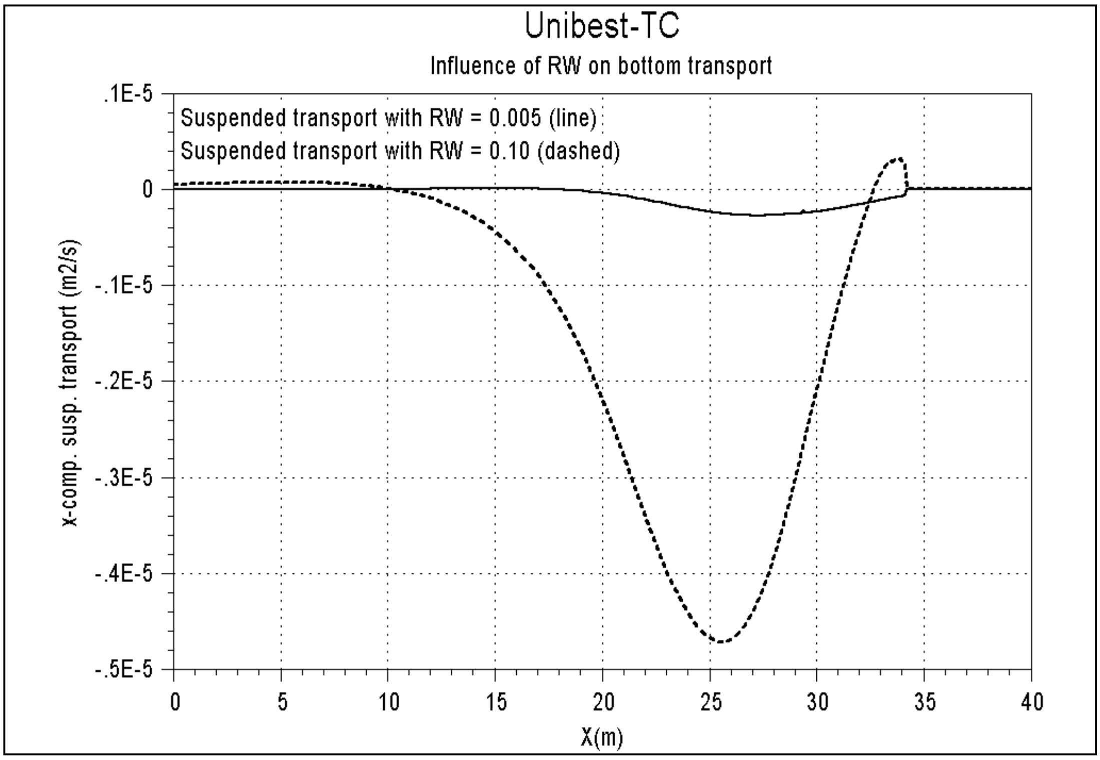


Figure D – 15; Influence of RW on the suspended sediment transport

# Appendix D-d; *Comparison between heavy minerals and hydr. equivalent quartz sediment*

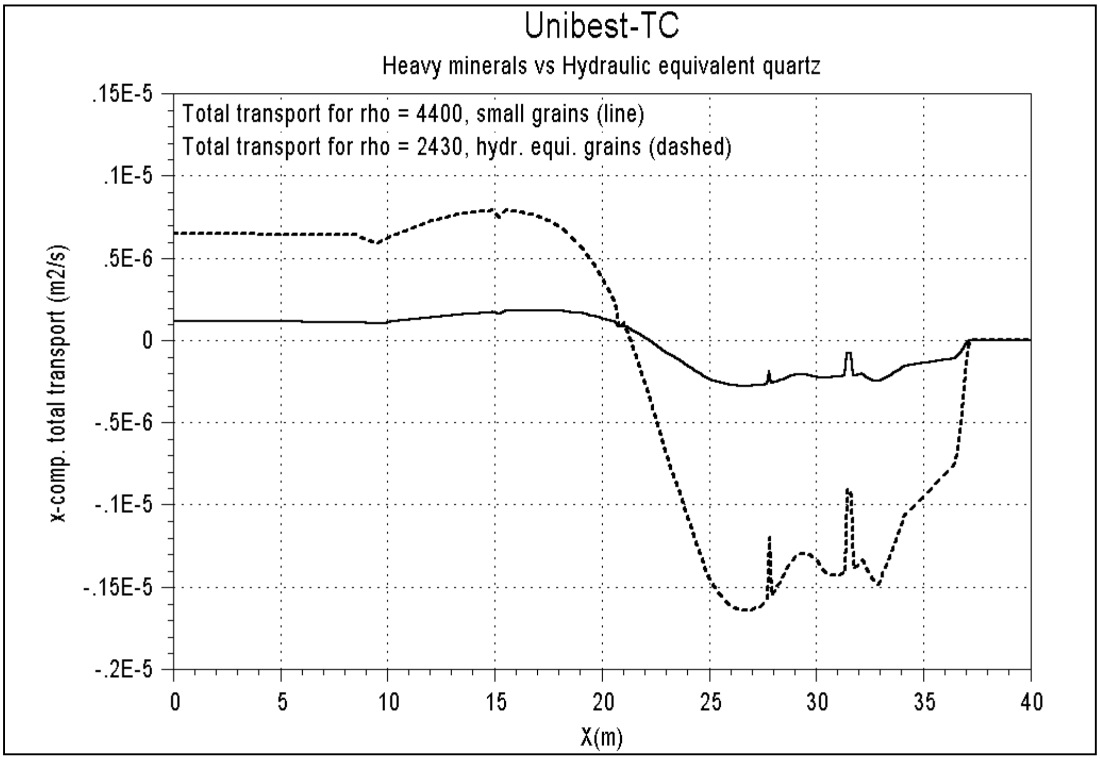


Figure D – 16; Differences between total transport figures

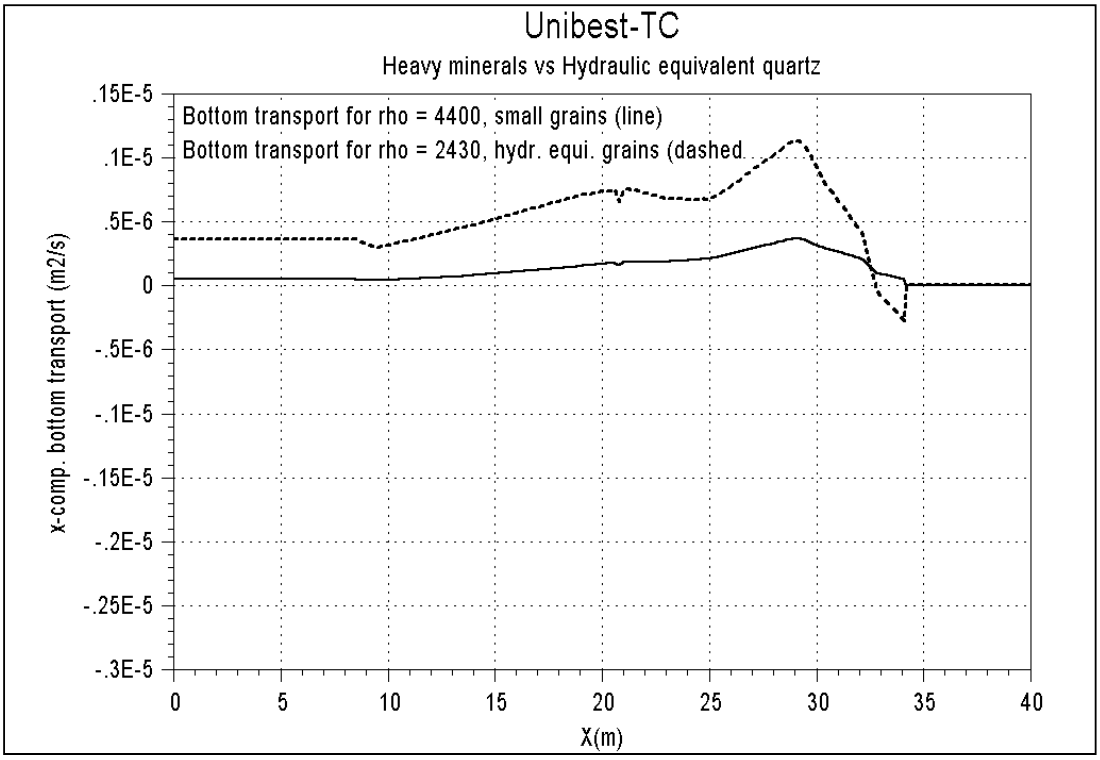


Figure D – 17; Differences between bottom transport figures

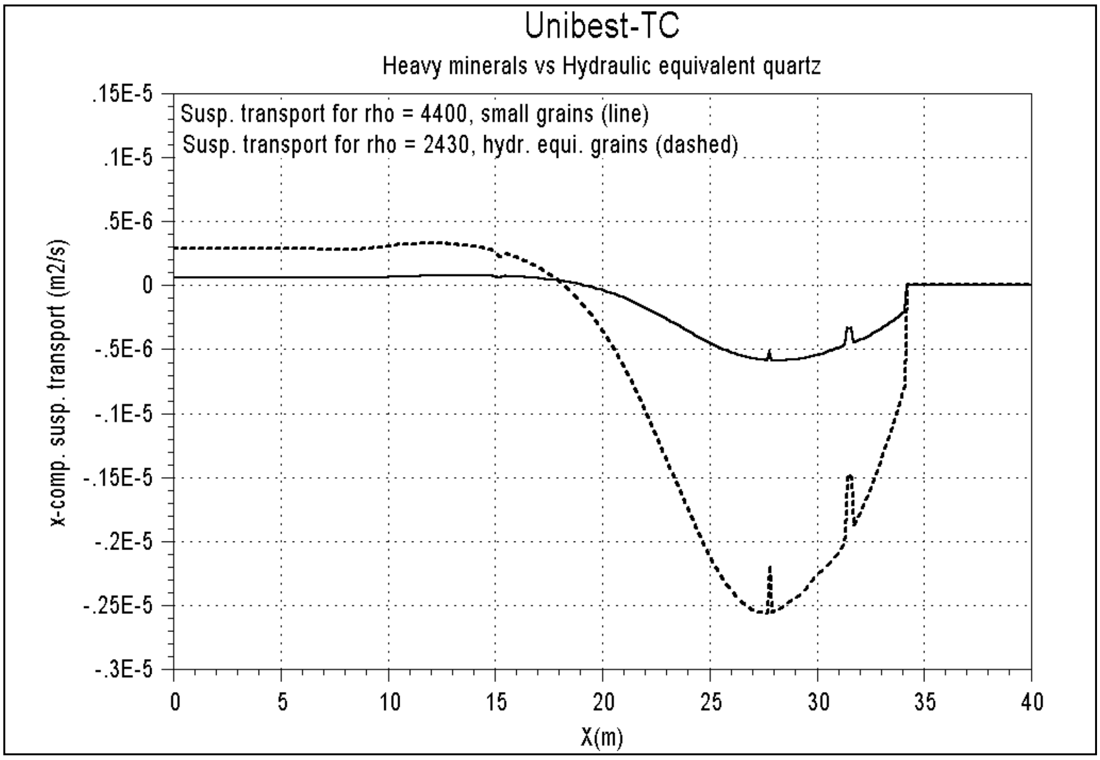


Figure D – 18; Differences between suspended transport figures

# Appendix E; Unibest-TC model results

Note: At some points in this appendix, the term “Heavy Mineral(s)” will be abbreviated to “H.M.”

# **Appendix E-a;** ***Results Unibest-TC simulations Serie A***

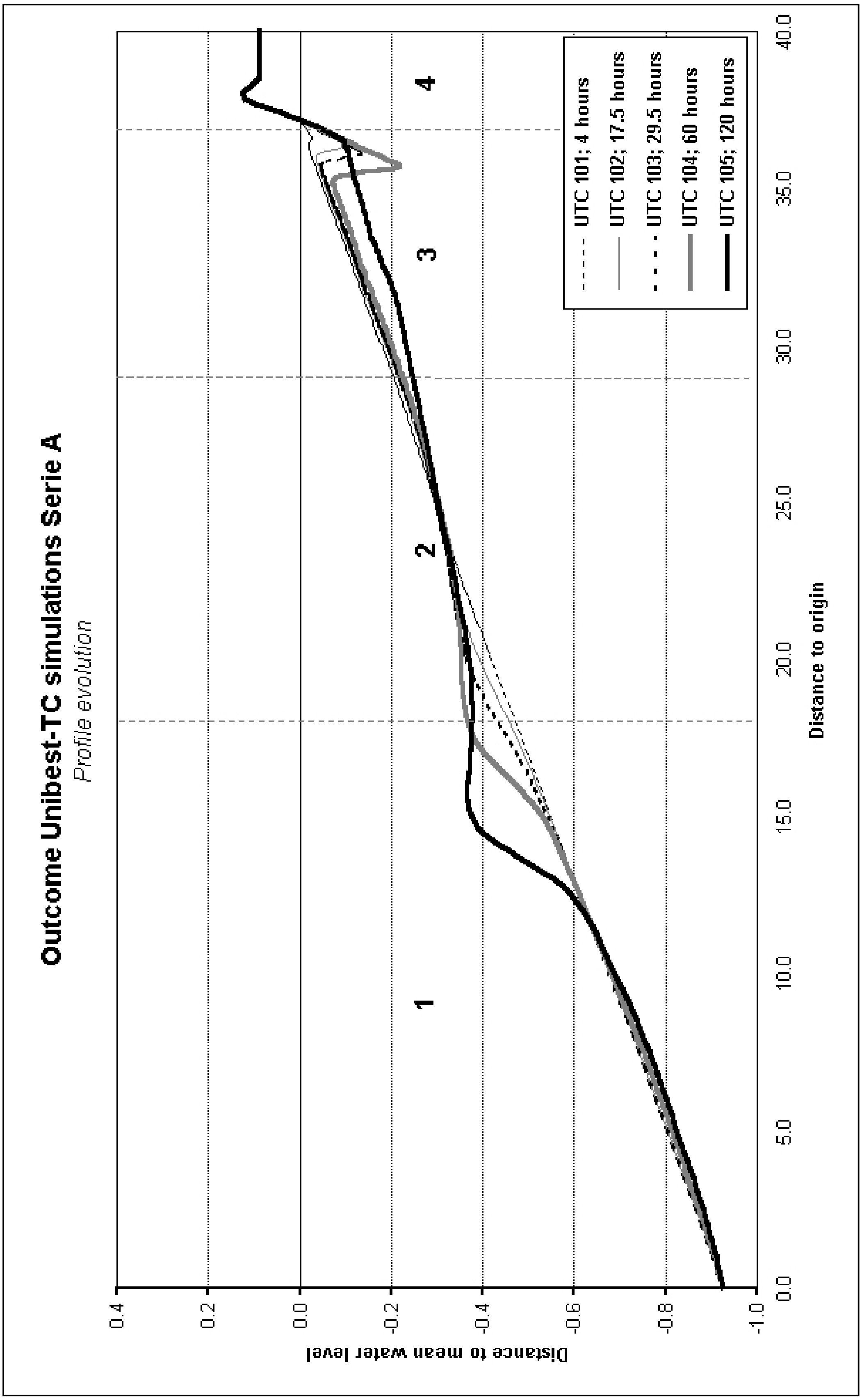


Figure E – 1; Profile evolution for successive time-intervals of Serie A

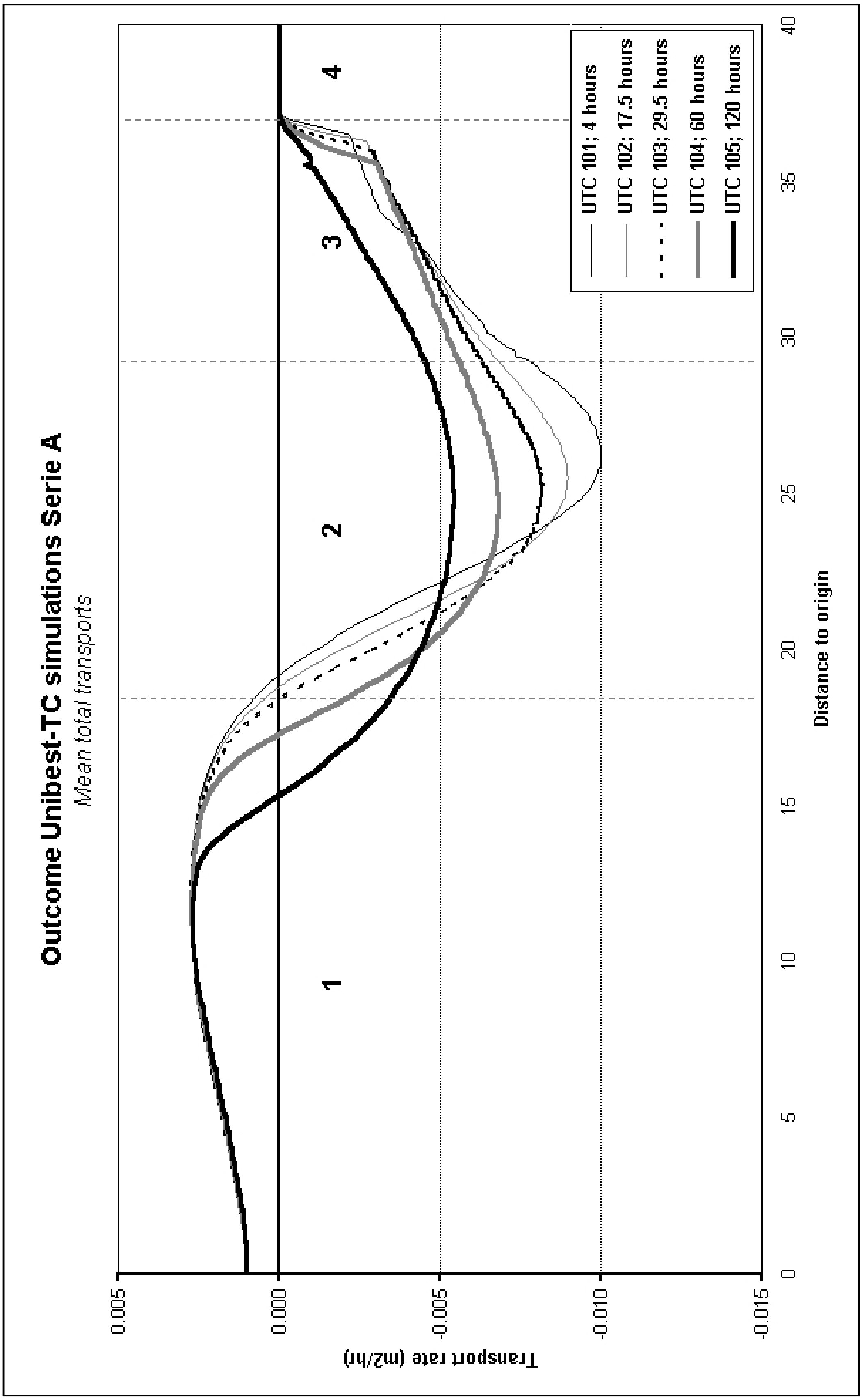


Figure E – 2; Mean transport rates for successive time-intervals of Serie A

# Appendix E-b; *Results Unibest-TC simulations Serie B*

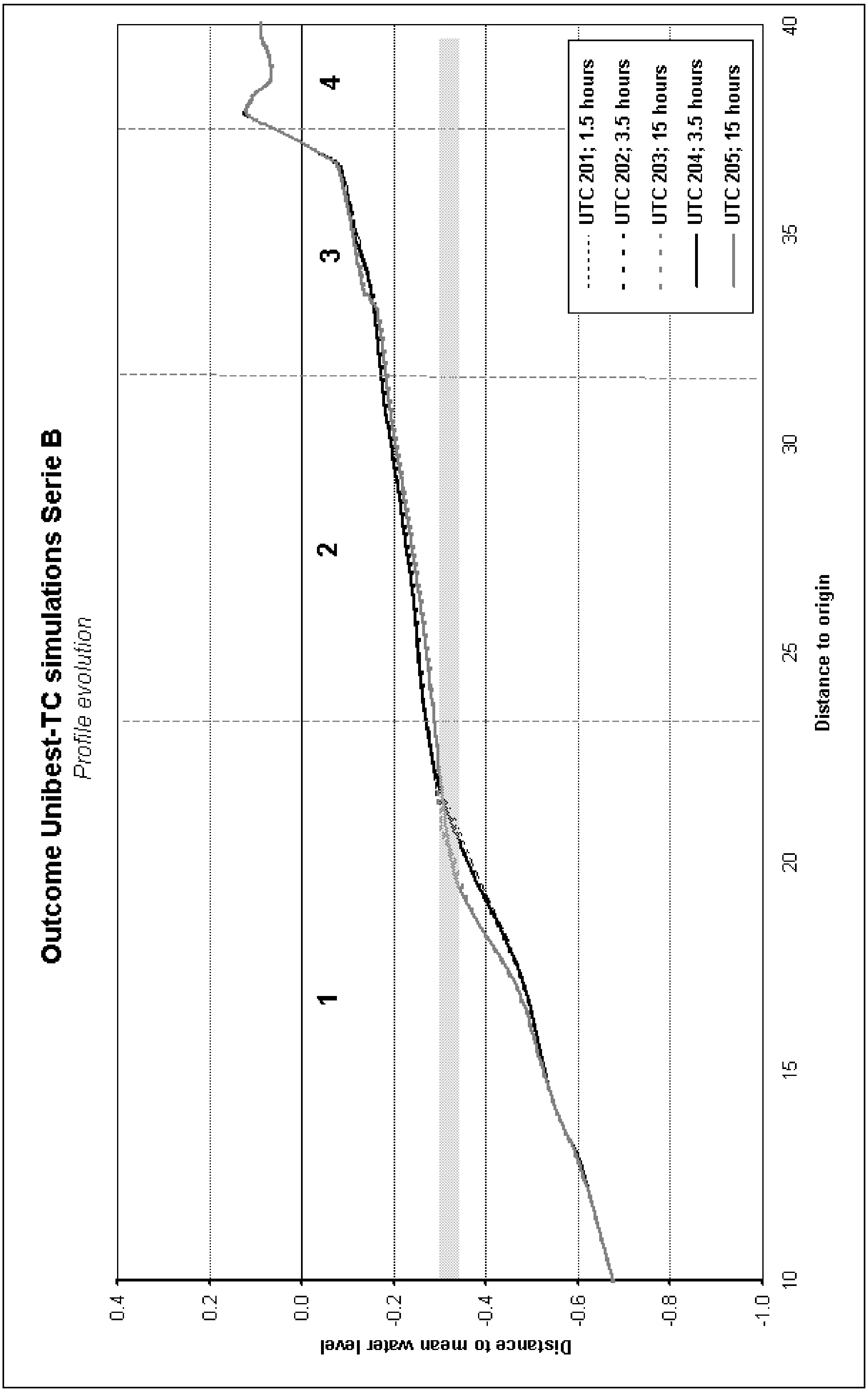


Figure E – 3; Profile evolution for successive time-intervals of Serie B

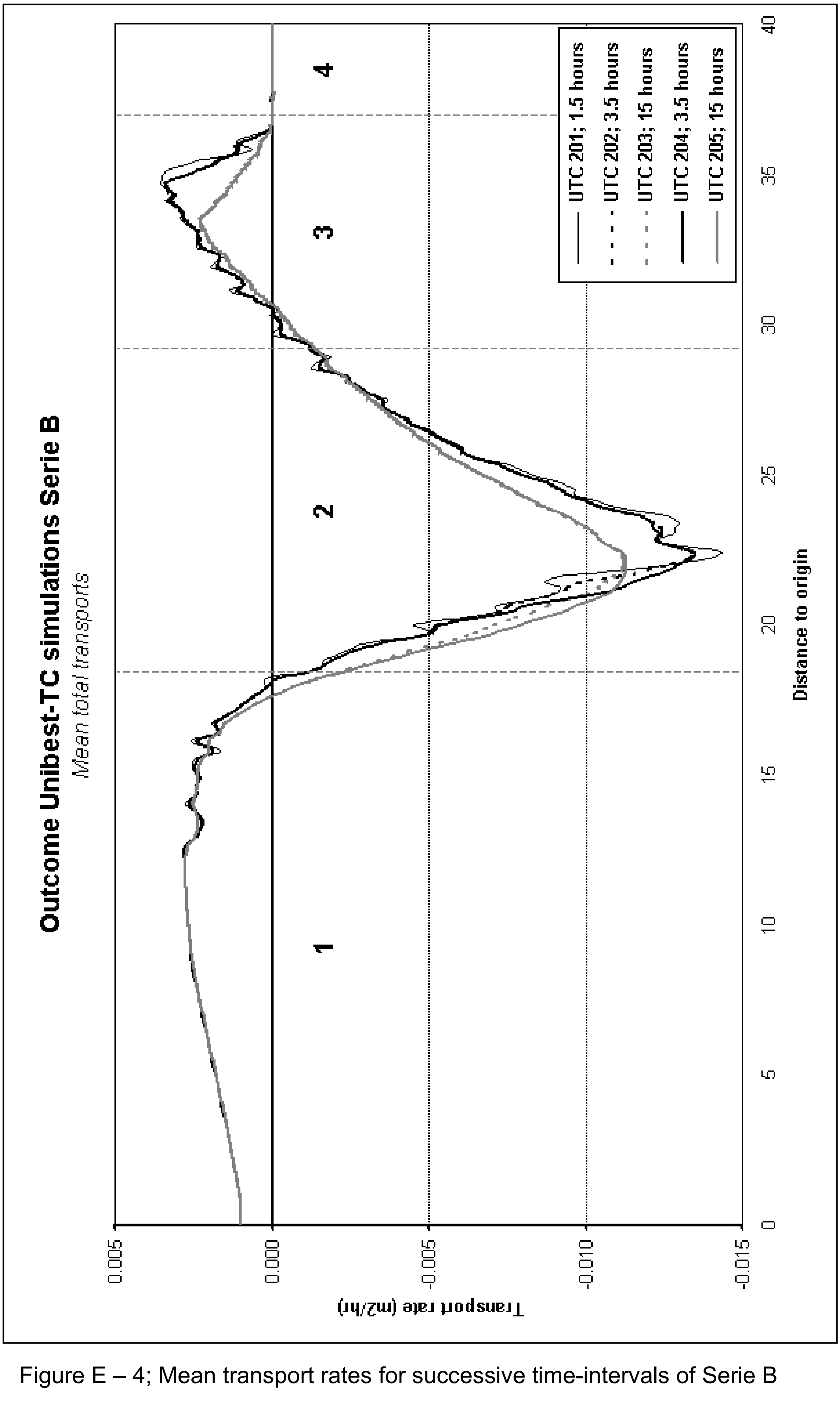


Figure E – 4; Mean transport rates for successive time-intervals of Serie B

## Appendix E-c; *Results Unibest-TC simulations Serie C*

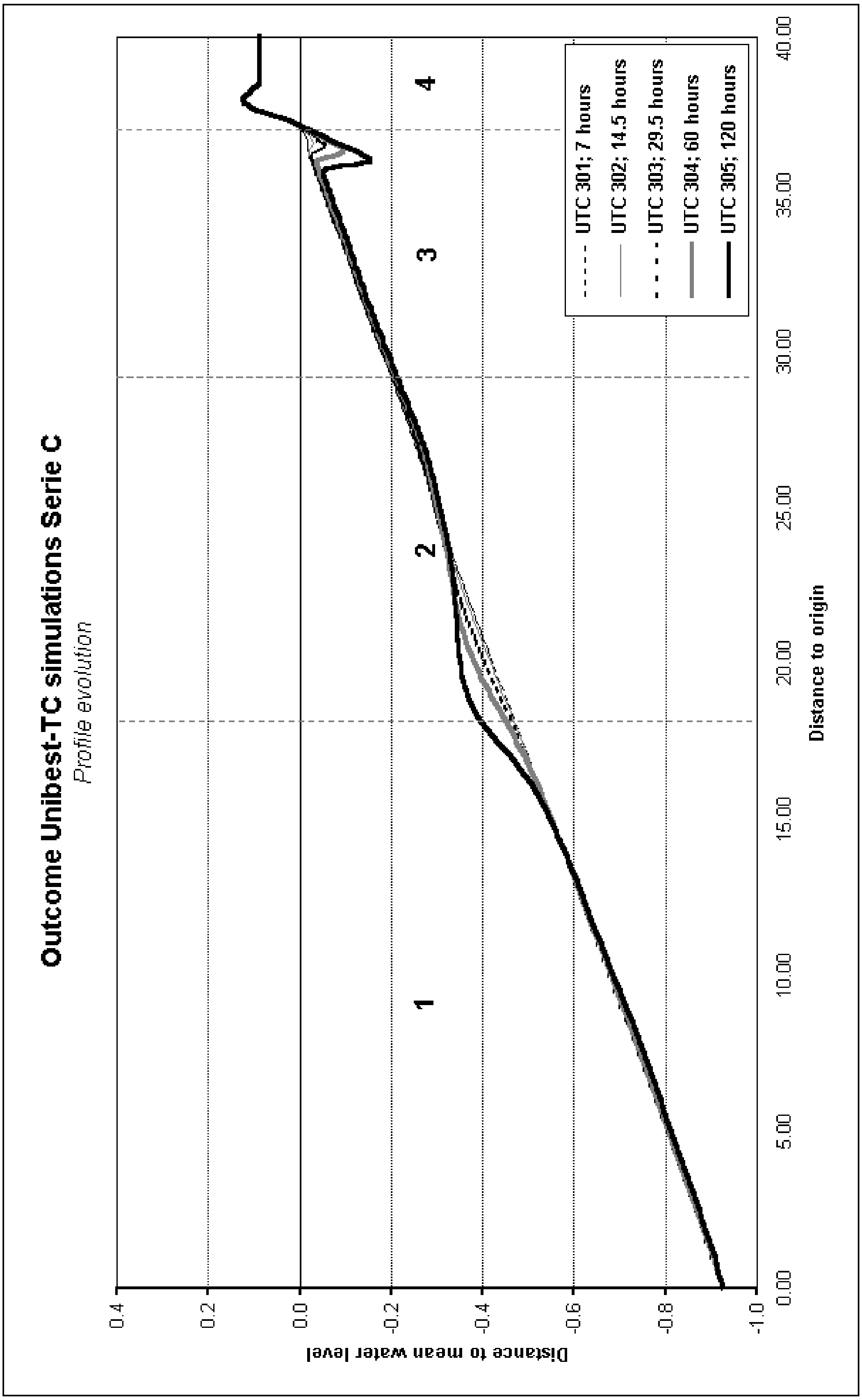


Figure E – 5; Profile evolution for successive time-intervals of Serie C

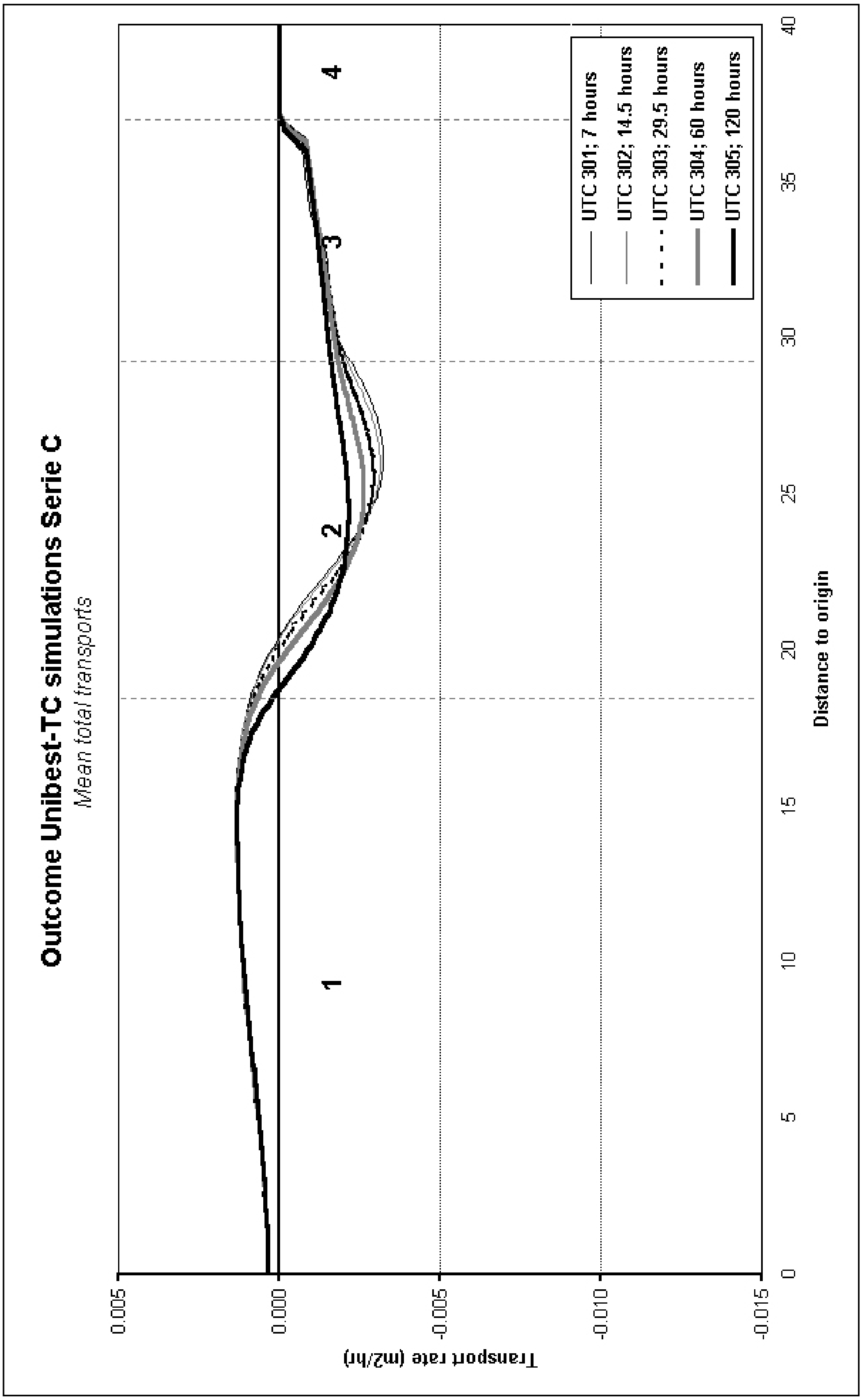


Figure E – 6; Mean transport rates for successive time-intervals of Serie C

# Appendix E-d; *Time-mean transport development Serie A*

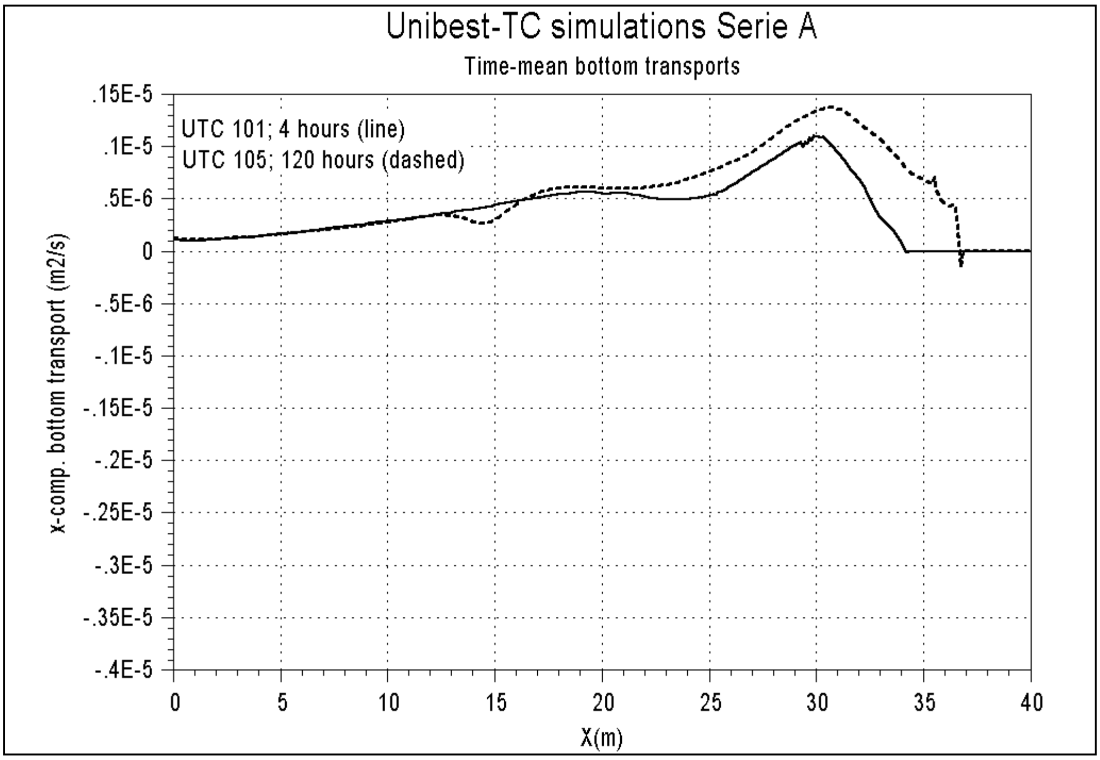


Figure E – 7; Mean bottom transports after 4 and 120 hours

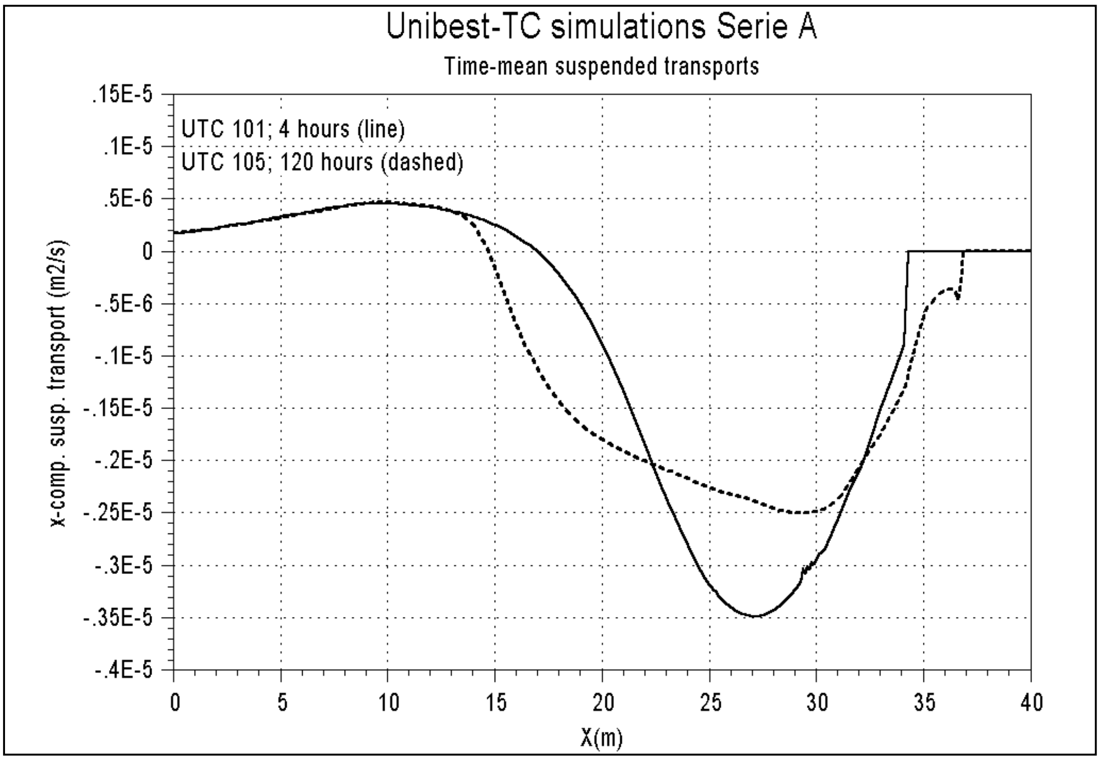


Figure E – 8; Mean suspended transports after 4 and 120 hours

# Appendix E-e; *Influence of H.M. placer on transport figures*

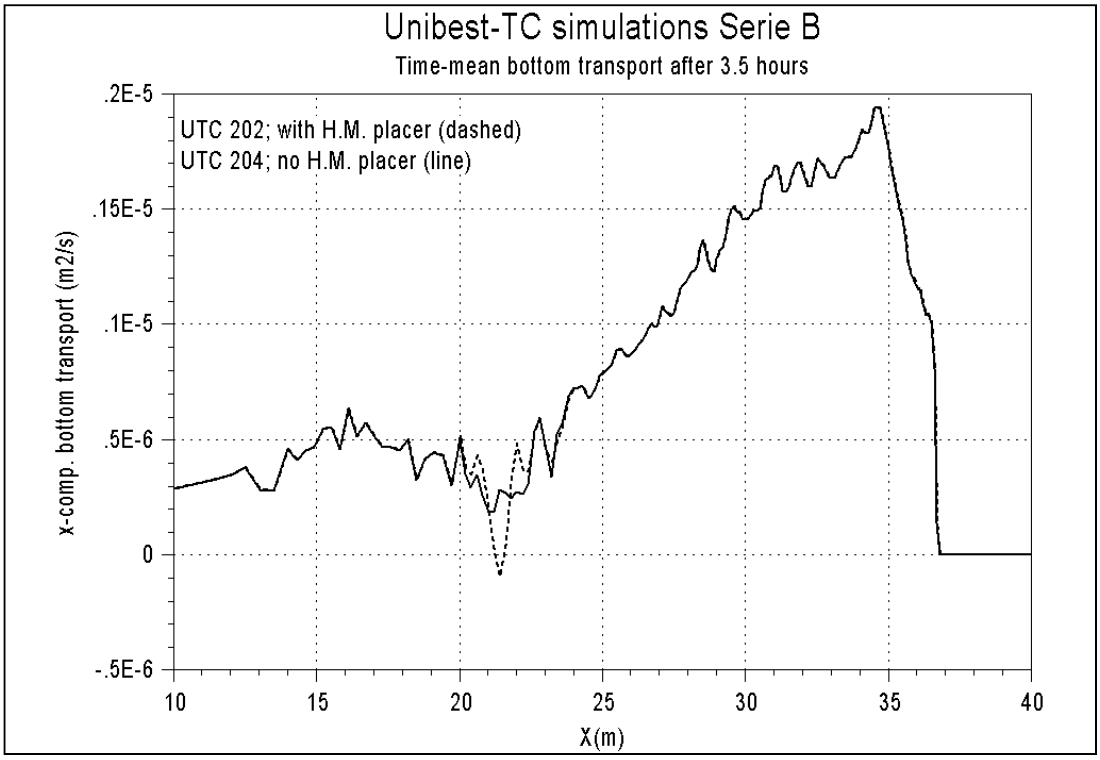


Figure E – 9; Mean bottom transports with and without heavy mineral placer

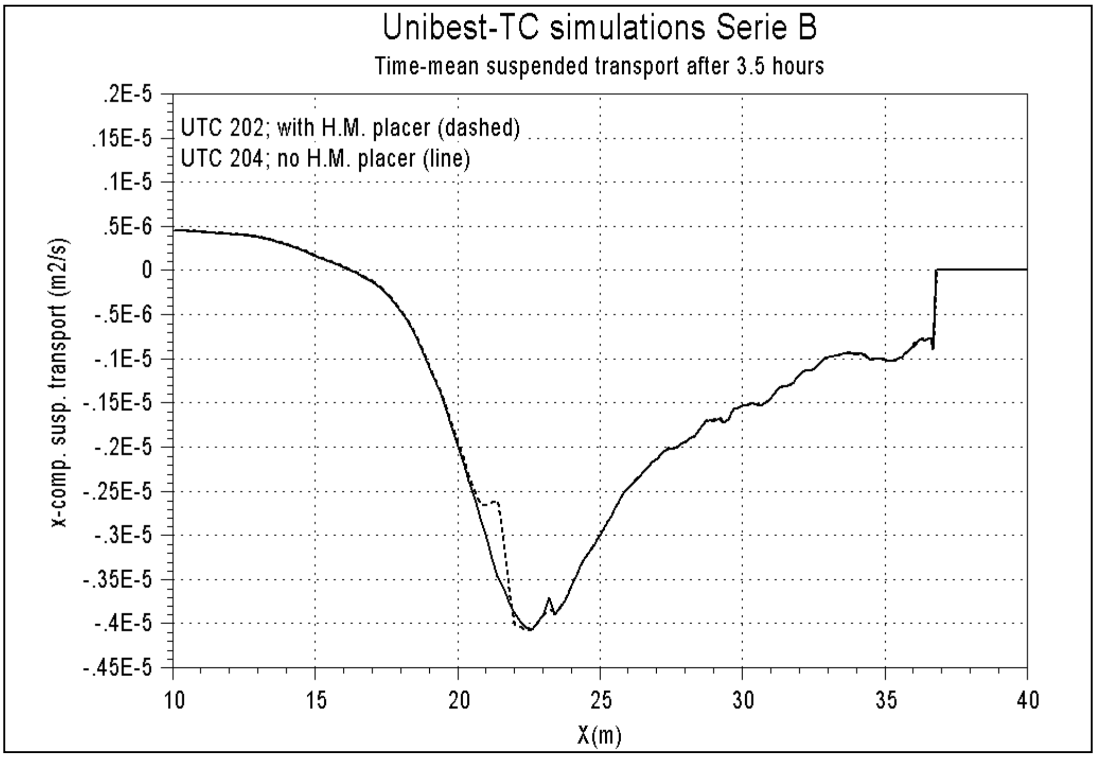


Figure E – 10; Mean suspended transports with and without heavy mineral placer

# Appendix E-f; *Time-mean transport development Serie C*

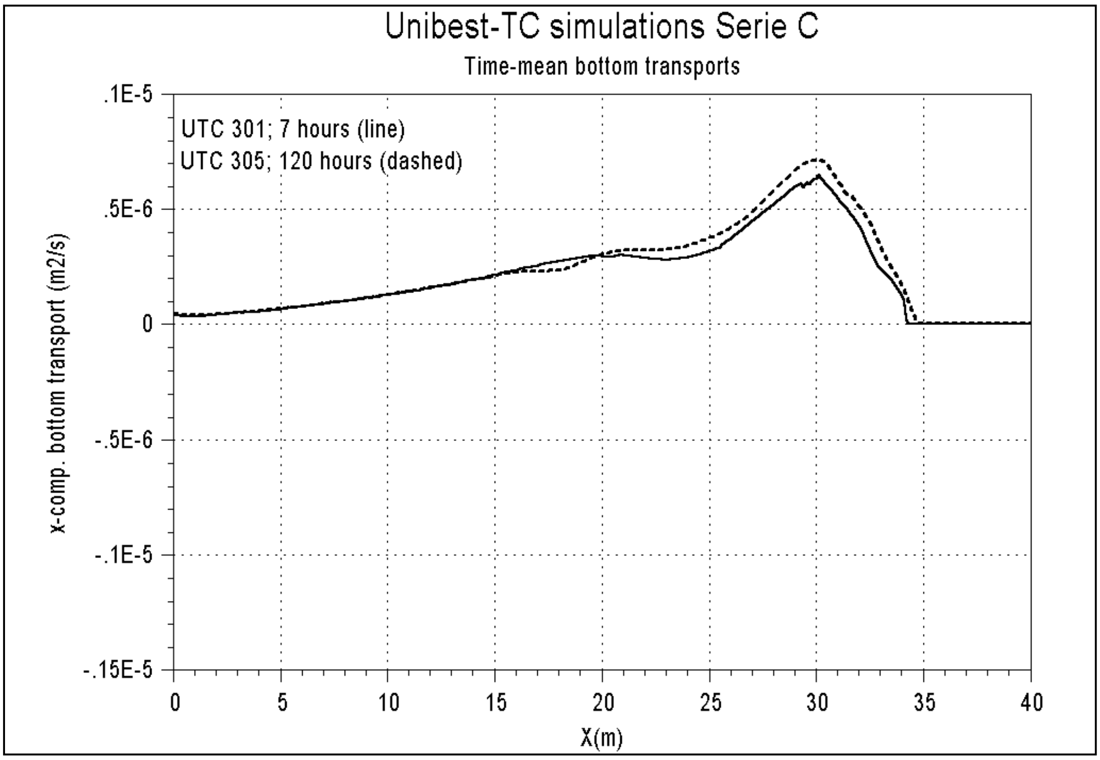


Figure E – 11; Mean bottom transports after 7 and 120 hours

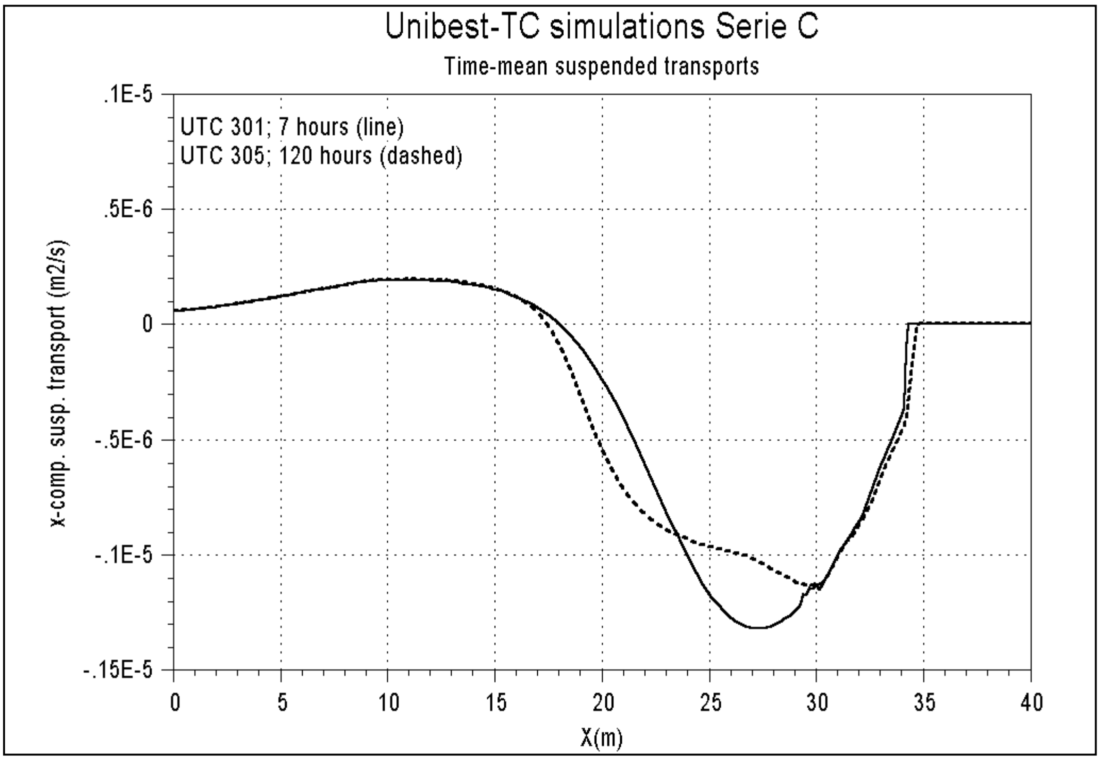


Figure E – 12; Mean suspended transports after 7 and 120 hours

# **Appendix E-g;** ***Serie A model results vs. experimental results***

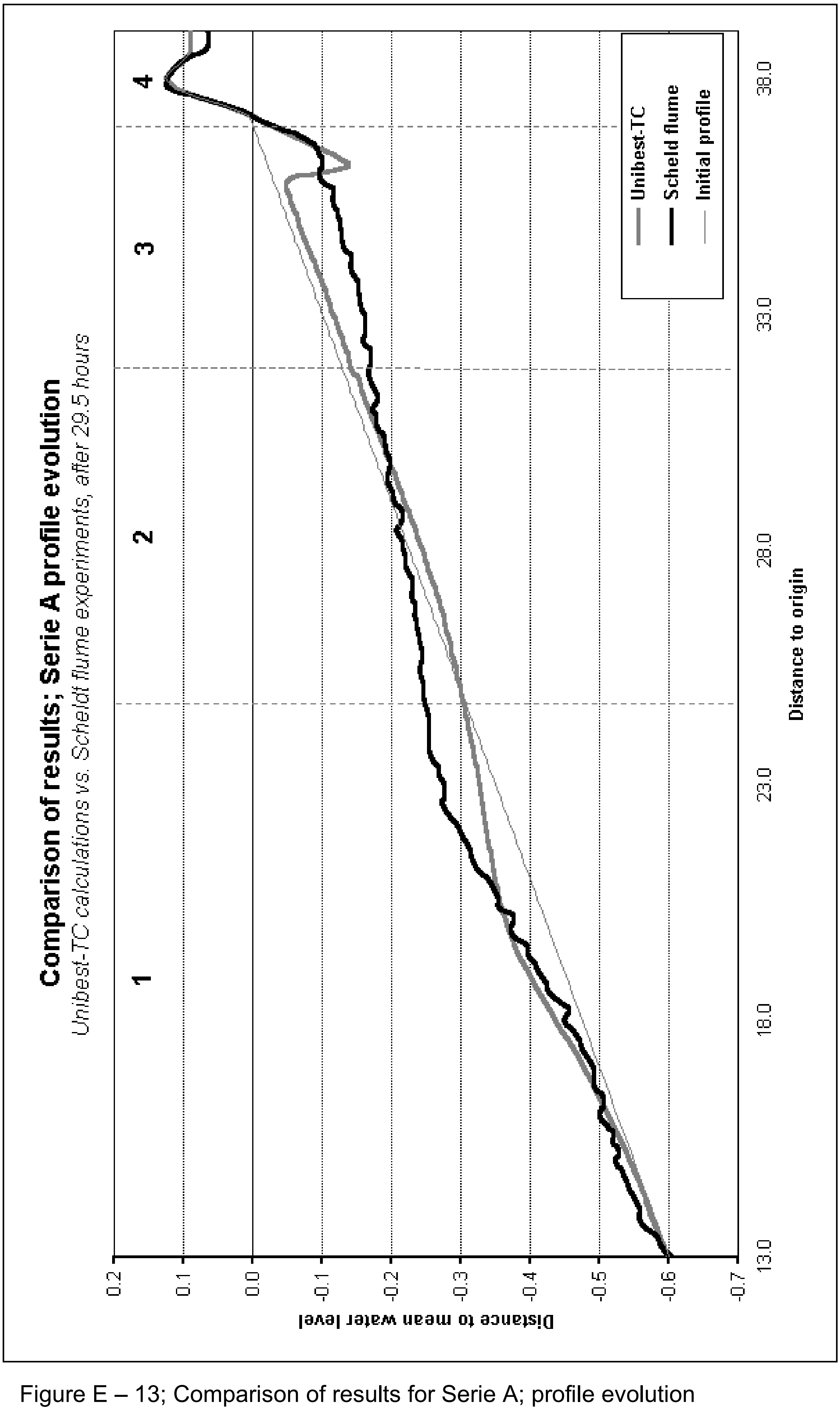


Figure E – 13; Comparison of results for Serie A; profile evolution

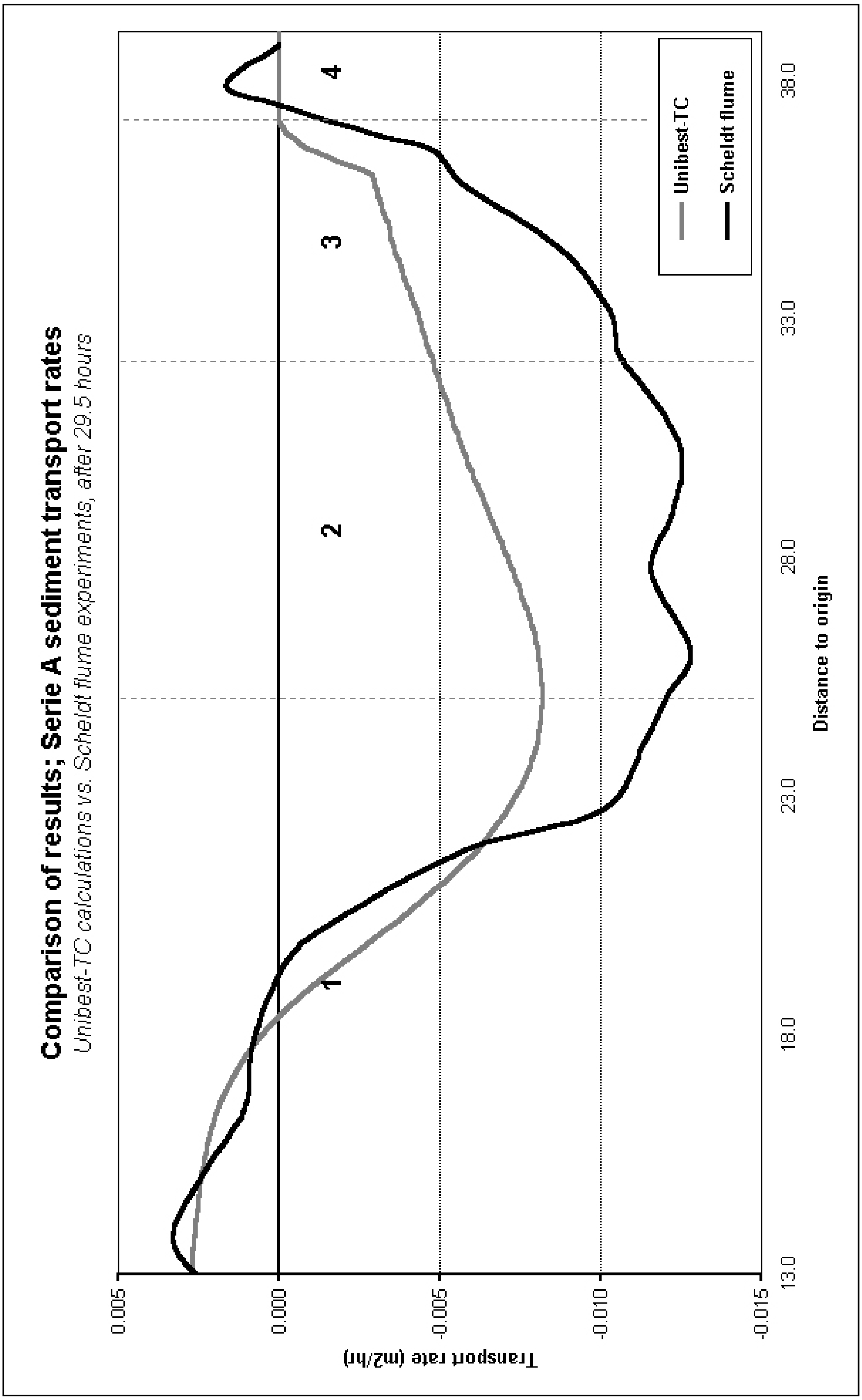


Figure E – 14; Comparison of results for Serie A; sediment transport rates

# Appendix E-h; *Serie B model results vs. experimental results*

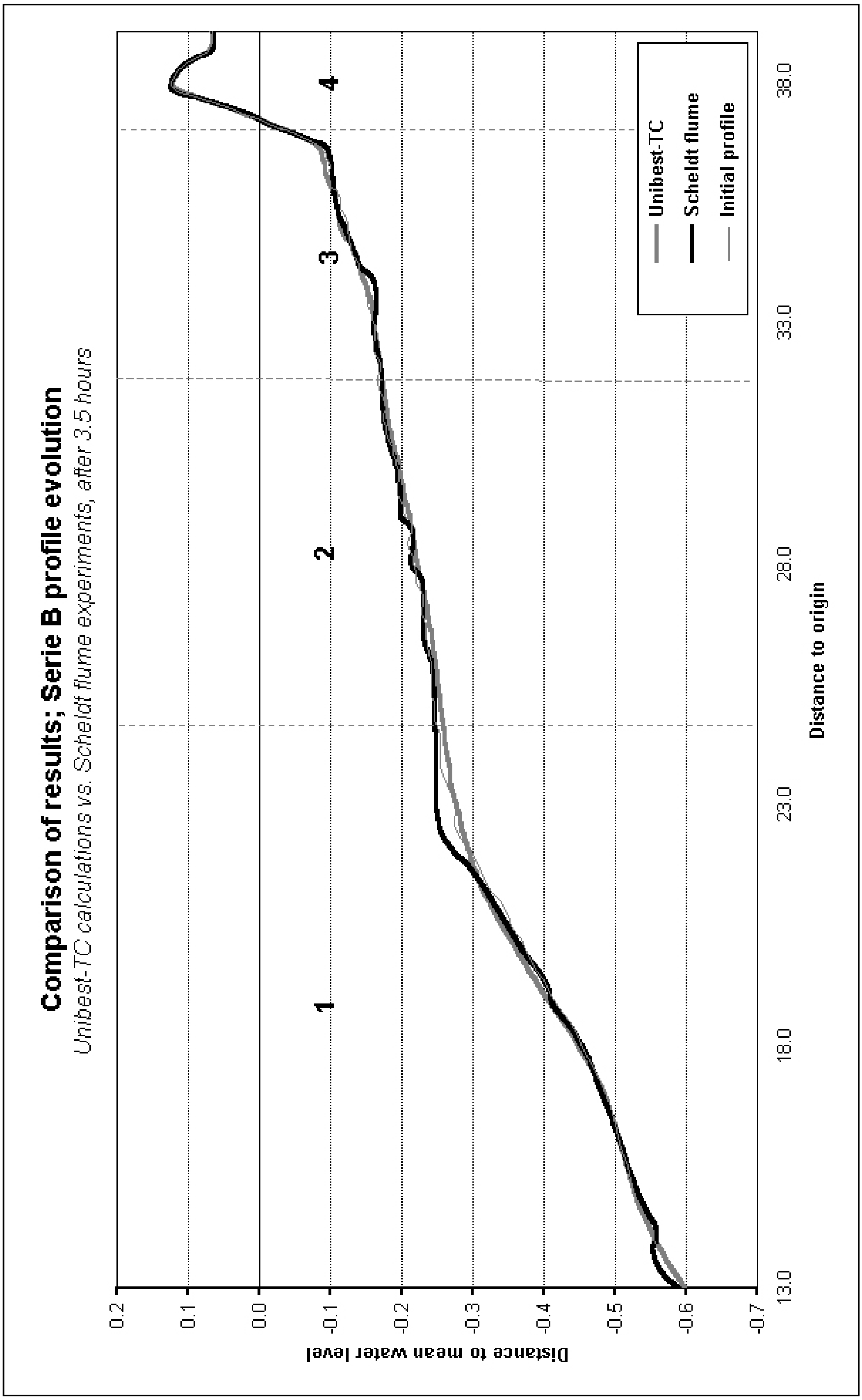


Figure E – 15; Comparison of results for Serie B; profile evolution

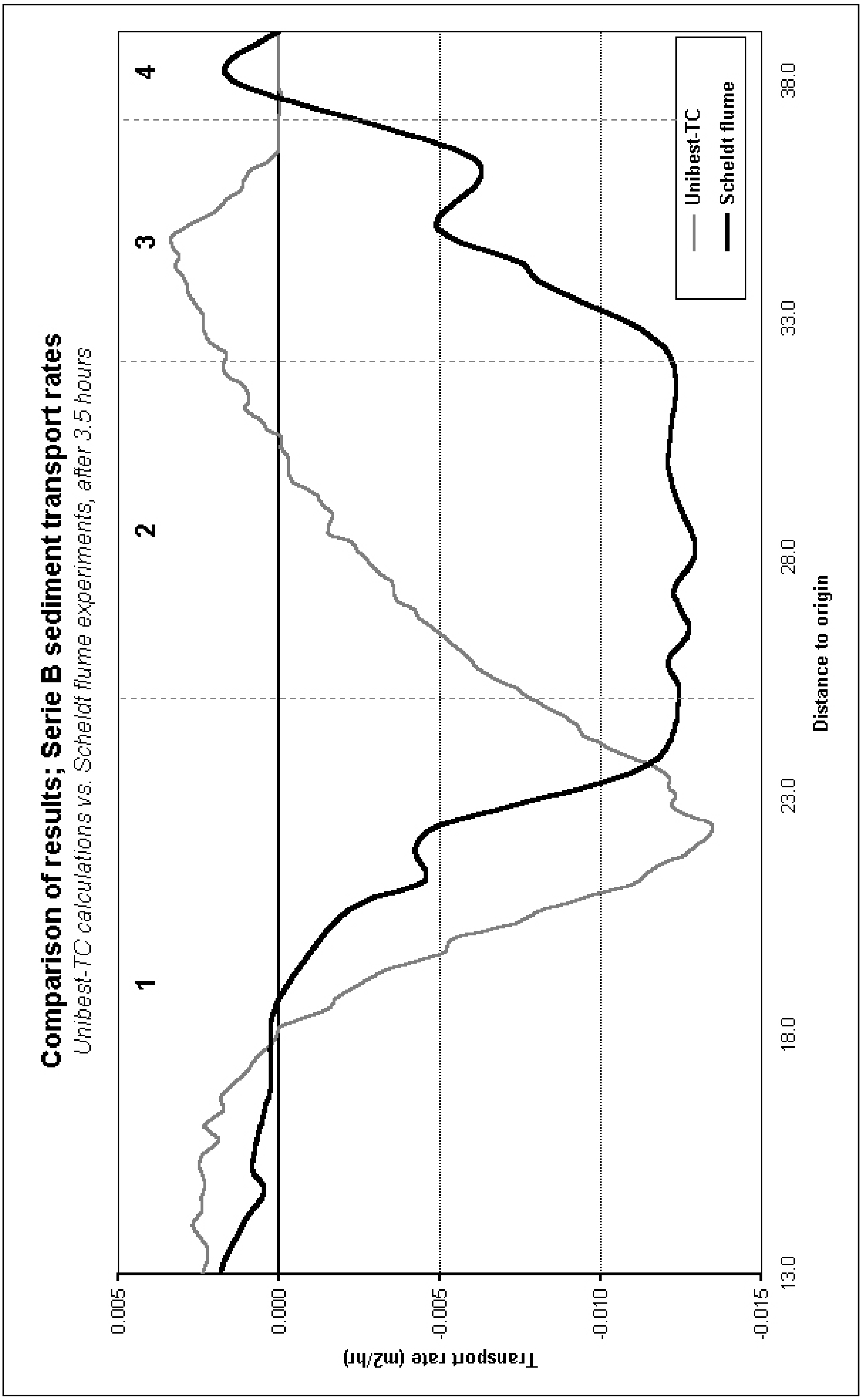


Figure E – 16; Comparison of results for Serie B; sediment transport rates

## **Appendix E-i;** ***Serie C model results vs. experimental results***

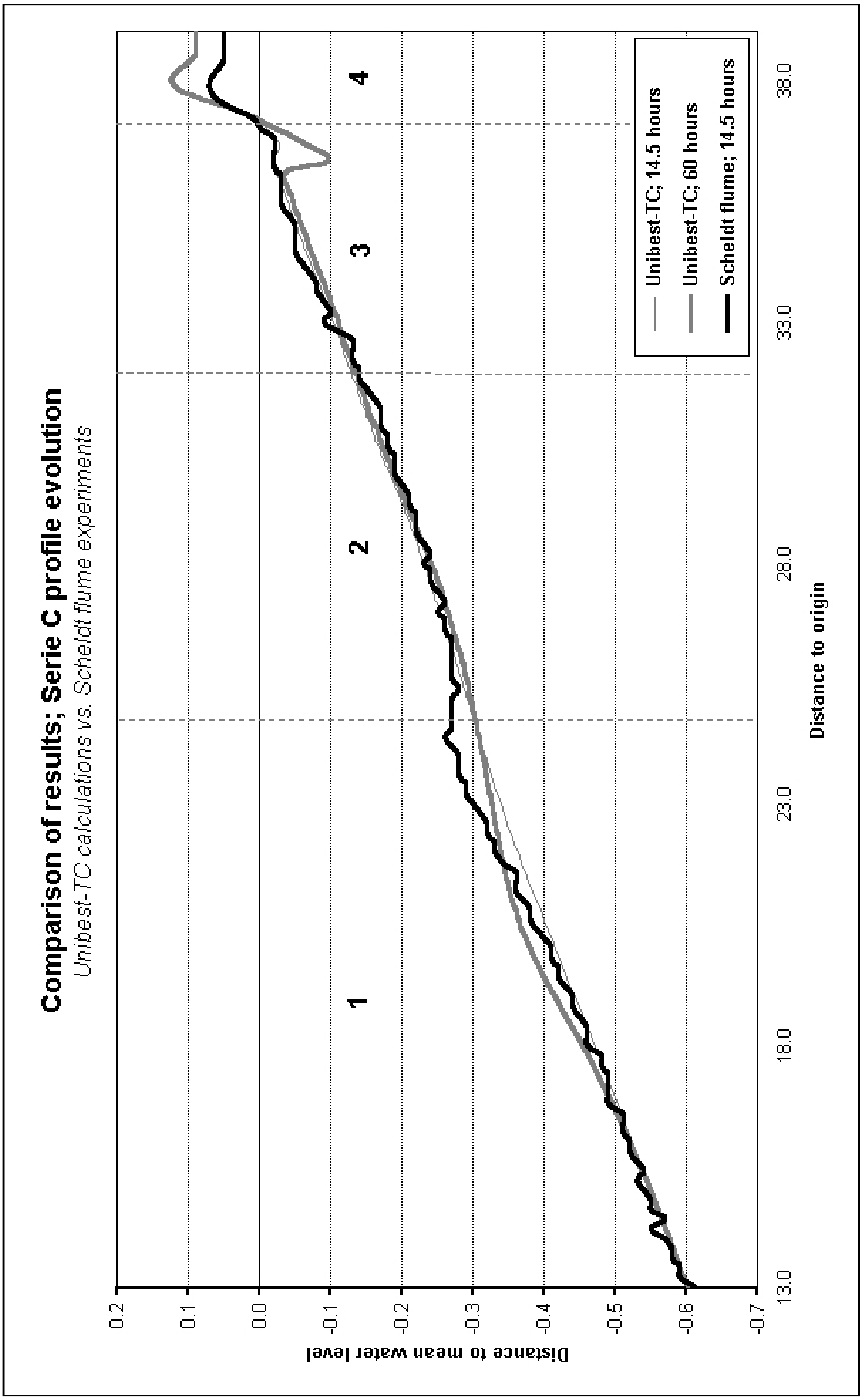


Figure E – 17; Comparison of results for Serie C; profile evolution

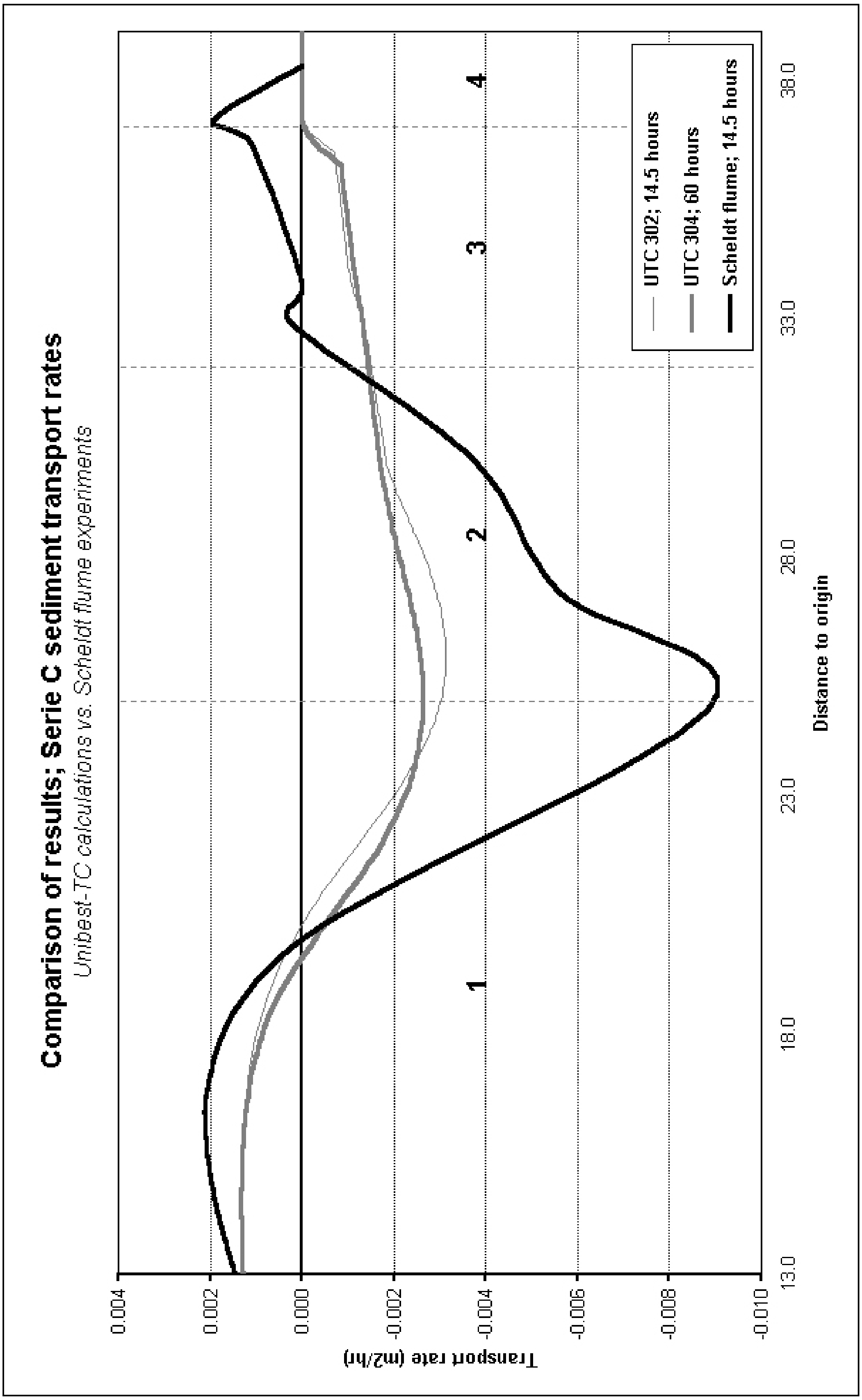


Figure E – 18; Comparison of results for Serie C; sediment transport rates

# Appendix F; Overview of model settings

| Run parameters | Serie A | Serie B | Serie C |
|---|---|---|---|
| **General parameters** | | | |
| DT | 8.20E-03 | 8.20E-03 | 8.20E-03 |
| NT | var | var | var |
| USTRA | 0 | 0 | 0 |
| JFR | 1 | 1 | 1 |
| TDRY | 22 | 22 | 22 |
| TEMP | 20 | 20 | 20 |
| SALIN | 0 | 0 | 0 |
| **Wave related parameters** | | | |
| ALFAC | 1 | 1 | 1 |
| GAMMA | 0 | 0 | 0 |
| BETD | 0.1 | 0.1 | 0.1 |
| FWEE | 1.00E-02 | 1.00E-02 | 1.00E-02 |
| C_R | 0.25 | 1.25 | 2.25 |
| K_IJL | off | off | off |
| **Current related parameters** | | | |
| FCVISC | 0.05 | 0.05 | 0.05 |
| RKVAL | 0.05 | 0.05 | 0.05 |
| DEEPV | 1 | 1 | 1 |
| **Grain size parameters** | | | |
| D50 | 1.29E-04 | 1.29E-04 | 1.25E-04 |
| D90 | 1.87E-04 | 1.87E-04 | 1.78E-04 |
| DSS | 1.12E-04 | 1.12E-04 | 1.06E-04 |
| DVAR | no | yes | no |
| FDIA0 | - | 1 | - |
| FDIA1 | - | 1.2 | - |
| FDIA2 | - | 1 | - |
| HDIA0 | - | 0.2982 | - |
| HDIA1 | - | 0.2982 | - |
| HDIA2 | - | 0.3388 | - |
| **Transport parameters** | | | |
| IBOD | yes | yes | yes |
| RC | 0.03 | 0.03 | 0.03 |
| RW | 0.05 | 0.05 | 0.05 |
| REMLG | 0.1 | 0.1 | 0.1 |
| TANPHI1 | 0.4 | 0.4 | 0.4 |
| TANPHI2 | 1 | 1 | 1 |
| XF1 | 23 | 23 | 23 |
| XF2 | 35 | 35 | 35 |
| ZDRY | vert | vert | vert |
| FACQB | 0 | 0 | 0 |

Note: The names of the parameters correspond to the names that are assigned in the input module of Unibest-TC, version 2.04 beta.
For a more detailed description of these parameters, the reader is referred to the Unibest-TC userguide. (Walstra, 2000)