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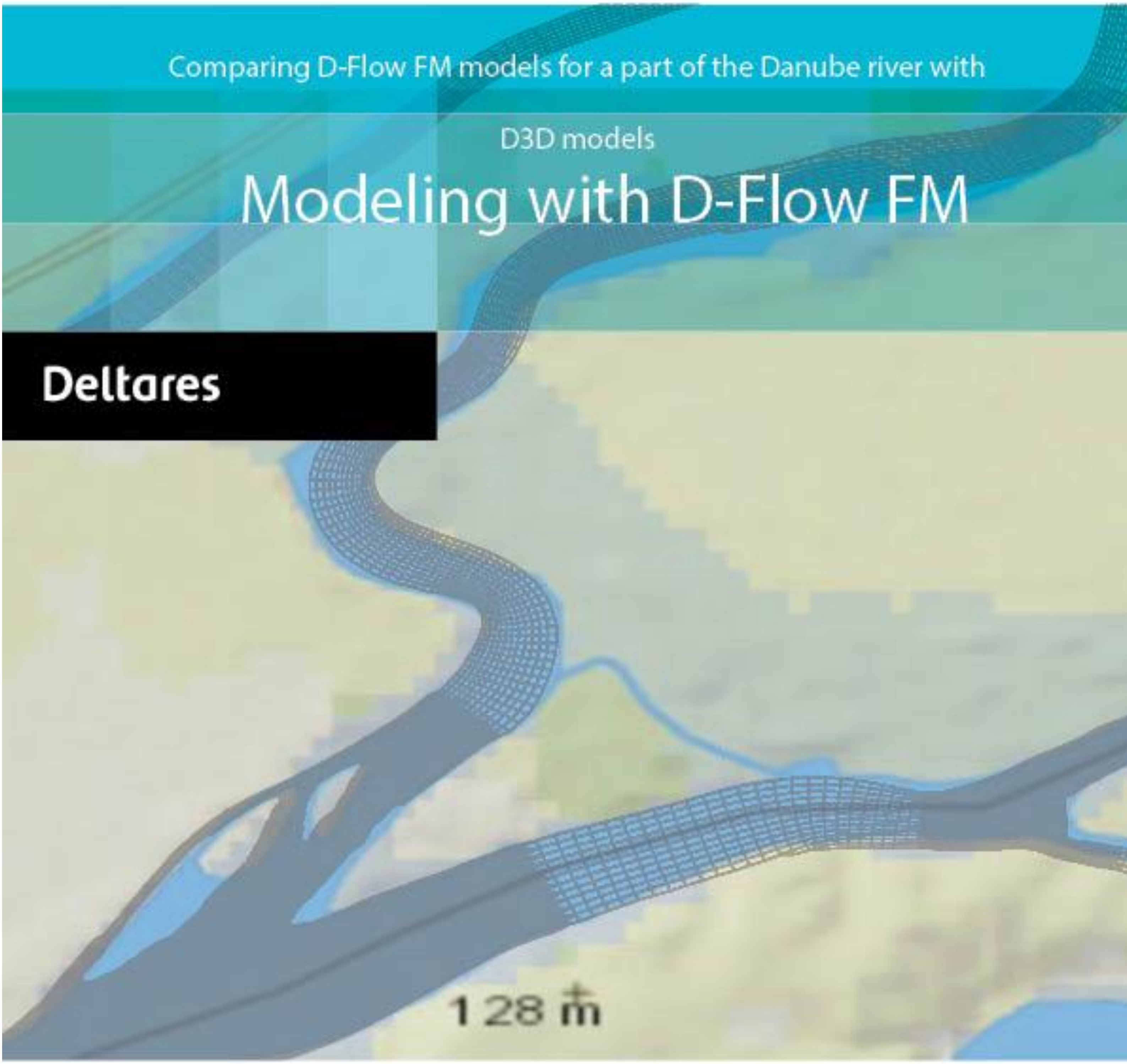
D3D models

Modeling with D-Flow FM

Deltares



Deltares

Enabling Delta Life

Modeling with D-Flow FM

Comparing D-Flow FM models for a part of the Danube River with D3D models

Bachelor final project
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Abstract

Problem indication

There are sedimentation problems in a part of the Danube River, forcing ships to make a large detour of more than 60 kilometers to reach the Canal Danube (See Figure 1-1). The implementation of some structures in the Danube River should prevent more sedimentation problems. The effect of the implementation of the structures has to been analyzed with hydrodynamic models. A Delft3D model has been built to analyze the effect of the structures. The area of the model is a complex area; it has a lot of curves and bifurcations. The study area also exists of interesting and less interesting areas for which a different level of detailed in the grid is desired. For this reason a model with a flexible computation mesh is desired.

D-Flow FM is still in development and the technology used in D-Flow FM has not yet been proven. Therefore a comparison between D3D and some D-Flow FM model is desired. There is a conversion tool available to convert a D3D model to a D-Flow FM model. First, the original Delft3d (D3D) model will be compared with the D-Flow FM conversion model. The difference that occurs between the computed model results is caused by the difference manner of computation D-Flow FM uses with respect to D3D. The computation of D-Flow FM is based on D3D, but there are still differences between these computations.

Model input data comparison

The bathymetry used for this comparison is the same in both models. The bathymetry is created with local measurements and interpolation between these measurements. Both models are run with the same upstream flow discharge, in the Danube branch 5080 m^3/s and in the Borcea branch 371 m^3/s.

Comparison between D3D model and D-Flow FM model

After comparing the models it seemed that the computed model results of both models reasonable corresponded. There were only small differences. There was just one relative difference in discharge at a cross-section bigger than 1 percent. The relative difference in discharge in the Epurasu branch (see Figure 1-2) was 5,7%. But, the discharge in this branch was compared with the total upstream discharge very low. A small difference in discharge would have a large effect on the relative discharge. Another difference that occurs was a difference in the water level. The water levels downstream were fixed, so the water level cannot differ downstream. Upstream there were differences in water level between the D3D model and the D-Flow FM model. The difference between D3D model and D-Flow FM model got bigger further upstream. Near de open boundary in the Danube branch the difference in water level between the D3D model and the D-Flow FM model was approximately 3,4 centimeter.

Model input data Analysis

Eight different models were used in the analysis, consisting of four different grids with each two different bathymetries. One of the bathymetries does not have structures, while the other one does. The same open boundary conditions as in the comparison between D3D and D-Flow FM were used. The specifications for models without structures are the same as for the models without structures. The first grid that has been used for the analysis is the D3D grid. The second is a D-Flow FM model converted from the D3D model. The models have the same grid, but they use a different software program. The third model has a detailed grid at the bifurcations in the Danube River (see Figure 1-1). The last model has a very detailed grid at the location of the possible implementation of the Bala Bottom sill (see Figure 3-3). The only settings that differs in the model with a very detailed grid at the location of the possible implementation of the Bala Bottom sill is the time-step. The grid cells are too small to use the same time-step as in the other models.

Analysis Different models

After comparing the different models in the analysis it seems that there were larger differences than in the comparison between the D3D model and D-Flow FM conversion model. Especially the model with the third grid with structures showed large deviations with the other models with structures. The differences between the models without structures were very small. The

maximum relative difference in discharge compared to the D3D model is maximum 0,5%. The maximum relative difference in discharge compared to the D3D model in the model with bathymetry with structures is 2,7%. The difference between the models in water level and velocity were very small.

D-Flow FM and D3D definitely differ from each other. The computation differs, the possibilities in the software differ and the computed model results differ due to the difference in the computation. However, the differences in the computed model results between D3D and D-Flow are not large.

Preface

After three months of work I hereby present you the report of my bachelor thesis project. Despite some problems with the software and some delay with facing and solving the problems the project is finished. Other parts of the bachelor thesis project went variously smooth or less smooth. But the final result satisfies me. Working individually for such a long time on a project was new for me; this project gave me the opportunity to experience that. Working individually gave me the opportunity to work in my own way independently. This does not mean that I prefer to work individually. I would prefer variety between individual and group work.

I enjoyed working on my bachelor thesis project at Deltares in Delft. It has been very educational for me to work on a real project with recently developed software. I obviously hope that my work was very useful for the project I worked on. I would like to thank some people who where helpful for me during the bachelor thesis project, hopefully without forgetting anyone.

At first, I want to thank Rolien van der Mark. She was my supervisor at Deltares, she mainly gave organizational support during my bachelor thesis project.

Second, I want to thank Mohamed Yossef and Ymkje Huismans. They provided me with information and data about the content of the project. Mohamed Yossef helped me mainly in the beginning, while Ymkje Huismans toke the project partially over later on. They also provided feedback on my work.

Wim van Balen helped me learning the software. I want to thank him for the support with regard to the software. His quick responses where very useful in the beginning of the bachelor thesis project, but also at the end he was still available to help me with problems.

Jan Ribberink, my supervisor at the University of Twente, helped me with his experience to start the bachelor thesis project smoothly and without any problems.

I wish you all the pleasure reading this report for my bachelor thesis project. If there are any questions, during or after reading this report, you can always contact me at the e-mail address below.

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Glossary

Bathymetry

Bathymetry is the underwater bottom-level with respect to the reference height.

Cross-sections

Cross-sections are lines across the river that covers the width fully or partly. Cross-sections can be used to measure the discharge at parts of the river. Therefore the cross-sections should cover the full width of the river. Otherwise a part of the discharge could miss the cross-section. Then the discharge missing the cross-sections will not be added to the total discharge at a cross-section.

D-Flow or D3D

D-Flow and D3D both stand for Delft3D Flow. D3D is software for hydrodynamic simulations with a curvilinear grid. More information about Delft3D-Flow can be found in Appendix B.

D-Flow FM

D-Flow FM stands for Delft3D Flow Flexible Mesh. D-Flow FM is software for hydrodynamic simulations with a unstructured grid. More information about D-Flow Flexible Mesh can be found in Appendix B.

Dry points

Dry points are points or cell in the D3D model that do not have a depth value. The cell will not be taken into account during the computation. Dry points are not allowed in D-Flow FM and they should be removed from any D-Flow FM model.

Eigen Oscillation

Eigen oscillations are longitudinal waves in the model cause by boundary conditions. More information about Eigen oscillations can be found in chapter 4.4.

Observation points

Observation points are locations in the river. The observation points can be used to measure, for example, the water level at some points in the river.

Open Boundary

Open boundaries are water to water boundaries. Since a model cannot complete cover a whole river system, there are boundaries needed between water and water. In contrary to closed boundaries (Boundary between water and land), open boundaries determines the progress of the flows inside the model.

Open Boundary Conditions

The conditions at open boundaries determine the kind of water to water boundaries. The condition could be a discharge, water level, velocity, etc. The conditions can be specified as uniform at the boundary or they could be differences between several points at an open boundary.

Run-Time

Run-Time is the length in time of a model. This is not the time that is needed to run the computation, just the difference between the beginning and the end of a model.

Spin-up time

Spin-Up is the time needed for a model to get used to the model input data. For example, if a model has a uniform initial water level, it will take time to get the real water level in the model. This is called the spin-up.

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1 Introduction

This introduction will help understanding the contents of this bachelor thesis project. First the problem indication will be given. After the spatial content is clear, the problem statement will be discussed. The research questions will be determined on the basis of the problem statement. After that, in the scope the limits of the project will be discussed. The research method will discuss the how the problem from this project will be solved. At last, the content of this report will be discussed in the Thesis Outline.

1.1 Problem indication

Ships have to, due to sedimentation problems in the Danube River, take a large detour to reach the “Canal Danube” in the Danube River. This canal is a short cut from to Danube to the Black sea. The Canal Danube is about 60 kilometers long and the canal Danube reduces the distance between Cernavodă and Constanţa about 400 kilometers (Berend, 2006) (Economic and Social Council of the United Nations, 2003). This makes the Canal Danube important for transport over water.

There are some sedimentation problems upstream of the Canal Danube in the orange circle in Figure 1-1. Therefore ships have to sail over the Borcea Branch (Figure 1-1 and Figure 1-2) of the Danube River to reach the Canal Danube. This is a detour of more than 60 kilometers.

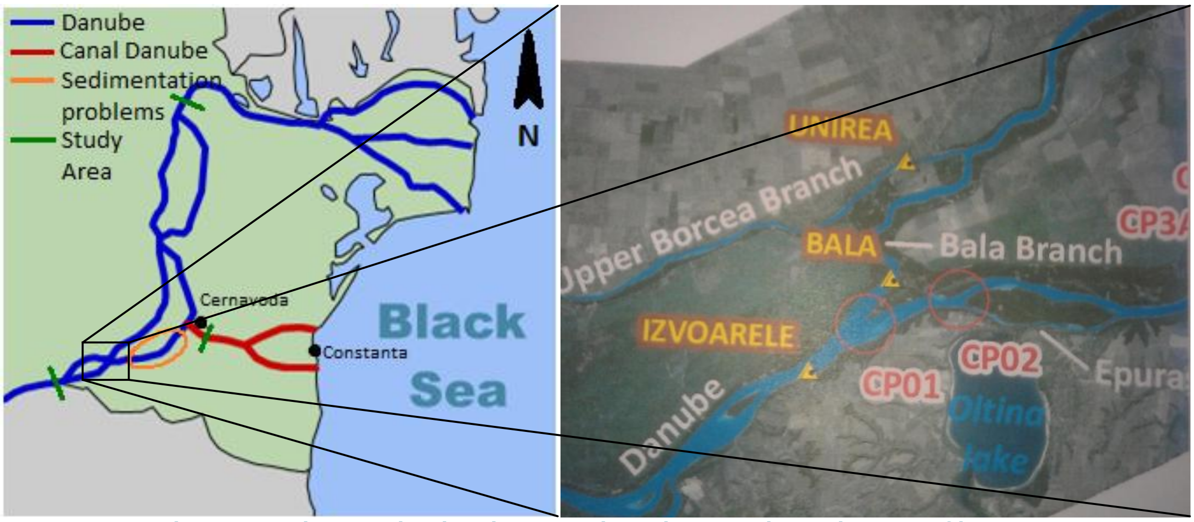

Figure 1-1; The Danube river in Romania and a zoom in on the area of interest

The sedimentation problems are caused by a low discharge in the lower Danube Branch. Upstream of the sedimentation problems there are two bifurcations who distribute the discharge over the branches. These bifurcations are remarked as critical points in a larger study of the Danube River. This larger study is displayed in Figure 1-1 between the green lines.

Figure 1-2; The Danube river with branches

A possible solution to prevent the sedimentation in the lower Danube branch is placing some structures downstream of the bifurcation in the Bala branch and upstream of the bifurcation before the Epurasu branch (Figure 1-1). A structure in the Bala branch should increase the flow discharge in the lower Danube branch. A larger discharge should help prevent more sedimentation problems in the lower Danube branch.

1.2 Problem Statement

The implementation of the structure should be investigated with hydrodynamic models. Two of such hydrodynamic models are D3D and D-Flow FM. A Delft3D-Flow (D3D) model with curvilinear grid is being built for the whole study area and of the study area of the bachelor thesis project (Figure 1-1). Because of the bifurcations and the large amount of curves in the river the area is very hard to model with just a curvilinear grid. Some parts of the model need to be very detailed, while other parts do not need to be detailed. D3D does not offer an opportunity to make difference in detail in a single model. Therefore there is need for a Delft 3D-Flow Flexible Mesh (D-Flow FM) model.

D-Flow FM is a newly constructed software program which simulates hydrodynamic problems. D-Flow FM is still under construction and it is not yet integrated within D3D. D-Flow FM consists of options to use a curvilinear grid and an unstructured grid (triangles, pentagons and hexagons) (See Appendix B for more information about Delft3D Flow Flexible Mesh). D-Flow FM is currently a stand-alone program and it is still in the validation phase.

In this bachelor thesis project the focus is on the bifurcations; CP01 and CP02 (See Figure 1-1). Critical points 1 and 2 are two bifurcations in the Danube. Critical points one splits the Danube branch in the Bala branch and the Danube branch. Critical point two splits the Danube branch in the Danube branch and the Epurasu branch. The study area of this project is shown in Figure 1-2. This is the area that needs a D-Flow FM model. The D-Flow FM model will help investigate the effects on the discharge of the implementation of a structure in the Bala Branch. Because of the uncertainty of D-Flow FM, a D-Flow FM model for the Danube need to be compared with the D3D model for the Danube first. The D-Flow FM model will be a conversion model. This project will be about the differences between D3D and D-Flow FM. The different possibilities of the software and the effect on the computed model results need to be discussed. A possibility of D-Flow FM that will be investigated is the possibility to use different levels of detail in one model. Eight different models will be compared; two of these models are D3D models. One of these models has bathymetry with structures and one has bathymetry without structures. Next to the D3D models 6 D-Flow FM models will be constructed with different levels of detail. High detail will be used for interesting locations while less detailed will be used for less detailed locations. Using less detailed parts of the grid for uninteresting areas save computational time. More information about the different models can be found in chapter 3.

A detailed problem statement can be found in Appendix A. The main problems will be divided in smaller problems in the appendix.

1.3 Research questions

This report will answer a main research question supported by 4 sub questions.

Main Question:
What are the differences between D3D models and D-Flow FM models for a part of the Danube?

Sub Questions:
1. What are the differences in the computation between Delft3D en D-Flow Flexible Mesh?
2. What are the differences in model input data used in the models?
3. What are the differences in computed model results between the D3D model and the converted model?
4. What is the effect of difference in level of detail in grids at bifurcations in D-Flow FM models?

Hypothesis:
It is hard to say what the differences will be, since D-Flow FM should approximately make the same computation as D3D does. The differences in the comparison of the Computed model results of the D3D model and the D-Flow FM model should be minimal. The differences for sub question 4 will probably be larger than the differences for sub question 3. Next to a different way of computation used for sub question 3, sub question 4 also contains different grids. The discharges, water level and velocity will differ.

Since, D-Flow FM is based on D3D there should not be large differences in the computation of the software programs. But, D-Flow FM is still in development. So, computation of the software programs are probably not completely equal, there will still be differences in computation between D-Flow FM and D3D.The differences for sub question 2 are choices made, for that chapter there is no need to discuss those differences here.

1.4 Scope

To prevent lack of time, there has to be a clear scope. This bachelor thesis project will only contain a model of the study area displayed in Figure 1-2. For this project D3D and D-Flow FM will be used. There are probably a lot of differences between the different software, models and computed model results. Treating all those differences would take too much time and it is probably unnecessary. Therefore, only the most important and notable differences per sub-question will be treated.

For sub question 1 the visible differences in the software will be discussed. There are probably a lot of numerical differences, but this project is too short to handle all the differences. There would also be a lack of knowledge to discover numerical differences.

For sub question 2 the differences in model input data will be discussed. There are not many differences and they are all important. That is why all the differences should be treated.

The comparison between the D3D model and the converted Flexible Mesh model will have a more extended comparison than the comparison for sub question 4. The most important difference between the D3D model en the D-Flow FM model for this project is the difference in discharge distribution at bifurcations in the river. Other important differences are for example the difference in water level and velocities. The differences will be, when possible, analyzed and expressed in relative differences.

Multiple models with different levels of details at bifurcations will be compared for sub question 4, an extended comparison as for sub question 3 is in terms of time is not possible and it is not necessary as well. Therefore, the differences between models without structures, the differences between models with structures and the differences in effect of the implementation of the structures will be discussed.

1.5 Research method

This research is a mathematical research (Järvinen, 2004). During this research a couple of computational software programs will be used to get results. The most important one is Delft3D-Flow Flexible Mesh. The computed model results of D-Flow FM model of the Danube are the reason that this bachelor thesis project exist. These results will be compared with the computed model results of D3D to decide whether the results from D-Flow FM model could be trusted. The computed model results will be compared and analyzed to answer sub question 3 and sub question 4. The different models that will be compared will be discussed to answer sub question 2.

1.6 Thesis outline

This report will first handle the comparison between D3D model and D-Flow FM model for a part of the Danube River. After the introduction every chapter will handle a sub-research question. First, the differences between the two different software programs will be discussed. The D-Flow FM software is still in development and does not have the same way of computation D3D has. The differences will be discussed in chapter 2.

There are different model input data for the different models. The model input data and differences in the model input data between models will be discussed in chapter 3. This chapter will first discuss the model input data that are similar, after that the differences in the models will be discussed.

Chapter 4 will answer the third sub question. There is a conversion tool available which converts the grid, bathymetry and the boundary conditions (See Appendix C). The computed model results between the D3D model and the D-Flow FM converted model should be quite equal, therefore a separate chapter is used to compare the D3D model and the D-Flow FM conversion model.

The last sub-research question will be answered in chapter 5. The effect of different level of details in D-Flow FM models will be discussed in chapter 5. This chapter will first discuss the differences between D-Flow FM models without structures. After the comparison of the models without structures, the differences in the model with structures will be discussed. At last, the differences between model without structures and model with structures will be discussed.

The conclusion will answer the main-research question. All the answers on the sub-research question will be used in the conclusion to answer the main-research question.

2 Differences between D3D en Flexible Mesh

The reason for the development of D-Flow FM is the desire for flexible meshes. In D3D it is only possible to use a curvilinear grid. While there are differences between the meshes of both models there are also differences in the computation. Differences between D3D and D-Flow FM that are known before the computation will be discussed below. Obviously the grid is the main difference, but other differences will be discussed as much as possible.

2.1 Grid

Using D-Flow FM offers the opportunity to use flexible mesh for different cell sizes in one model. Important parts of the grid could be very detailed, while less important parts of the grid could have a coarser grid. This could decrease the computational time. For this project, the important parts of the grid are the bifurcations and the structures. D-Flow FM also makes it easier to make a grid of complex areas.

Figure 2-1 shows clear differences in the grid. The left side of the figure is a curvilinear grid in D3D. The edge of this grid does not match very well with the land boundary (blue line). The edge of the grid from the D-Flow FM model does match much better with the land boundary.

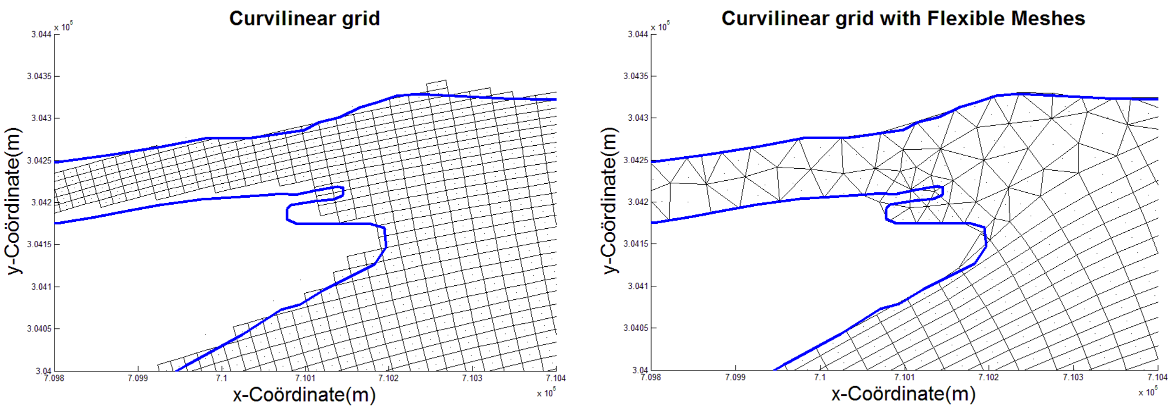

Figure 2-1; Difference in Grid between D3D and D-Flow FM

D-Flow FM also offer opportunities to differ in level of detail. Figure 2-2 shows the transition from coarse to detail in a flexible mesh model. The location of the transition from coarse to detail is shown with a red rectangle in Figure 2-3. The computational time of the model will decrease when uninteresting part of the grid are coarse.

Since there will be differences in the grid, the location were the bathymetry will be stored will be different as well. This will also cause different results. The differences should not be large, since the same land boundary (Figure B-2 in Appendix B) is used to generate the grid and the samples to create the bathymetry is also the same.

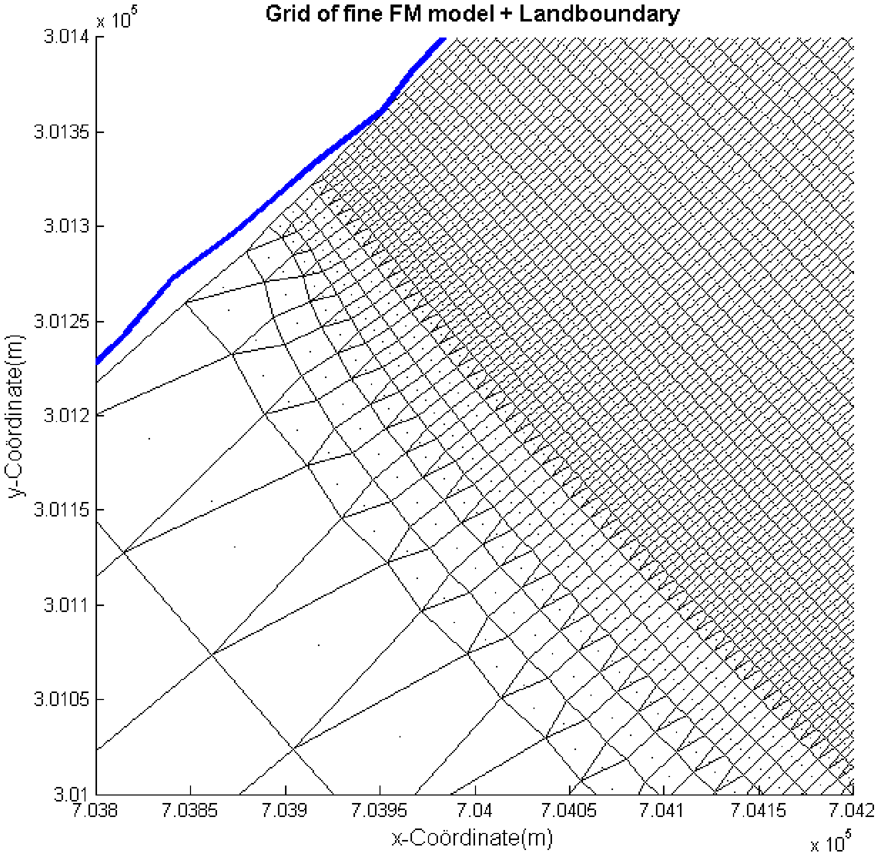

Figure 2-2; from coarse to fine in D-Flow FM

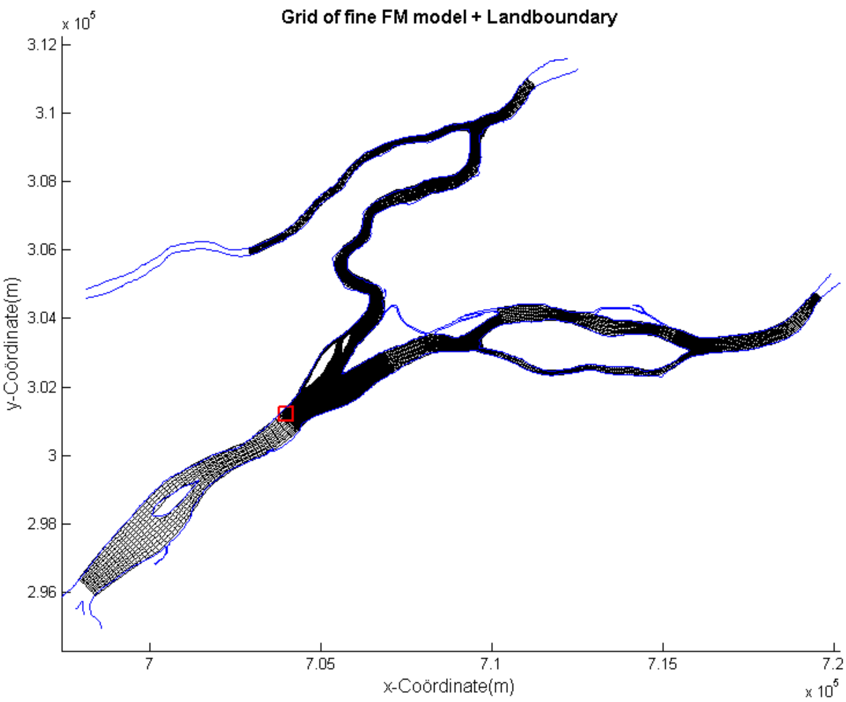

Figure 2-3; Location of the transition from coarse to fine

2.2 Computation

D-Flow FM uses the same computational methods as D3D to compute curvilinear areas of the grid. D-Flow FM also offers the opportunity to use a 1D model. But since D-Flow FM is still in development, some computations of D3D are not yet available in D-Flow FM. To make the computations of D3D and D-Flow FM as much as possible similar to each other, the expertise of one of the D-Flow FM developers (Herman Kernkamp) has been asked. The settings that will be used in D-Flow FM and D3D that could cause differences in the computational results will be discussed below.

2.2.1 D-Flow FM

There are two different ways to specify the bathymetry in D-Flow FM. There are possibilities to specify the bathymetry at the net cell circumcenters (See + in Figure 2-4) or at the net nodes (See • in Figure 2-4). Since most previous developments of D-Flow FM are based on a grid with bathymetry at net nodes, the bathymetry in the model used for the analysis will be specified at net nodes. The bottom levels at velocity points (net cell link) will be calculated using the mean level of the surrounding net nodes. The bottom level at net cell circumcenters will be equal to the lowest bottom level of all the connected net cell links. The last parameter that will be discussed is conveyance2D. The conveyance calculates the hydraulic radius. In this case the hydraulic radius is equal to water depth.

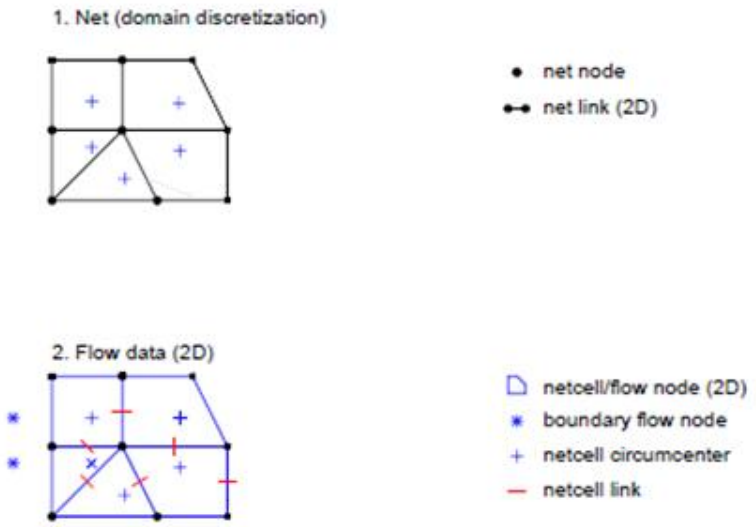

Figure 2-4; Net properties D-Flow FM

2.2.2 Delft3D

To match the calculation in D-Flow FM as close as possible, the bathymetry in D3D should also be specified at the grid corners. Advective terms are not implemented in D-Flow FM yet, but they are required in D3D. According to Herman Kernkamp, the best way to make a good comparison was using a cyclic scheme to solve the advective terms in D3D. The bottom level at velocity points have been calculated in the same way as in D-Flow FM. The mean bottom level of the two surrounding grid corner have been used to calculate the bottom level at the net nodes. To do this in D3D as well, the parameter DpuOpt should be equal to mean. The bottom level at cell center in D3D is calculated by the maximum bottom level of the four surrounding cell corners. This sounds strange since the lowest value of the surroundings net nodes has been used in D-Flow FM, but the bottom level in D-Flow FM is specified counterclockwise in comparison with the bottom level in D3D.

The vertical level in D3D is specified as positive towards the bottom level and negative towards the water level. In D-Flow FM the vertical level is positive towards the water level and negative towards the bottom level. This is illustrated in Figure 2-5.

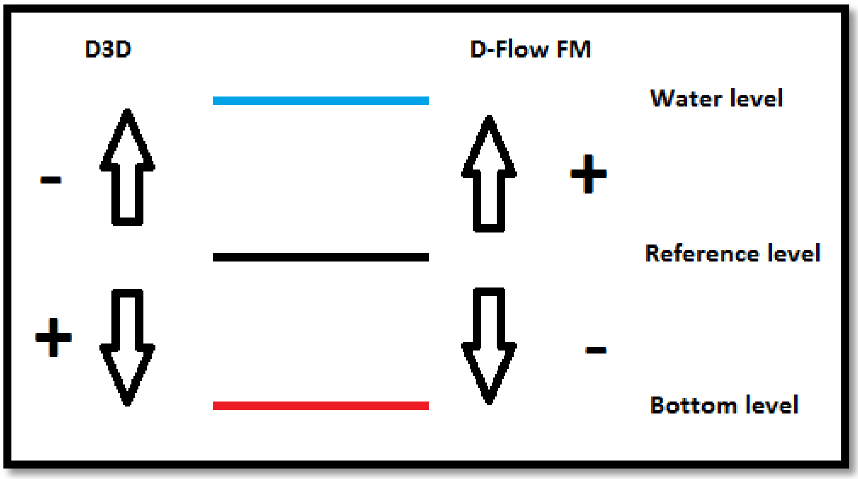

Figure 2-5; Clockwise interpretation of water level

2.3 Time-Step

The cell sizes of the models differ a lot. If the time-step is too large, D-Flow FM cannot calculate the discharge in the small cells properly. A smaller time-step should be used in models with small cells. Since it is not clear which time-step is satisfying for the small cells, an automated time-step is used in the models with small cells. This automated time-step is CFL (Courant Friedrichs-Lewy)-based. When using a CFL-base time-step, the time-step is calculated on the basis of the cell-sizes.

2.4 Conclusion

While D-Flow FM does not use exactly the same method to compute a curvilinear grid, there will be some difference in the computed model results between D3D and D-Flow FM. The difference in the computed model results between the D3D model and the converted model are caused by the incomplete development of D-Flow FM. There are three important differences in the computation between D3D and D-Flow FM:

- D-Flow FM uses next to a curvilinear grid also flexible meshes like triangles, quadrilaterals, pentagons and hexagons.
- There are some numerical differences between D3D and D-Flow FM through the incomplete development of D-Flow FM.
- D-Flow FM has a option to use a CFL-Based time-step while D3D does not have such an option.

The differences between the D3D models and the detailed D-Flow FM models will be larger than the difference between the D3D model and the D-Flow FM conversion model. Not just the computation differs in this case, the grid and the time-step in more detailed model differs also from the D3D model. The different grids and other model input data will be discussed in the next chapter.

3 Model input data analysis

Different models will be used to analyze the difference between Delft3D to analyze the implementation of structures in Delft3D and D-Flow FM. This chapter will discuss the differences between the models used in the analysis. Other model input data like the bathymetry and the external forcing will also be discussed in this chapter.

3.1 External forcing

There are two kinds of external forcing. External forcing that just effects the output and external forcing that also contains model input data. The open boundaries contain input for the model. A model cannot contain a whole river system, open boundary contain the conditions at the edges of a model. The open boundary conditions could be a discharge, water level, velocity or something else.

Cross-sections and observation points are locations where the output will be made visible. Both the open boundaries and the cross-sections are displayed in Figure 3-1 and they will be discussed in more detail below.

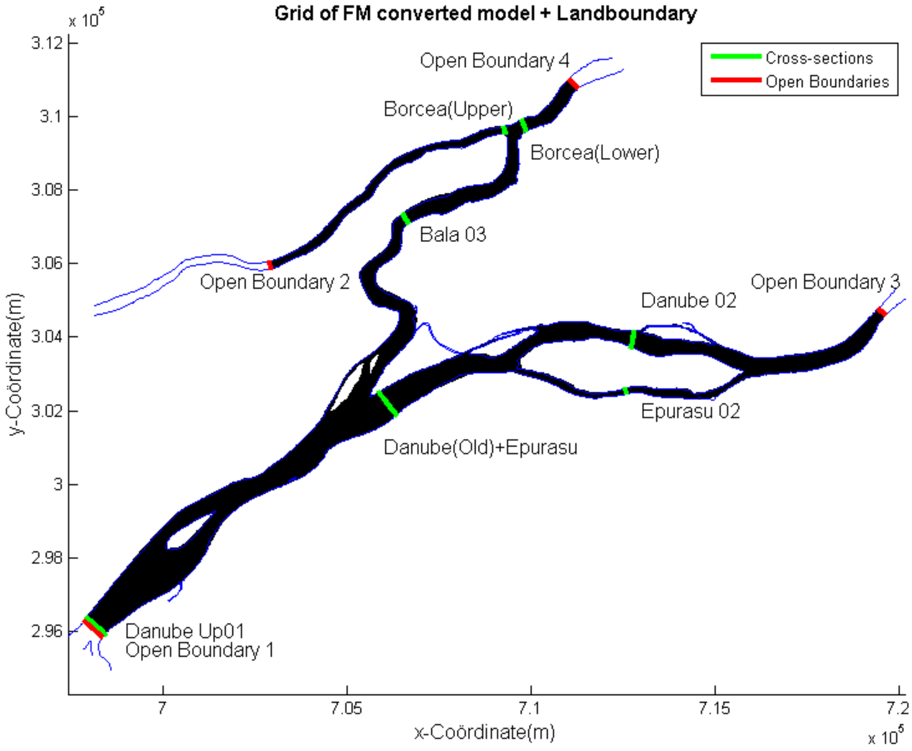

Figure 3-1; Cross-sections and open boundaries

3.1.1 Open boundaries

As displayed in Figure 3-1 there are four open boundaries. The conditions at the upstream boundaries are discharges and the conditions at the downstream boundaries are water levels. The values for the discharges and the water level are displayed in Table 3.1. The values are based on local data measurements.

Open Boundary	Name	Type	Amount
1	Danube up	Discharge	5080 m^3/s
2	Borcea up	Discharge	371 m^3/s
3	Danube down	Water level	7,37 m
4	Borcea down	Water level	7,59 m

Table 3.1; Open boundary conditions

3.1.2 Cross-sections and observation points

The computed results of the different models will be compared over time and over space. The discharges over time at the cross-sections displayed in Figure 3-1 are compared with each other. The water level at different observation points in the D3D model will be compared with the water level at observation points in the D-Flow FM model. The observation points lay in the middle of the associated cross-section.

There were more cross-sections available than the cross-sections used. The reason that the cross-section shown in Figure 3-1 has been used is that they perfectly measure the discharge distribution at bifurcations. The cross-sections Danube Up01 and Borcea (Upper) have been added to see if the discharge at the cross-section was the same as the discharge at the upstream open boundaries. In an earlier stage of the project there was a problem that the discharge at the cross-sections Danube Up01 and Borcea (Upper) was not equal to the discharge at the respectively open boundaries Danube Up and Borcea Up. There are no bifurcation between those open boundaries and cross-sections, so the discharge should be approximately equal. Adding the cross-sections Danube Up01 and Borcea (Upper) makes it easy to check if the condition at the open boundary worked well.

3.2 Bathymetry

Two different bathymetries have been used for the analysis in chapter 5. One version of the bathymetry is the current situation and the other version of the bathymetry is the current situation with the implementation of some structures in the Bala branch and the Epurasu branch.

3.2.1 Samples V10

The bathymetry used to visualize the current situation is called samples V10. The samples consist partly of local data measurements and partly of interpolation between those measurements. The samples were developed for a long time. The samples used for the analysis is the tenth version of the samples. The samples are shown in Figure 3-2. It seems from the samples that the bathymetry in the Danube is very unequal. Different grids could make a large different in the computed model results. If a coarse grid is used, bumpy areas could become very smooth. Unequal bathymetry could also cause unequal water levels with peaks.

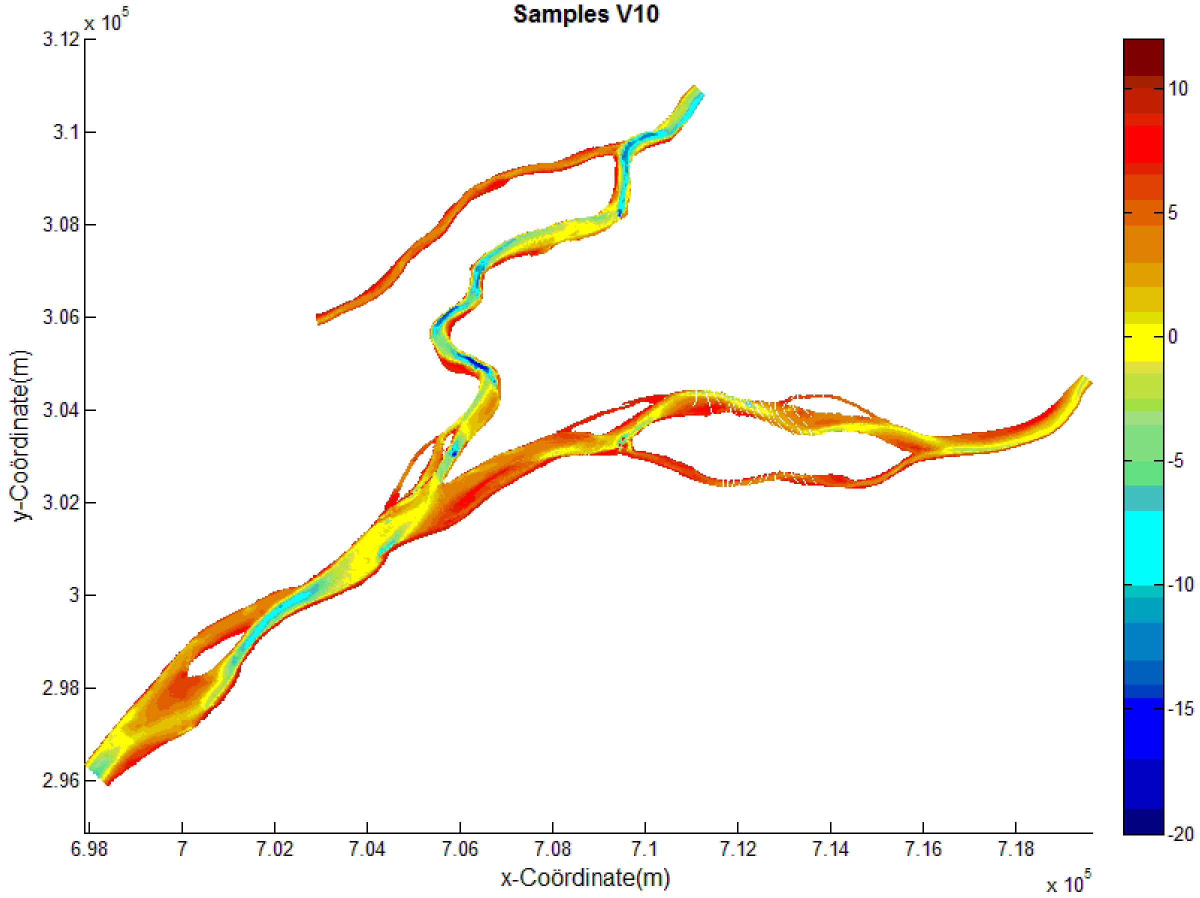

Figure 3-2; Samples V10

3.2.2 Samples V10 with structures

Samples V10 with structures is the bathymetry used for samples V10 and the implementation of three structures in the Bala branch and before the Epurasu branch. The two structures shown in Figure 3-3 are the Bala guiding wall and the Bala Bottom sill. The dataset used, is not very detailed. It is hard to say how the Bala guiding wall and the Bala Bottom sill look. That is why there is an extensive description for the structures:

Bala guiding wall

The Bala guiding wall consists of two parts. The first part is a guiding wall at the left side of the Bala/Upper Danube branch. The second part is a bank protection at the right side of the Bala branch. The red dots of the Bala guiding wall in Figure 3-3 are an increase of the bottom level to 11 meters. The guiding wall prevents water to flow through the left side of the islands in the Bala branch. The Bala guiding wall also protects the right side of the Bala branch from sedimentation.

Bala bottom sill

The Bala bottom sill is an increase of the bottom level at a part of the Bala branch to 0,22 meter above the reference level with a slope. The slope has a maximum angle of 1:1.5 near the top of the structure. The Bala bottom sill is located across the Bala branch between the two sides of the Bala guiding wall.

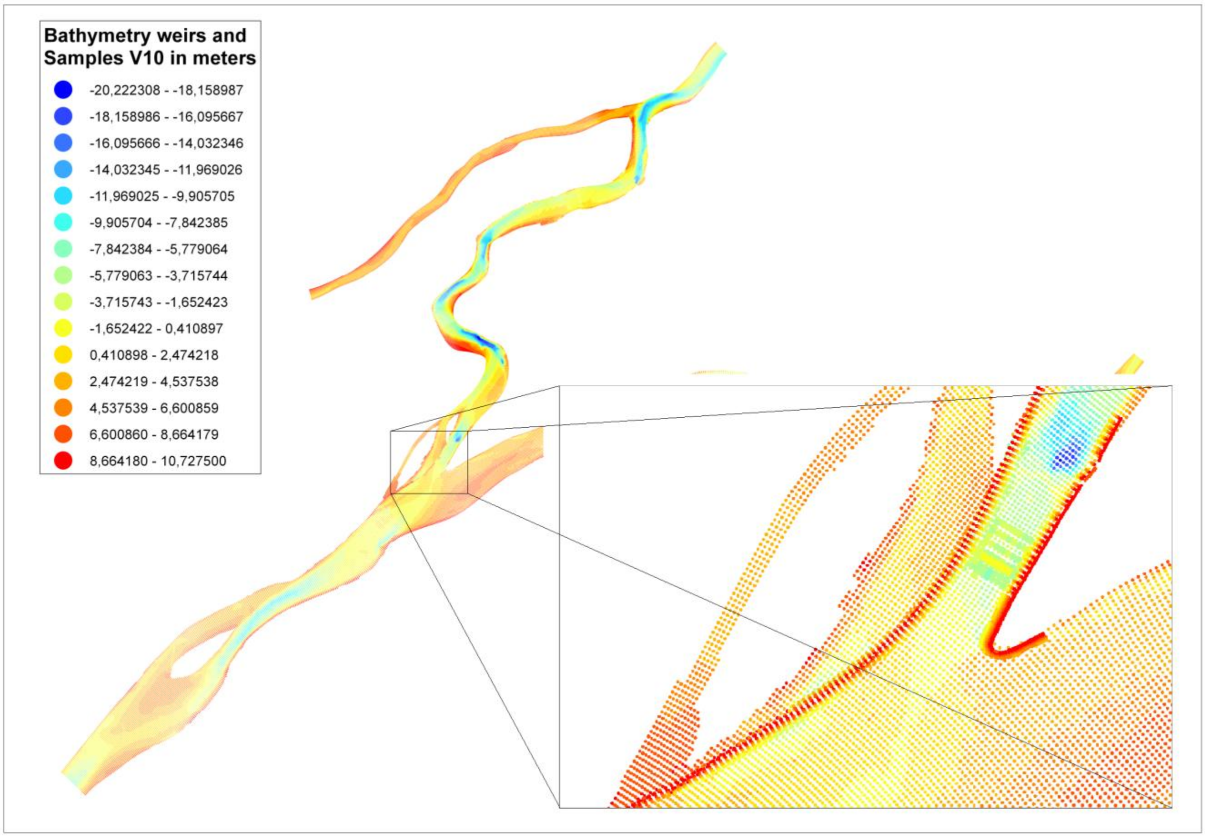

Figure 3-3; Samples v10 with structures and zoom in on Bala bottom sill and Bala guiding wall

The last structure is a dyke with opening before the Epurasu branch. The dataset of the dyke before the Epurasu branch is much more detailed than the dataset of the other structures. The dyke before the Epurasu branch prevents a high discharge in the Epurasu branch. This should increase the discharge in the Lower Danube branch. The Epurasu dyke is shown in Figure 3-4.

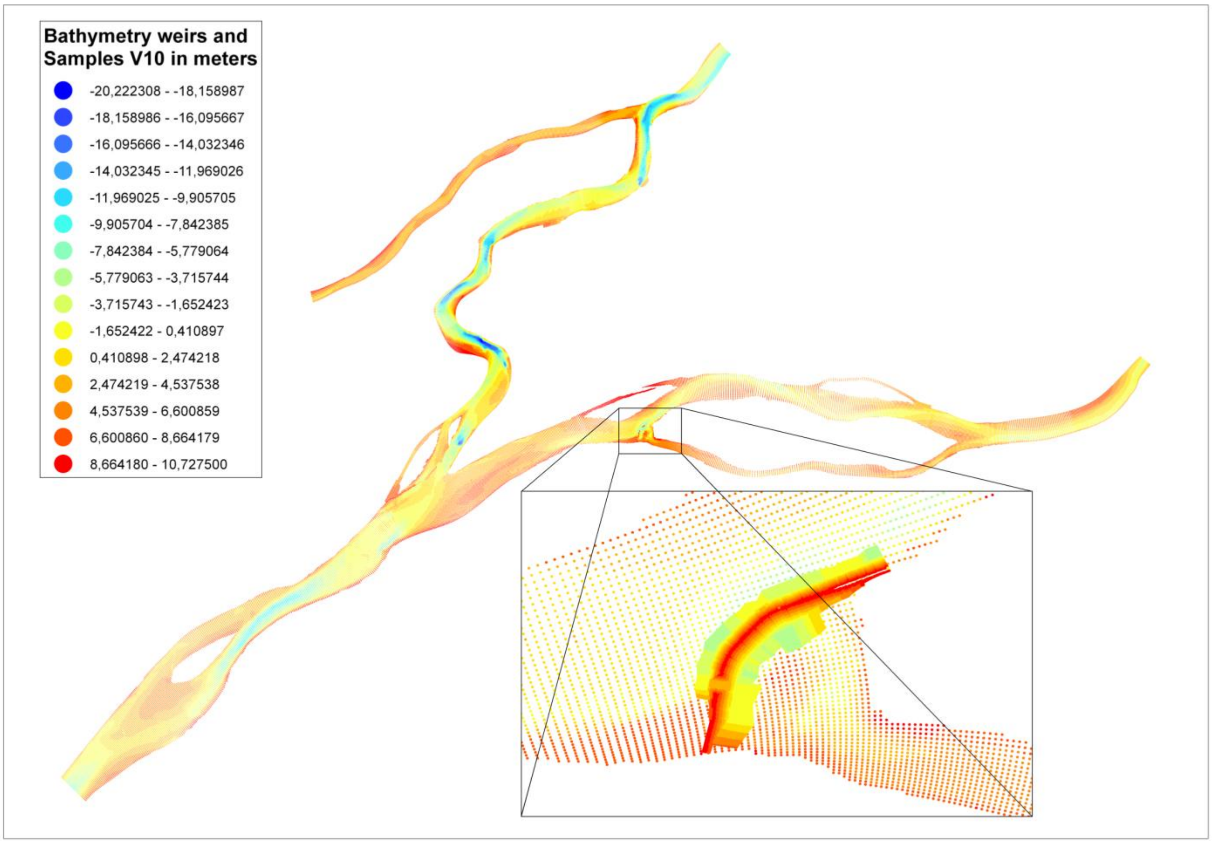

Figure 3-4; Samples V10 with structures and zoom in on Epurasu dike with cunete

3.3 Grids

Different grids have been developed to analyze the differences between D3D and D-Flow FM. The original D3D grid is used to construct the D-Flow FM conversion model, the grid of this model is exactly the same as the grid of the D3D model. The grid is converted by a conversion tool (See Appendix C). The computed model results of the D-Flow FM should match the computed model results of the D3D the most.

The other two models that have been created are the D-Flow FM Detail model and the D-Flow FM Detail 1*1 model. The D-Flow FM Detail model is detailed on the locations of the bifurcations. The discharge distribution is determined at the location of the bifurcations. Therefore, the bifurcations are interesting areas in the model and a detailed grid is desired for these locations. The rest of the area is less interesting, so a less detailed grid is used for these parts.

The D-Flow FM Detail 1*1 model is equal to the D-Flow FM Detail model, except for the location of the possible implementation of the Bala bottom sill (See Figure D-2). Since the Bala Bottom sill has a very steep slope and the area at the location of the possible implementation of the Bala bottom sill is very unequal, a very detailed grid is required a the location of the possible implementation of the Bala bottom sill. The D-Flow FM Detail 1*1 has a grid with cells of 1 meter by 1 meter at the location of the possible implementation of the Bala bottom sill.

There will be a closer look at the differences between these models with the bathymetry without structures in chapter 4. But first, the different grids will be shown and discussed. For each grid, a characteristic part of the grid will be shown. The entire grid of each model can be found in Appendix E. At last the cell sizes of the different grid and the different parts of the grid will be discussed. This gives some insight in the differences between D3D and D-Flow FM.

3.3.1 Delft3D

The grid of the D3D model, shown in Figure 3-5, is made for the main channel and parts of the floodplain. The parts of the floodplain covered by the grid are dry points in the D3D model. Figure

3-5 makes the disadvantage of D3D clear for areas with a lot of curves and bifurcations. The edge of the grid does not match the land boundary very well. The edge of the grid is very angular, while the land boundary is curvilinear.

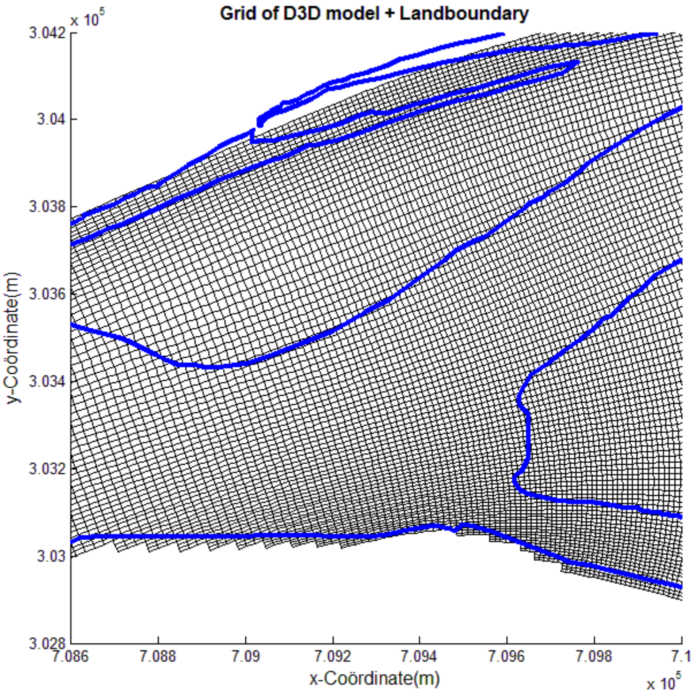

Figure 3-5; Part of grid of D3D model

3.3.2 D-Flow FM conversion

The grid shown in Figure 3-6 is converted with a conversion tool (Appendix C) from D3D to D-Flow FM. The Delft3D grid (Figure 3-5) is used to make the D-Flow FM grid. Except that the dry points in Delft3D have been removed from the D-Flow FM conversion grid, the grid is the same. D-Flow FM cannot calculate with dry points, that is why they have been removed in the D-Flow FM conversion grid. This grid is used to get the results as close to the D3D model as possible. This grid is not optimized to the possibilities of D-Flow FM. The other D-Flow FM grids, which are shown in Figure 3-7 and Figure 3-9 are improved with the possibilities of D-Flow FM.

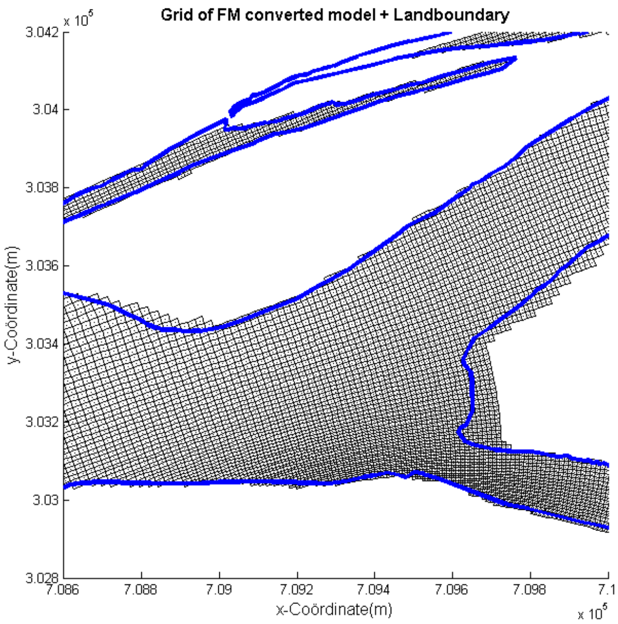

Figure 3-6; Part of grid of D-Flow FM conversion model

3.3.3 D-Flow FM Detail

The grid shown in Figure 3-7 is called D-Flow FM detail and the grid is detailed at critical points one and two and coarse at the rest of the model. Critical points one and two are the bifurcations and the discharge distribution is determined at the bifurcations. The rest of the model is not very interesting for the discharge distribution. A coarse grid is satisfactory for the uninteresting part of the grid. Having a coarse grid for uninteresting parts of the grid saves a lot of computational time.

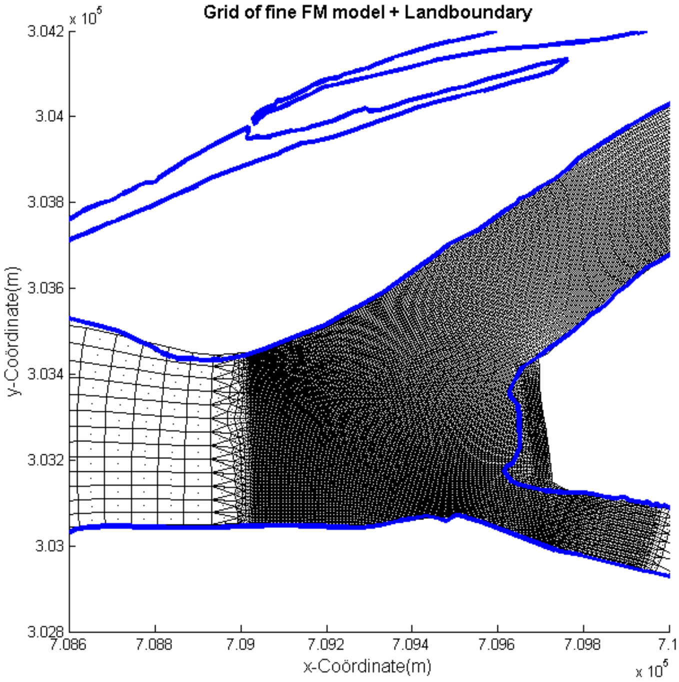

Figure 3-7; Part of grid of D-Flow FM detail model

The grid is based on the grid of the D-Flow FM conversion model. The grid is improved where possible. While the edges of the grid in the D-Flow FM conversion model did not match the land boundary very well, the D-Flow FM detail model had some improvements which made the edge of the grid matches the land boundary quite good. Figure 3-8 shows an example of an improvement of the grid, the left side of the figure shows the D-Flow FM conversion model and the right side shows the D-Flow FM detail model. Figure 3-8 is just meant to show an example of an improvement in the D-Flow FM detail model. The area use is a less detailed part in the D-Flow FM detail model.

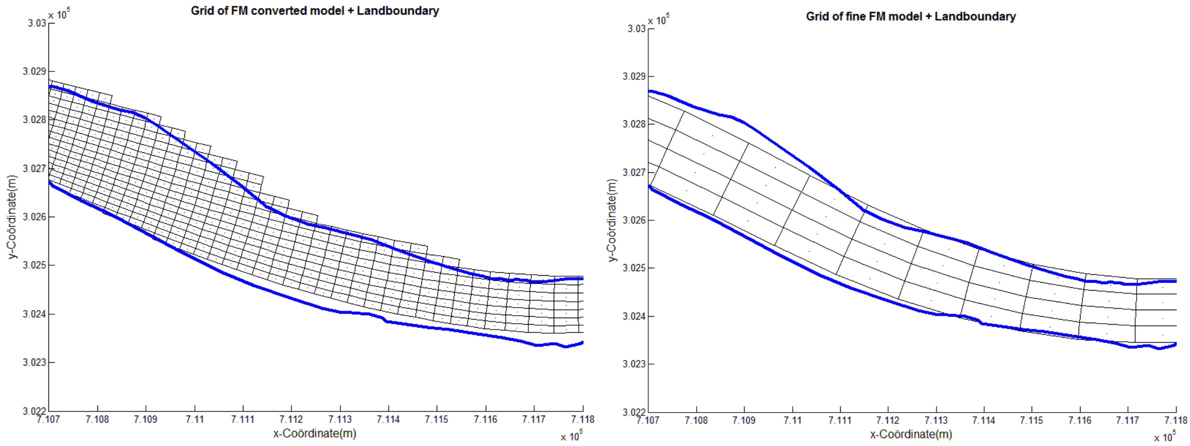

Figure 3-8; Improvements in grid of D-Flow FM detail model with respect to D-Flow FM conversion model

The edges of the grid in the D-Flow FM model are less angular than the D-Flow FM conversion model.

3.3.4 D-Flow FM detail 1*1

The D-Flow FM detail grid is used to make the D-Flow FM detail 1*1 grid. Those grids are almost the same. The only difference between the models is that the D-Flow FM detail 1*1 has a much more detailed grid at the location of the possible implementation of the Bala bottom sill (See chapter 3.2.2). The detailed part of the D-Flow FM detail 1*1 model is shown in Figure 3-9. It is not possible to shown the whole detailed part of the model, in that case it is only possible to see a black area and it is not possible to see the cells. Appendix E shows more figures of the D-Flow FM detail 1*1 grid.

The reason such a detailed grid is desired is that Bala bottom sill (See Appendix D.1) has a steep slope for which it is impossible to calculate properly with a coarse grid.

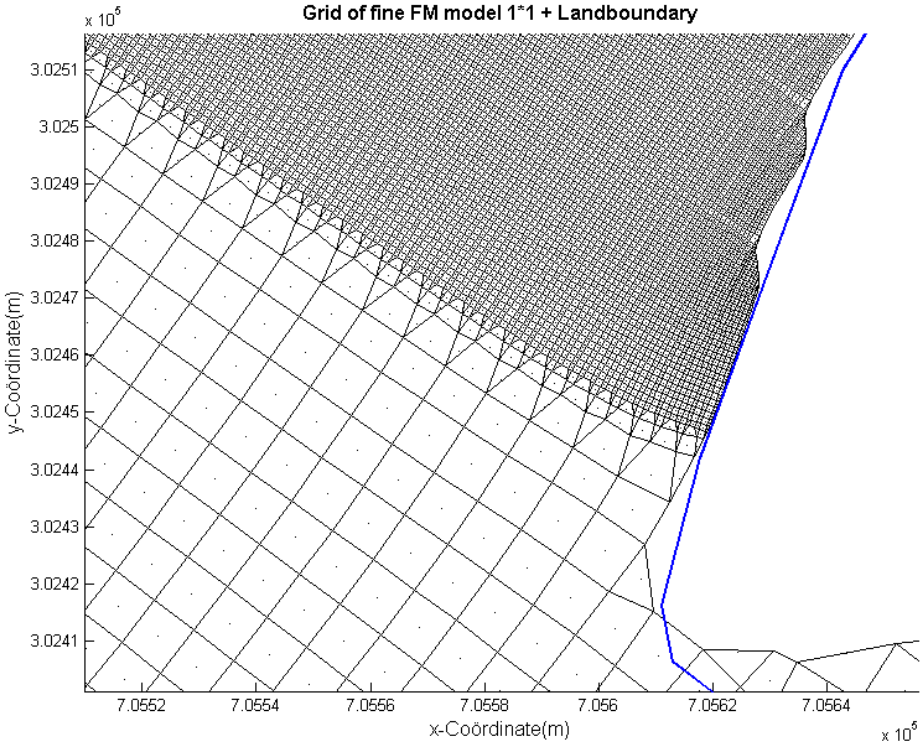

Figure 3-9; Part of grid of D-Flow FM Detail 1*1 model

3.3.5 Cell Sizes

The averages cell sizes give some insight in the differences between the models. The average cell sizes are shown in Table 3.2. The cell sizes above the interrupted line are the average cell size per model. The cell sizes below the interrupted line are differences between the detailed and the coarser part of the D-Flow FM detail and the D-Flow FM detail 1*1 models. The first value is the average cell size of the coarse part of the D-Flow FM detail models. The second value is the average cell size of the detailed part of the grid of the D-Flow FM model and the last value is the average cell size of just the very detailed part of the D-Flow FM detail 1*1 model. While the average cell size of the whole D-Flow FM Detail 1*1 model is just twice as small as the D-Flow FM conversion model, the average cell size of the detailed part is just 1 square meter. D-Flow FM offers good opportunities to differ the cell size in a model.

Model	Cell size in square meters
Delft3D	~240
D-Flow FM Conversion	214,92
D-Flow FM Detail	261,93
D-Flow FM Detail 1*1	107,24
D-Flow FM Detail coarse	3905,82
D-Flow FM Detail fine	58,18
D-Flow FM Detail 1*1 fine	0,988

Table 3.2; Average cell size of different models and part of the models

3.3.6 Computation time

Since a lot of models will be used during a project such as this project it is interesting to know how long it takes for a model to run. This depends on multiple things, such as the grid, time step and the model time. The model time (virtual time length of the model) is the same in all models. This is not possible for the time-step; the grid cells are too small in the D-Flow FM Detail 1*1 model (see chapter 2.3). The computational times are displayed in Table 3.3. These values are based on the last run of each model. The computer used to run the models is a Deltares computer with a Intel core i3 processor.

Model	D3D	D-Flow FM conversion	D-Flow FM Detail	D-Flow FM Detail 1*1
Computational time	~20 hours	~20 hours	~12 hours	12 to 16 weeks

Table 3.3; Computation time per model

The computation time is for the first 3 models is quite equal, the reason that the D-Flow FM Detail 1*1 model differs so much from the other model is that the time-step is so small. The time-step in the first three model is manually adapted to 1,5 seconds. The time step in the D-Flow FM Detail 1*1 model is automatically adapted to 0,008 seconds (CFL-based).

3.4 Conclusion

When the different grids in chapter 3.3 are combined with the different bathymetries in chapter 3.2 there will be 8 different models, the grids are shown in Table 3.4. Each grid will be used for two models, once without structures and one with structures. The differences in the computed model results will be discussed in chapter 5. The D3D model and the D-Flow FM conversion model will be compared in more detail in chapter 4. The bathymetry without structures will be used for this comparison.

Grid / Bathymetry	D3D	D-Flow FM conversion	D-Flow FM Detail	D-Flow FM Detail 1*1
Without structures	Original D3D grid	Conversion of the D3D grid, created with a conversion tool	Detailed at the locations of the bifurcations. Coarse at other parts of the grid.	The same as D-Flow FM Detail model. More detailed at possible location of Bala bottom sill.
With structures				

Table 3.4; Different models used in the analysis

The model input data of the models should not cause differences in the computed model results. The model input data are exactly the same in all models. The location and the condition of the open boundary are exactly the same in all the models. The location of the cross-sections and the observation points are also the same in all models. The conditions at the cross-sections and the observation points depend on the computed model results.

4 Comparison D3D versus converted model

The difference between the computed model results will be discussed in chapter 5. It is interesting to take a closer look at the effect of the numerical difference between D3D and D-Flow FM. This is possible with the comparison between D3D model and the D-Flow FM conversion model. The computed model results of the D3D model and the D-Flow FM conversion model will be compared in more detail. The bathymetry used for this comparison is the bathymetry without structures. Since there are no differences between the grid, the bathymetry and the model input data, the only differences are the numerical differences between Delft3D and D-Flow FM.

Most important to know for this project is the difference in discharge distribution. The structures will probably being placed to change the discharge distribution. The discharge distribution will be compared first. After that, the absolute difference in discharge between the models will be compared. It is also interesting to know why the differences occur. Therefore, the water level at observation points and the water level in the Bala branch will be compared as well. At last the spin-up will be compared.

4.1 Discharge

The difference in discharge distribution and the absolute difference in discharge at cross-sections depend on each other. The absolute difference gives a good overview of the difference while the difference in discharge distribution is interesting for this study. Both differences will be discussed. First, the difference in discharge distribution will be discussed and second, the absolute difference in discharge will be discussed. The relative difference will be discussed shortly as well.

4.1.1 Discharge distribution at bifurcations

The discharges with respect to time at the cross-sections mentioned in Figure 3-1 are shown in Figure 4-1. The high discharge in the beginning is caused by the spin-up. The spin-up will be explained further in chapter 4.4.

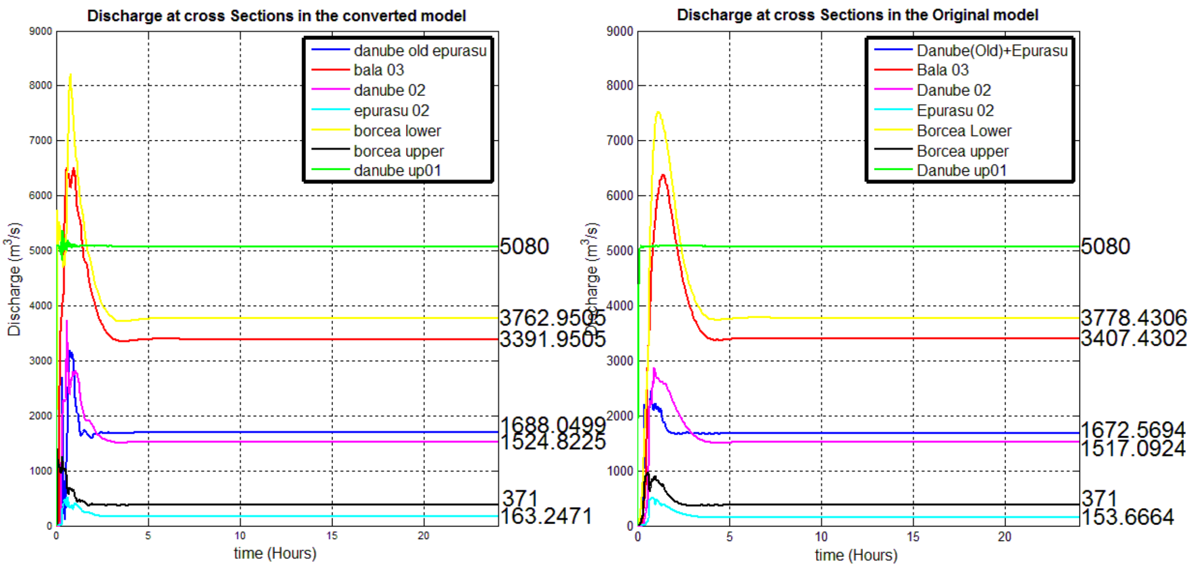

Figure 4-1; Discharge in the D3D model and the D-Flow FM conversion model

The discharges over time at cross-sections look quite equal at first sight. Below the difference in discharge distribution is calculated. Therefore the ratio of the discharge between to two different branches after a bifurcation has been calculated for both models. The relative difference in the discharge distribution between D3D and D-Flow FM is calculated by the difference in percentage between the two ratios.

The ratio between the distribution of discharge in the D3D model at the bifurcation between the Bala branch and the Lower Danube branch is:

$$\frac{Discharge\ Bala\ 03}{Discharge\ Danube\ (Old) + \ Epurasu} = \frac{3407{,}430}{1672{,}569} = 2{,}037$$

The ratio between discharges at the same bifurcation in the D-Flow FM model:

$$\frac{Discharge\ Bala\ 03}{Discharge\ Danube\ (Old) + \ Epurasu} = \frac{3391{,}951}{1688{,}050} = 2{,}009$$

The relative difference in the distribution of discharge between D3D and D-Flow FM model at the bifurcation between the Bala branch and the lower Danube branch is:

$$\frac{Ratio\ D3D}{Ratio\ D - Flow\ FM} = \frac{2{,}037}{2{,}009} = 1{,}014 - 1 = 0{,}014 * 100 = 1{,}4\ \%$$

The ratio between discharges at the bifurcation between the Lower Danube branch and the Epurasu branch in the D3D model is:

$$\frac{Discharge\ Danube\ 02}{Discharge\ Epurasu\ 02} = \frac{1517{,}092}{153{,}666} = 9{,}873$$

The ratio between discharges at the same bifurcation in the D-Flow FM model is

$$\frac{Discharge\ Danube\ 02}{Discharge\ Epurasu\ 02} = \frac{1524{,}823}{163{,}247} = 9{,}341$$

The relative difference in the distribution of discharge between D3D and D-Flow FM model at the bifurcation between the Lower Danube branch and the Epurasu branch is:

$$\frac{Ratio\ D3D}{Ratio\ D - Flow\ FM} = \frac{9{,}873}{9{,}341} = 1{,}057 - 1 = 0{,}057 * 100 = 5{,}7\%$$

The difference in discharge distribution is just 1,4% at the bifurcation between the Bala branch and the Danube branch. The difference at the bifurcation between the Epurasu branch and the Danube branch is larger: 5,7%. The difference at the bifurcation between the Epurasu branch and the Danube branch is notable since there are only numerical differences between the models.

4.1.2 Difference in discharge at cross-sections

The absolute difference in discharge at cross-sections between the models is shown in Figure 4-2. The difference in discharge at the cross-sections Danube Up01 and Borcea Upper is almost equal to zero. These cross-sections lay before a bifurcation. The discharge here should be equal to the discharge at the open boundary. Since the same open boundary conditions have been used in both models, the difference between the models at upstream boundaries should be zero.

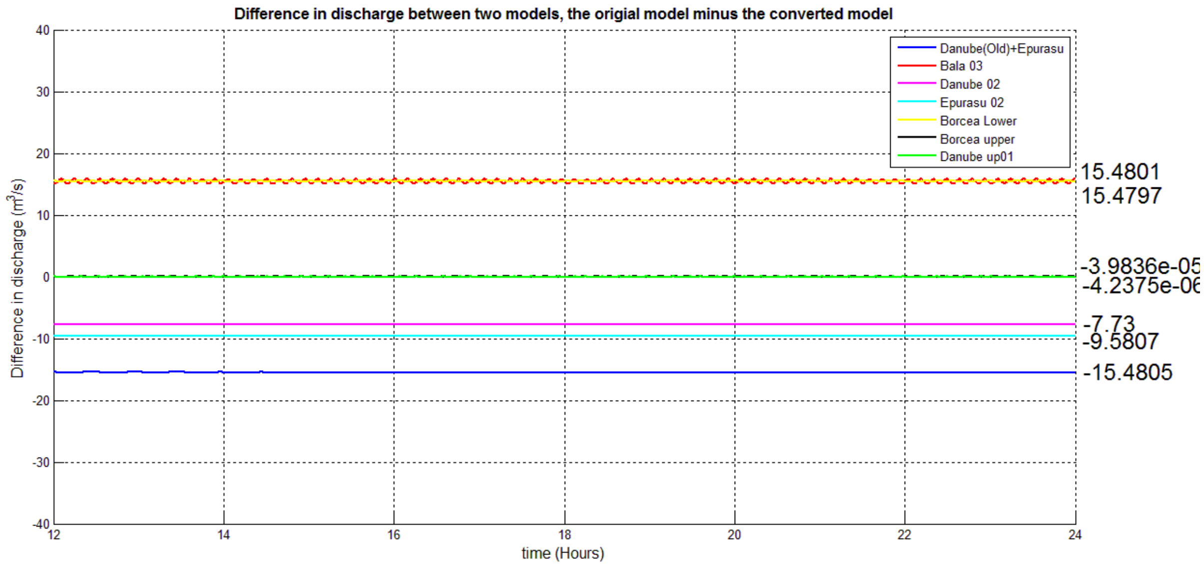

Figure 4-2; Difference in discharge between the D3D model and the D-Flow FM model

The absolute difference just gives a good overview of the differences. It does not say much if the original discharge is not known. Therefore the deviation in percentage from the D-Flow FM conversion model with respect to the D3D model is calculated in Table 4.1. The difference from Figure 4-2 is used in the table, it is multiplied with -1 to get the desired results. There are no outstanding deviations, except for the deviation at the Epurasu 02 cross-section. At that cross-section the difference in discharge in percentage is 6,23%. This large relative difference is caused by the low discharge in the Epurasu branch. The absolute difference in the Epurasu branch is not bigger than the differences in other branches. Since the discharge in the Epurasu branch is low, the relative difference of a small deviation is larger than with a higher discharge.

Cross-section	Discharge in D3D model	Difference in discharge between models	Deviation from D-Flow FM conversion in percentage
Danube(Old) + Epurasu	1672,57	15,48	0,93%
Bala 03	3407,43	-15,48	-0,45%
Danube 02	1517,09	7,73	0,51%
Epurasu 02	153,67	9,58	6,23%
Borcea Lower	3778,43	-15,48	-0,41%

Table 4.1; Deviation from discharge from D3D model with respect to discharge in D-Flow FM model

4.2 Water level at observation points

Just as the discharges at cross-sections, the difference in water level at observation points (Figure 4-3) between the D3D model and the D-Flow FM seems quite small. But if you take a look at the difference in the average water level, stated at the end of each line, there are some differences. The differences between the water levels are shown in Figure 4-4. A first conclusion while looking at the water level at observation points and the differences in water level between the models is that the difference in water level between models at observation points with a higher water level are larger.

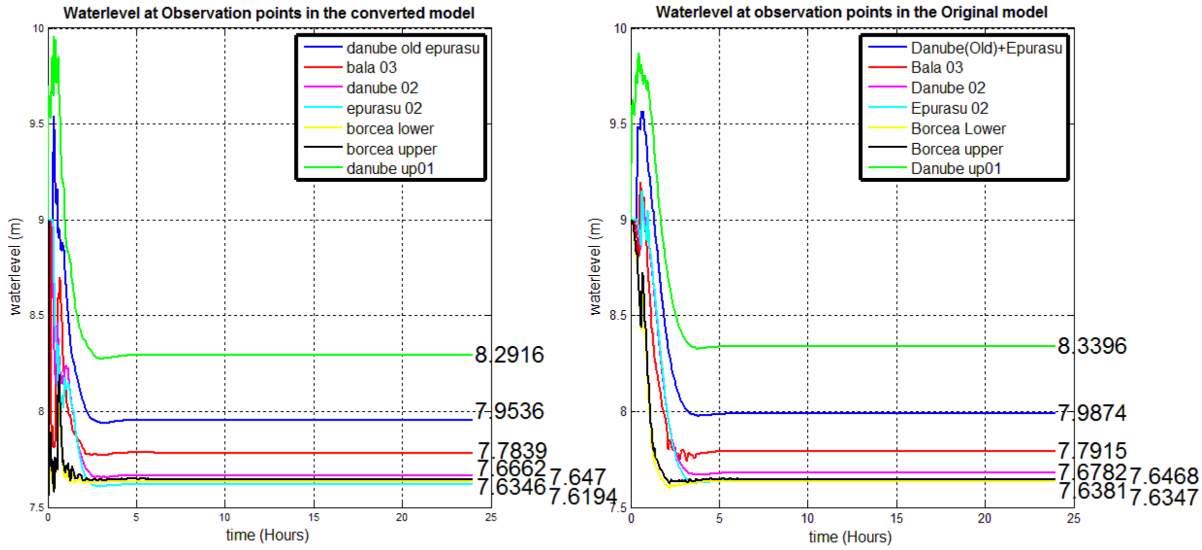

Figure 4-3; Water level in the D3D model and the D-Flow FM converted model

What is associated with the remark above is that the differences in water level at observation points upstream are higher than downstream. The water level upstream is higher than the water level downstream and the water level downstream is fixed, that is why the differences downstream are very low. The differences in water level between the models are caused by the numerical differences.

Table 4.2 contains the deviation in water level at observation points from the D-Flow FM model with respect to the D3D model. The deviation of D-Flow FM model with respect to the D3D model is also shown in Figure 4-2. The largest difference occurs at the Danube (Old) + Epurasu observation point. But, all differences are very small. The difference in water level upstream seems higher than the difference in water level downstream. The water level in the D3D models is upstream higher than the D-Flow FM model.

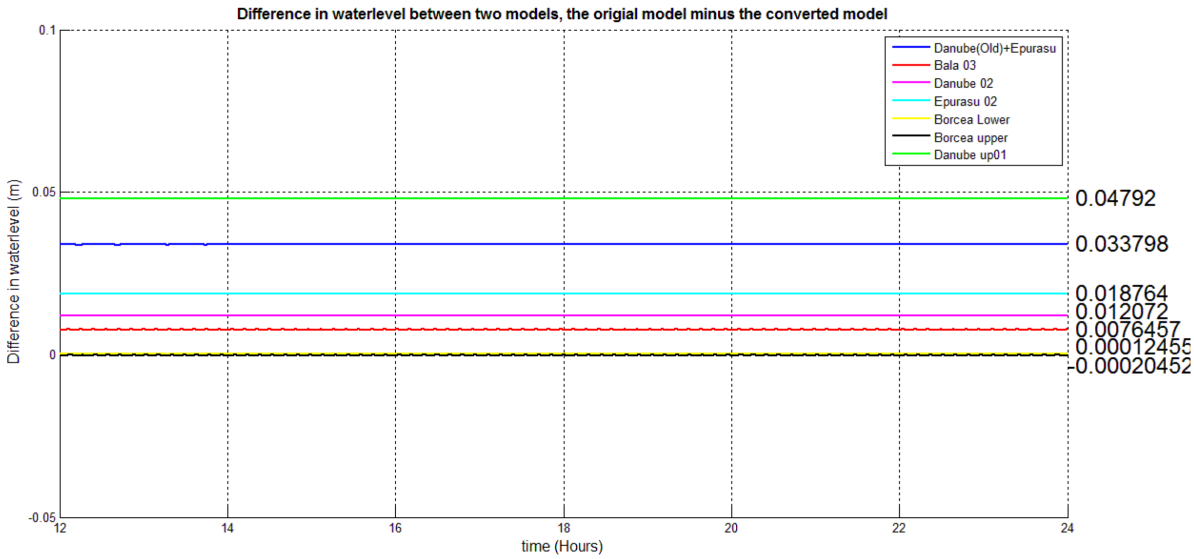

Figure 4-4; Difference in water level between the D3D model and the D-Flow FM conversion model

Observation points	Water level in D3D model	Difference in water level between models	Deviation from D-Flow FM conversion in percentage
Danube(Old) + Epurasu	7,987	-0,0338	-0,004%
Bala 03	7,792	-0,0076	-0,001%
Danube 02	7,678	-0,0121	-0,002%
Epurasu 02	7,638	-0,0188	-0,002%
Borcea Lower	7,635	-0,0001	0,00

Table 4.2; Deviation from water level from D3D model with respect to discharge in D-Flow FM model

4.3 Water level in Bala branch

It is expected that the implementation of the structures in the Bala branch will have a large effect on the water level in the Bala branch. The water level in the Bala branch will possibly change when the Bala bottom sill gets implemented in the model. Therefore, the difference in water level in the Bala branch is important to know. The water level is measured at a line crossing the location where the Bala bottom sill will be implemented. The line is displayed in Figure 4-5. This line is chosen according to grid indices in the D3D model, so that the line lays exactly in the middle of the Bala branch at the location of the possible implementation of the Bala bottom sill.

The water level across the line in the D3D model and the D-Flow FM conversion are displayed in Figure 4-6. The water level of the D-Flow FM model is lower over the whole line. This corresponds with the lower water level in D-Flow FM at observation points. The lines in the plot are almost parallel. The difference seems to be a little bit larger upstream of the bottom sill. This makes sense since the water level downstream is fixed and the water level at upstream observation points in the D3D model is higher than the water level at upstream observation points in the D-Flow FM model.

The downward peak in the water level is caused by the unequal bathymetry discussed in chapter 3.2.1. The water level with the bottom level over the line displayed in Figure 4-5 is displayed in Figure 4-7. The water level at the location of the downward peak in the bottom level is lower in the D-Flow FM model, while the peak in the D3D model is bigger. The unequal bathymetry has higher effect on the D3D model. The peak in the D3D model is 7 centimeter, while the peak in the D-Flow FM model is just 4 centimeter.

When there are no differences between the D3D model and the D-Flow FM model in the discharge, but there are differences in the water level the friction coefficient has to be different as well.

$$Q \sim C * \sqrt{R * i} * A$$

With:

$R \sim h$ For wide channels

$A \sim h * b$

So:

$$Q \sim C * \sqrt{h * i} * h * b$$

$$Q \sim C * h^{\frac{3}{2}} * i^{\frac{1}{2}} * b$$

When the water level upstream in D3D is higher and the discharge (Q), bottom slope (i) and the channel width (b) are equal, the friction coefficient has to be lower in the D3D model. There should be a difference between D3D and D-Flow FM on how they are calculating the friction coefficient. Otherwise differences in the water level could not occur, if all other circumstances stay equal. The difference in the friction coefficient could cause the small difference in the discharge, but this is very hard to demonstrate.

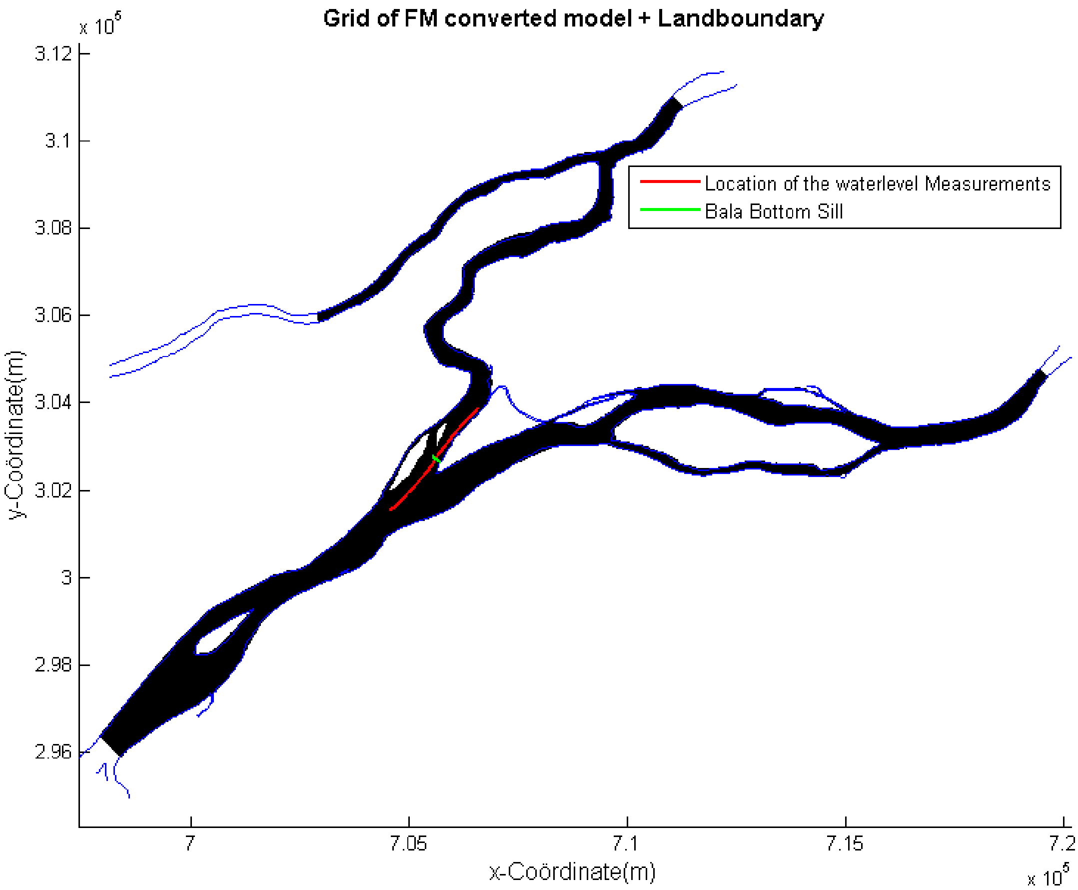

Figure 4-5; Line over where the water level is plotted

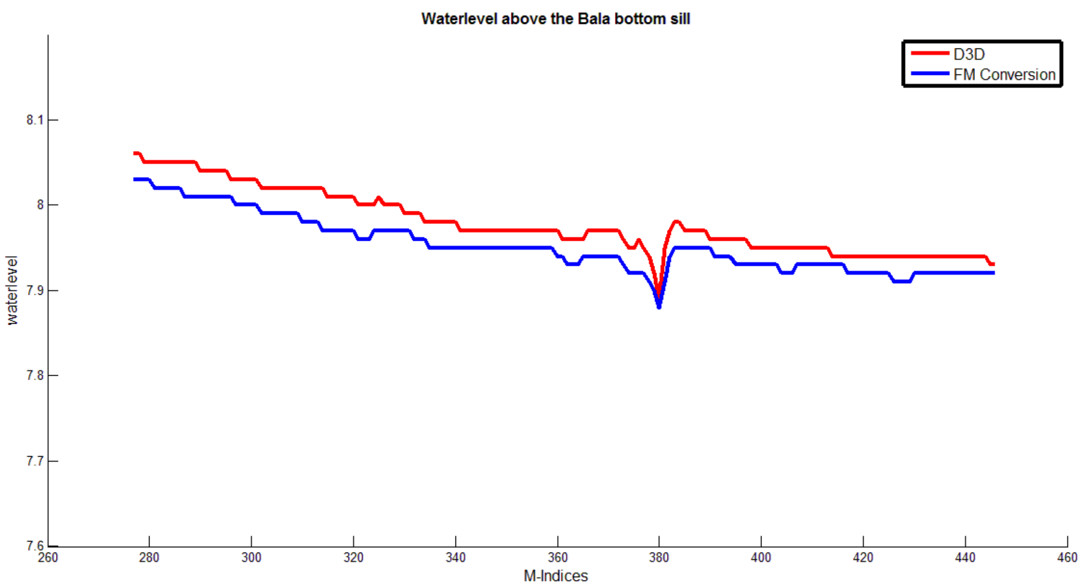

Figure 4-6; Water level in the Bala branch

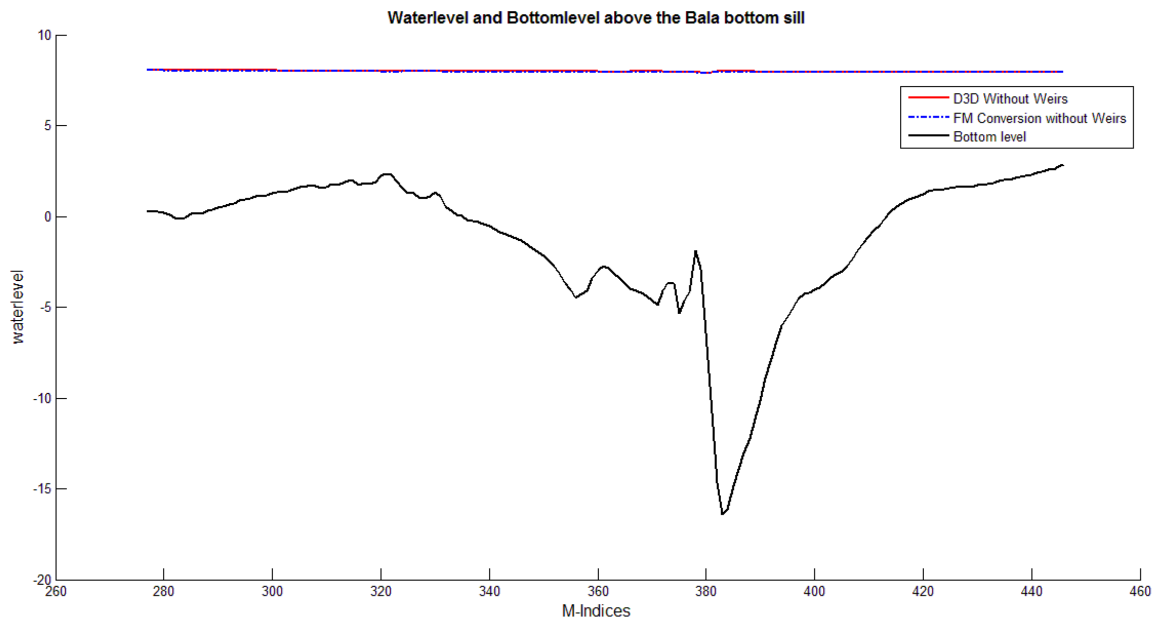

Figure 4-7; Water level and bottom level in the Bala branch

4.4 Spin-up

Both models have a uniform water level in the beginning. A uniform water level does not exist in a real river with flowing water. Therefore, the model has to get used to the open boundary conditions. For example, the water level at the open boundary in the Borcea branch is 7,59 meter above the reference level. There is a large difference between the 7,59 meter and the 9 meter used in the beginning of the simulation. It takes some time for the model to change the uniform water level of 9 meter at the open boundary in the Borcea branch to 7,59 meter. This is called the spin-up. The spin-up time depends on for example, the size of the model and the difference between the uniform water level and the water level at open-boundaries.

Figure 4-8 shows the different spin-ups of the models. The discharge at cross-sections in the first 6 hours is displayed. The discharges in the spin-up of the D3D model seem to change smoother than the discharges in the D-Flow FM model. Something else that could be concluded from Figure 4-8 is that the spin-up of the D-Flow FM model is finished earlier than the spin-up of the D3D model.

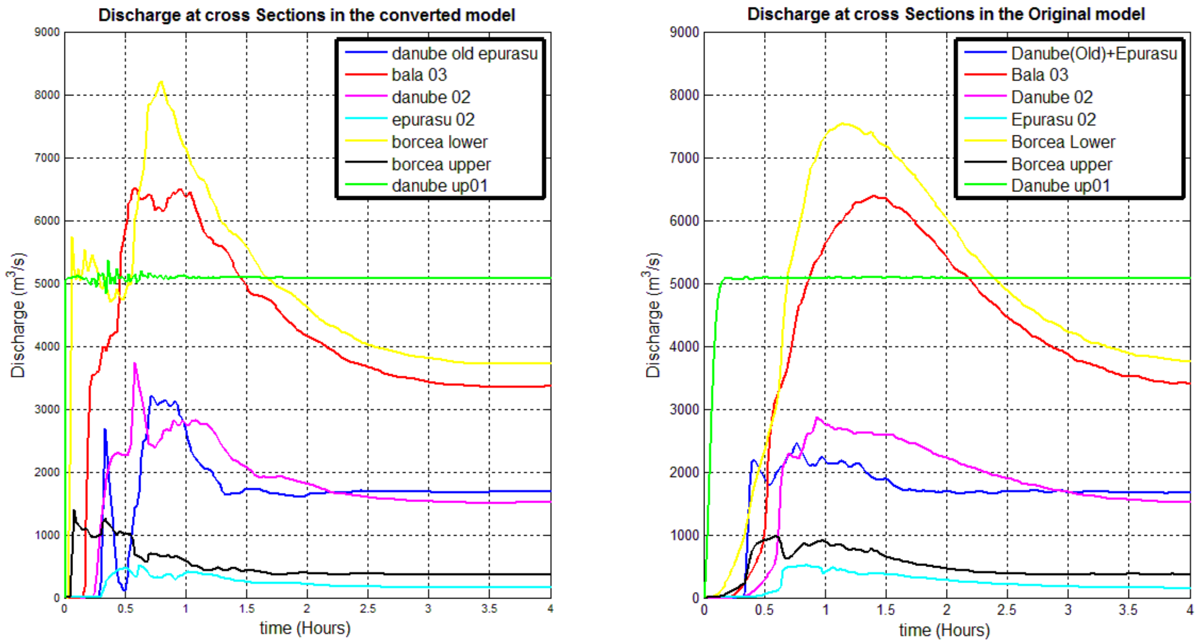

Figure 4-8; Spin-up of both models

Both effects have been caused by a smoothing boundary conditions parameter in D3D model. This parameter is not yet available in D-Flow FM. The parameter removes “Eigen oscillations” from the computed model results. “Eigen oscillations” will be discussed later. The smoothing boundary conditions parameter changes the open boundary conditions in the beginning of the computation of the model. The boundary conditions get adjusted as showed in Figure 4-9. The boundary conditions (F) increases from the initial value (Fi) linearly to the beforehand determined boundary conditions (Fb) from time-step 0 until the smoothing time (Tlfsmo) is reached. The boundary conditions will then remain the same until the end of the computation (Tstop).

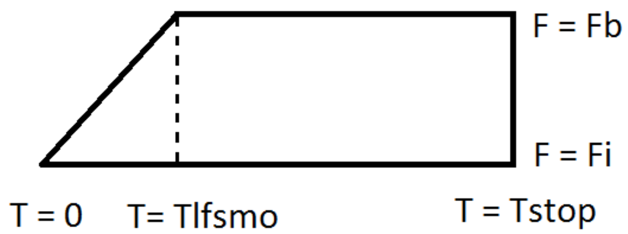

Figure 4-9; Smoothing boundary conditions parameter

While it takes some time before the final boundary conditions will be used, it also takes more time before the spin-up is finished.

The discharges at cross-sections show peak downwards after upwards peaks. These downward peaks are caused by “Eigen Oscillation”. “Eigen Oscillations” are waves across the model caused by open boundary conditions that are not well adjusted to each other. The “Eigen Oscillation” in the discharge in the Bala 03 cross-sections is shown in Figure 4-10. “Eigen Oscillations” are short longitudinal progressive waves with a wavelength coupled with the length of the model area. These waves are caused by disturbance at open boundaries. The waves caused by the conditions at open boundaries get trapped in the model area. The waves could be prevented by chosing the boundary conditions wisely. This though requires some calculations; to prevent wasting time on those calculations D3D has a smoothing parameter.

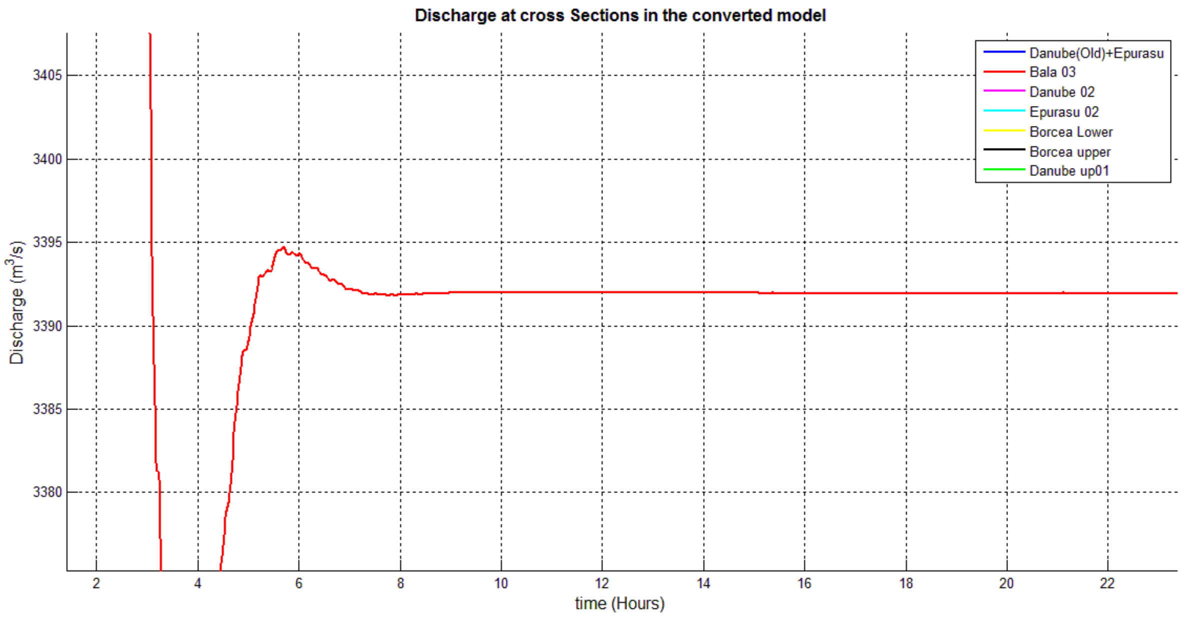

Figure 4-10; Eigen Oscillations in the D-Flow FM conversion model

4.5 Conclusion

While the models should be approximately equal, there are some notable differences between the D3D model and the D-Flow FM model in the computed model results. D-Flow FM uses the same calculation for the curvilinear grid as the calculation used in D3D. Though it seems from chapter 2 that there are still some differences, these differences should not cause large differences in the computed model results. However, the computed differences seem to be larger than expected.

The discharge ratio at the bifurcation between the Danube branch and the Epurasu branch with advantage for the Epurasu branch is higher in the D-Flow FM model. The discharge ratio in the D3D model at the bifurcation between the Danube branch and the Epurasu branch is 9,873 in advantage of the Danube branch, while the discharge ratio is 9.341 in the D-Flow FM model. This seems very little, but the discharge in the Epurasu branch in the D-Flow FM model is 6,23% higher than the discharge in the Epurasu branch in the D3D model.

There are small differences in water level; through the uneven bathymetry it is hard to quantify the difference in water level. Qualifying the differences might be clearer: While the water level downstream is fixed there are no differences downstream. Upstream the water level in the D3D model is higher than the water level in the D-Flow FM model. This difference rises when the distance to the upstream boundaries rises. This difference is caused by a difference between D3D and D-Flow FM on how they are calculating the friction coefficient. Generally, the friction coefficient in D3D is higher than the friction coefficient in D-Flow FM. The difference in friction coefficient could also cause difference in discharge. But, it is hard to say if the different friction coefficient causes the different discharges.

D3D has a smoothing boundary conditions parameter; this parameter is not available in D-Flow FM. This parameter removes “Eigen oscillations” from the model, but including this parameter also means that the spin-up takes longer.

5 Analysis different models

The different grids discussed in chapter 3.3 will be compared in this chapter. An extended comparison can be found in Appendix F. This chapter will just contain a summary of the results found in Appendix F. First the models without structures will be compared, after that the models with structures will be compared. At last, the differences between the models with structures and the models without structures will be discussed. The effect of the implementation of the structures can be found when the models without structures will be compared with the models without structures.

In this chapter the deviation of the discharges at cross-sections, the water level at observation points and the average velocity with respect to the D3D model at the Danube 02 cross-section will be compared. This cross-section is chosen because the possible implementation of the structures is meant to increase the discharge over the Danube 02 cross-section. The D3D model is used as a basis to make the other models, which is why the other models will be compared with the D3D model. The values for the D3D model at the Danube 02 cross-sections for the Discharge, water level and velocity have been added.

The average velocity is not very interesting for this research. But, this research continues with a morphologic research. Velocities are very interesting for a morphologic research. That is why the average velocity has been added to the comparison of the computed model results of the models. The location of the cross-sections and the observation points are displayed in Figure 5-1. Each observation point lies in the middle of the cross-sections with the same name.

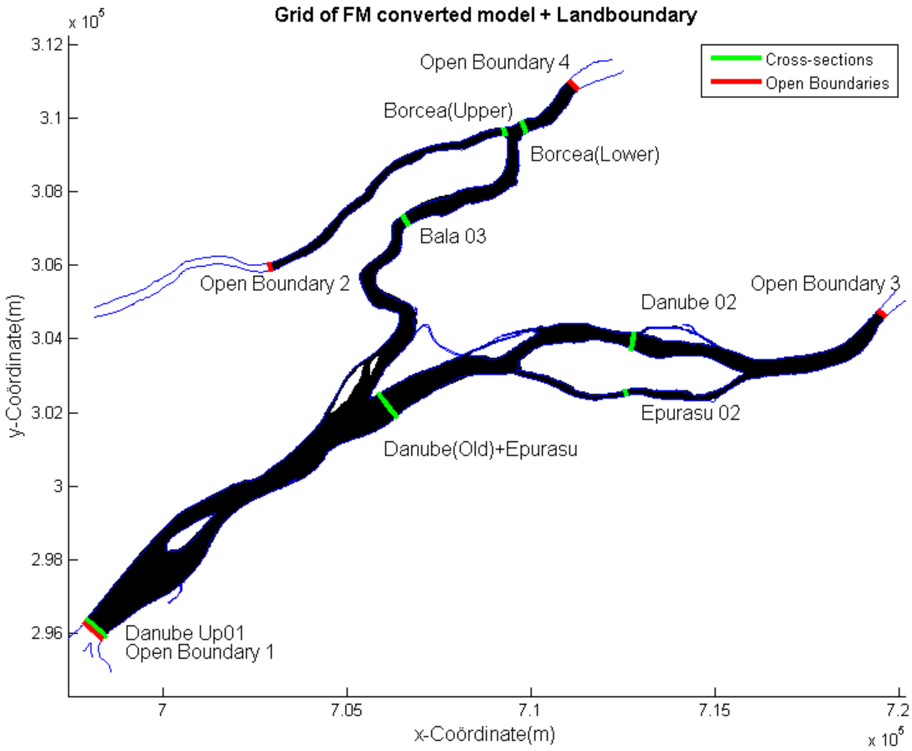

Figure 5-1; Cross-sections and observation points

5.1 Models without structures

The deviation of the models without structures at the Danube 02 cross-sections with respect to the D3D model without structures is displayed in Table 5.1. De deviation from the discharge and water level is in all models reasonable small. The biggest deviation in discharge in is the deviation of the D-Flow FM Detail model. This deviation is just 0,58 percent. The biggest deviation in the water level at the Danube 02 observation point is also the deviation of the D-Flow FM detail model. This deviation is -0,60% with respect to the water level at the observation point Danube 02 in the D3D model without structures. The deviation for the average velocity is larger than for the discharge and the water level. The largest deviation occurs again in the D-Flow FM Detail model. But this deviation is almost equal to the deviation of the D-Flow FM detail 1*1 model. The deviation of the average velocity in the D-Flow FM detail model with respect to the D3D model is -6,8% percent. This is obviously larger than the deviation of the discharge and the water levels.

	Discharge	Water level	Velocity
D3D	1517,1 m^3/s	7,6782 m	0,9372 m/s
D-Flow FM Conversion	0,51 %	-0,16 %	-1,72 %
D-Flow FM Detail	0,58 %	-0,60 %	-6,80 %
D-Flow FM Detail 1*1	0,53 %	-0,58 %	-6,77 %

Table 5.1; Deviation with respect to the D3D model for models without structures

5.2 Models with Structures

The deviation of the models with structures with respect to the D3D model with structures is displayed in Table 5.2. The deviation of the discharge of the model with structures is larger than the deviation of the models without structures. Especially the D-Flow FM detail model shows a high deviation with respect to the D3D model. The discharge of the D-Flow FM detail 1*1 model shows the lowest deviation. This is quite notable, since the grid of the D-Flow FM detail model differs most from the grid of the D3D model. The deviation in the water level are smaller than the deviation in the discharges. The largest deviation is the deviation of the D-Flow FM detail model at the Danube 02 observation point and is just -0,89%. The deviation of the average velocity is just as with the models without structures larger than the deviation of the water level and discharge. The largest deviation is the deviation of the D-Flow FM detail model at the Danube 02 cross-sections. The deviation with respect to the D3D model is -8,59%.

	Discharge	Water level	Velocity
D3D	1644,4 m^3/s	7,7209 m	1 m/s
D-Flow FM Conversion	-1,85 %	-0,34 %	-2,82 %
D-Flow FM Detail	-2,75 %	-0,89 %	-8,59 %
D-Flow FM Detail 1*1	-0,88 %	-0,73 %	-7,90 %

Table 5.2; Deviation with respect to the D3D model for models with structures

5.3 Difference between structures and without structures

At first, the deviation of the difference between models without structures and the models with structures looks much larger than the deviation of the models separately. This is due to the small effect of the structures in comparison with the original discharge, water level or velocities. The deviation of the effect of the structures with respect to the D3D model is displayed in Table 5.3. It seems that the effect of the implementation of the structures is much larger in the D3D model than in the other models. Especcially the effect in the D-Flow FM detail models is very low. The effect of the structures on the discharge in the D-Flow FM detail model deviates 42,4% from the effect on the structures in the D3D model.

	Discharge	Water level	Velocity
D3D	127,3 m^3/s	0,0427 m	0,0735 m/s
D-Flow FM Conversion	-30,0 %	-33,2 %	-30,9 %
D-Flow FM Detail	-42,4 %	-52,7 %	-44,7 %
D-Flow FM Detail 1*1	-17,6 %	-26,9 %	-22,0 %

Table 5.3; Deviation with respect to the D3D model for effect of implementation of structures

5.4 Conclusion

After looking into the computed model results in this chapter it seems that there are definitely differences between the models. It seems in this chapter that a different grid or a small difference in the computation definitely has effect on the computed model results, even when the same bathymetry is used in the models. Next to the results in this chapter the results from Appendix F will be taken into account in this conclusion. Below a small summary of the differences is given.

The discharges in the models without structures are almost equal, the maximum relative difference in just 0,52%. The discharges in the models with structures show much larger relative differences, the maximum relative difference between the models with structures is 2,7%, five times as large as without structures. Especially the discharge in the D-Flow FM Detail model with bathymetry with structures differs from the other models.

The D3D models have a higher water level upstream. The water level downstream is fixed, that is why there are no differences downstream.

The implementation of the structures has effect on the water level at observation points and the average velocity at cross-sections. The effect of the structures on the discharge is bigger. The biggest effects occur in the D3D model, while the smallest effects occur in the D-Flow FM Detail model.

6 Discussion

Now the results of this project are known, it is interesting to know why the results differ from the hypothesis. It is also interesting to know what the results actually mean. At last, the importance of this project for the practice will be discussed. But first, the difference between the results and the hypothesis will be discussed.

In the hypothesis is stated that the difference between models is chapter 5 would be bigger than the differences in chapter 4. Chapter 4 just contains the comparison between the D3D model and the D-Flow FM conversion model. The differences in chapter 4 were bigger than expected. The difference in computation between D3D and D-Flow FM seem to have a reasonable effect on the computed model results. There are no shockingly big differences, but the differences were worth mentioning. The differences between models in chapter 5 were indeed larger than the differences between the D3D model and the D-Flow FM conversion model. Especially the computed model results from the D-Flow FM Detail model with bathymetry with structures was deviated from the other computed model results. Concluding this, it seems that small differences in the grid could have a reasonable difference in the computed model results.

Now the difference between the results and the hypothesis has been discussed, the use of the results could be discussed. It seemed that differences in grid could have reasonable effect on the computed model results. Other differences in the grid could also have effect on computed model results. The results from this project are not necessarily applicable to other areas. For other areas to computed model results might be exactly the same or have even bigger differences. Next to this conclusion, it has to be mentioned that the computation of D-Flow FM still has a lot of uncertainties. While D3D uses proven technology, D-Flow FM does not.

What was very useful of this project was the confirmation that D-Flow FM could save computation time compared with D3D, but D-Flow FM models could also cost very much computational time. This depends on size of the grid cells. The size of the grids cell determines the time-step in the model. Decreasing the time-step costs a lot of computational time, that is why the computational time is so large in the D-Flow FM Detail 1*1 model.

This project demonstrated that D-Flow FM could save computational time by making less important parts of the grid coarse and important parts of the grid fine. But, if the grid is too fine, it can cost a lot of computational time. It also seemed from this report that with flexible mesh it is possible to make nice grids, from which the grid boundary could match the land boundary very well. What has not been explained in this report, but has been experienced during the project is that there is a large lack of documentation on D-Flow FM. This research could have helped the D-Flow FM developers facing that problem.

7 Conclusion

On the basis of the 4 sub questions the main research question will be answered in this chapter. Every sub question has been answered in a different chapter. For convenience, the most important conclusions will be repeated below. After that, the main question will be repeated and answered.

Sub Question 1

- D-Flow FM uses next to a curvilinear grid also flexible meshes like triangles, quadrilaterals, pentagons and hexagons.
- There are some numerical differences between D3D and D-Flow FM through the incomplete development of D-Flow FM.
- D-Flow FM has a option to use a CFL-Based time-step while D3D does not have such an option.

Sub Question 2

- Eight different models will be used in the comparison of D-Flow FM with D3D. Four of these models without structures and the other models with structures.
- There are 6 D-Flow FM models, two with the same grid as the D3D model, two models with a detail grid at critical points 01 and 02 and two models with a very detailed grid at the location of the possible implementation of the Bala bottom sill.
- The model input data will be the same for all the models in a comparison.

Sub Question 3

- The computed model of the D3D model and the D-Flow FM model are quite equal, but there are some notable differences.
- The discharge in the Epurasu branch in the D-Flow FM model differs 6,23% from the D3D model.
- The water level upstream in D3D is higher than the water level in D-Flow FM. This is caused by a higher friction coefficient in D3D.

Sub Question 4

- The differences between the models without structures are quite small.
- The differences between models with structures are five times as large as the differences between models without structures.
- The implementation of the structures has the biggest effect in the D3D model.

Main Question

What are the differences between D3D models for a part of the Danube and D-Flow FM models for a part of the Danube?

The computation for the curvilinear grid in D-Flow FM is based on the calculation in D3D, but there are still differences. The computation of the flexible meshes is still in development, the computation has not been calibrated yet. The time-step in the D-Flow FM Detail model had to be different than the other models. A large time step with small cell-sizes is impossible.

Eight different models have been used in the analysis. But first, the original D3D model and the D-Flow FM conversion model have been compared to see the differences between D3D and Flexible Mesh. These models both use exactly the same grid, same bathymetry and the same model input data. Only difference was the one model ran in D3D and the other one in D-Flow FM. There were also some differences in the settings, but the settings have been chosen such that the computation would look the same as much as possible.

It seems from the comparison that there were no large differences between D3D and Flexible Mesh. The discharge distribution seemed quite equal, the relative difference of the discharge distribution was 1,4% at critical point 01 and 5,7% at critical point 02. What was most notable was the difference in water level. The water level upstream in the D3D model was higher than the water level in the D-Flow FM conversion model. The last notable difference was the difference in spin-up. While the spin-up was finished earlier in the D-Flow FM conversion model, "Eigen Oscillations" where removed earlier in the D3D model. This difference is caused by a smoothing boundary conditions parameter in D3D.

As said before, eight different models have been used in the analysis. Four different grids have been used, with each two different bathymetries. One bathymetry without structures and one bathymetry with structures have been used. All models have the same open boundaries, cross-sections and observation points. The difference between the computed model results of the different models where larger than with the comparison of D3D and D-Flow FM. Especially the differences between models with structures were large. The difference between the model in discharge amounted to 47 m^3/s at the Danube (Old) + Epurasu cross-section. This is a relative difference with respect to the discharge at the cross-section Danube (Old) + Epurasu in the D3D model of 2,7%. It was not coincidence that the water level in D3D was higher in the comparison. The water level in D3D seems higher than all other models in the comparison.

An overview of the important difference between the models of the analysis is shown in Table 7.1. The most important differences are shown in this table. This means only some discharge at the Danube (Old) + Epurasu and the Danube 02 cross-sections are displayed. Both of these cross-sections lay behind a bifurcation. The difference in discharge distribution can be demonstrated by showing the discharge at the Danube (Old) + Epurasu and the Danube 02 cross-sections. All other difference in discharge can be distracted from the discharge at the Danube (Old) + Epurasu and the Danube 02 cross-section. The water level at the observation points Danube up is added to see the higher water level upstream in the D3D model.

So, there are definitely differences between D3D and D-Flow FM. Not only the computed model results differ but also the possibilities in the software and the computation differs. However, the differences are not very large, there are definitely no outstanding differences.

Model	D3D	D-Flow FM Conversion	D-Flow FM Detail	D-Flow FM Detail 1*1
Average Cell size (m^2)	~240	214,9	261,9	107,2
Computational Time	~20 hours	~20 hours	~12 hours	12 - weeks
Time-step (s)	1,5	1,5	1,5	~0,008
Discharge Danube (Old) + Epurasu without structures (M^3/s)	1672,6	1688	1680,6	1681,4
Discharge Danube (Old) + Epurasu with structures (M^3/s)	1789,1	1765,9	1741,4	1779,5
Discharge Danube 02 without structures (M^3/s)	1517,1	1524,8	1525,9	1525,1
Discharge Danube 02 with structures (M^3/s)	1644,4	1613,9	1599,2	1630
Water level Danube Up without structures (m)	8,340	8,292	8,254	8,254
Water level Danube up with structures (m)	8,418	8,347	8,298	8,318

Table 7.1; Important differences between the different models

8 Recommendations

This chapter will contain recommendations for three different groups. All groups might be interested in these recommendations after my experience with this project and D-Flow FM in general. The groups to whom the recommendations will be given are:

- People who want to continue with this project
- D-Flow FM users in general
- D-Flow FM developers

All recommendations will be given bullet points wise, so the recommendations are a nice overview for the people the recommendations are stated to.

People who want to continue with this project

- Try a larger time step in the D-Flow FM Detail 1*1 model. The time-step is CFL-based, what means that it gets adapted automatically. It could probably be larger with the same results. This might save a lot computational time.
- According to the D-Flow FM developers there are two possibilities to get a good comparison between D3D and D-Flow FM. This project only contains one method explained in chapter 2.2. The settings of the other comparison are displayed below; it might be an option to determine which comparison is the best. The settings are option inside the software program.
    - Bathymetry at cell center
    - For D3D
        - Use Flooding scheme
        - DpsOpt = DP
        - DpuOpt = min
    - For D-Flow FM
        - Botlevtype = 1
- The models used for this project are all 2d models, developing 3d models is an option for further continuing with this project.
- It might be interesting for the comparison between D3D and D-Flow FM to use a completely different area than the Danube.

D-Flow FM users in general

- Use the grid generating tutorial to learn how to make grids.
- For other comparisons between D3D and D-Flow FM, use the conversion tool available in the open earth tools. Make sure you read the instruction file carefully. Not everything from the D3D model gets converted.
- The current D-Flow FM manual contains some useful information, but far from everything D-Flow FM is usable for is documented. Ask the D-Flow FM developers if anything is not clear from the manual.
- For D-Flow FM users at Deltares
    - It is possible to run D-Flow FM on the cluster, but it is not as easy as with D3D. There is documentation available on how to do it. Ask the D-Flow FM developers if the documentation is not enough.

D-Flow FM developers

- The documentation of D-Flow FM is very limited. I would advise to work on the documentation. For new users it is impossible to get used to D-Flow FM with just the current available documentation.
- The D-Flow FM developers have a lot of new developments in planning. If changing the interface is not one of them, I would advise developing the interface. The interface works, but it could be a lot easier and less complicated.

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Appendices

Appendix A Problem definition

This project consists of multiple problems. The main problem is that the effects of the implementation of a structure in the Bala Branch of the Danube River have to be investigated. Therefore the certainty of D-Flow Flexible Mesh has to be investigated. Some problems have to be solved before the main problem could be solved. But at first, there is need for some D-Flow Flexible Mesh models.

A.1. D-Flow Flexible Mesh Models

D-Flow FM uses, in contrast to Delft3D-Flow, multiple kinds of shapes to model flows. While D3D uses only a curvilinear grid, there are changes needed, with respect to the D3D model, in the grid and in the input data. A Curvilinear grid works as well in D-Flow FM. But parts of the study area are complicated to model, that is why a D-Flow FM model could help improving the computed model results. That is why there is need for a network which has next to curvilinear parts also triangulated parts. D-Flow FM is a standalone program which uses other files than D3D does, all the input data which is used for the D3D models should be converted to make the input data suitable for D-Flow Fm.

A.1.1. Network

There is need for a network that can compute satisfying results. There are multiple demands for a good grid. The boundary of the grid should approximately flush with the land boundary. The network should be fine enough for the implementation of a structure. The net-links of a D-Flow FM grid have to satisfy a good orthogonality and a good smoothness. For good computed model results there is also a validated bathymetry (Bottom level of the river) needed. More explanation about the computational reasons for a good network is displayed in Appendix B.

A.1.2. Input data

There are several files needed for running computations in D3D and D-Flow FM. The available D3D files, there extension, the needed D-Flow FM files and their extension are displayed in Table A.1.

The available files from earlier D3D models have to be converted to compare the D3D model with the D-Flow FM model. The D-Flow FM files are explained in Appendix B.

D3D File	D3D extension	D-Flow FM File	D-Flow FM Extension
Master Definition File	.mdf	Master Definition Unstructured file	.mdu
Grid File	.grd	Network File	_net.nc
Depth values	.dep	Samples	.xyz
Thin Dams	.thd	Thin Dams	_thd.pli
Open boundary locations	.bnd	Open boundary polylines	.pli
Boundary time series file	.bct	Component file for polyline	.cmp
Boundary Files	.bnd .bct	External Forcing File	.ext
Observation points	.obs	Observation points	_obs.xyn
Cross-sections	.crs	Cross-sections	_crs.pli

Table A.1; Files required in D3D and D-Flow FM

A.2. Uncertainty of Delft 3D-Flow Flexible Mesh

D-Flow FM is still in development, the calculations of D-Flow FM are uncertain. D-Flow FM does use proven technology of Delft3D and Sobek. But these technologies are combined and flexible administration is added. That combination is not a proven technology yet. That is why the model results of the D3D model have to be compared with the model results of the D-Flow FM model. Once the model results of the D3D and the D-Flow Fm model are quite similar it gives some more trust about the correctness of the D-Flow Fm model and about the analysis which should be done in a later stadium.

A.3. Effect of structures in D-Flow FM models

For the analysis of the implementation of some structure in the Danube River, there is a very detailed grid needed at the location where the structures should be placed. D-Flow FM allows users to make a detailed grid at some parts of a model and a less detailed grid at other parts of the grid. Therefore there is a different grid needed then the grid used for the comparison between D3D and D-Flow FM. These detailed models should be compared with the other models as well. The models will be compared with the D3D models and the D-Flow FM conversion model.

Appendix B D-Flow Flexible Mesh

B.1. D3D

Delft3D-Flow simulates non-steady flows in relatively shallow water. It incorporates the effects of tides, winds, air pressure, density differences (due to salinity and temperature), waves, turbulence (from a simple constant to the k-ε model) and drying and flooding. With the integrated heat and mass transport solver, Deltares' front running knowledge of stratified hydrodynamics has been built into this program. The output of the program is used in all the other programs in Delft3D suite.

D3D is the standard program and covers curvilinear and rectilinear grids, full 2D hydrostatic flow, advection-diffusion module for salinity, temperature and substances, density driven flows, float (drogue) tracking, meteorological influences, on-line visualization and wave-current interaction. The D3D includes 3D flow and turbulence modeling, spherical grids, domain decomposition (connect multiple grids; refinement in both horizontal and vertical direction allowed), structures (structures, gates, floating structures, semi-transparent structures) and horizontal large eddy simulations (sub-grid turbulence in horizontal)(Deltares, 2012).

B.2. Difference with D3D

D-Flow FM is a newly developed program. The program is based on D3D and has some influences of Sobek. This coupling is made because Delft3D was used on estuarine and coastal issues while Sobek is mostly used for freshwater issues. Despite that D-Flow FM has a lot similarities with D3D, there are some serious differences which needs to be discussed. The most important difference is the network. The network, with triangular meshes, is the reason D-Flow FM was developed. The whole interface of D-Flow FM is different from D3D. At last, there are some differences between D3D and D-Flow FM in the flow geometry.

B.2.1. Network

Where D3D only handles a curvilinear grid (see Figure B-1, left side), D-Flow Fm also uses triangles, pentagons, hexagons, etc. (see Figure B-1, right side). The preference hereby goes to triangles in non-linear areas. Triangles have in general a better orthogonality and smoothness (See Smoothness and Orthogonality). Using a Flexible Mesh makes it easier to model difficult areas. The network sticks much better to the land boundary (Chapter B.4.1) in the D-Flow FM (Figure B-1, right side) network then in the D3D (Figure B-1, Left side) grid.

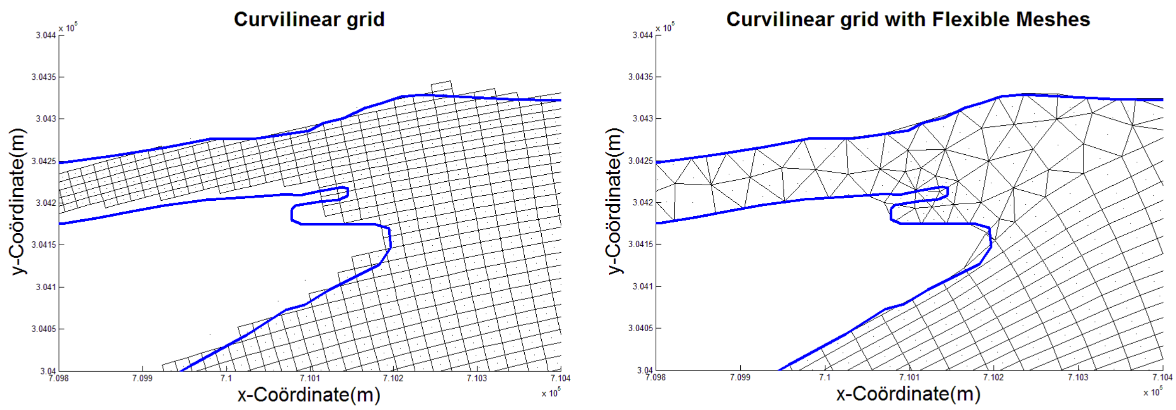

Figure B-1; Difference in Grid between D3D and D-Flow FM

B.2.2. Interface

The interface from D-Flow FM differs a lot from the interface of D3D. D3D uses different interfaces for creating the grid, inserting flow input and running a computation. D-Flow FM has just one interface which can handle all the different tasks. The interface of D-Flow FM looks like the interface of RGFGRID in D3D. Most of the screen in D-Flow FM and in RGFGRID is used to display the grid/network. The interface of the Flow input differs a lot from D-Flow FM.

B.3. Master Definition Unstructured File

The Master Definition Unstructured File (MDU-file) is the file from where D-Flow FM runs the computations. The MDU-file directs to all other files. The MDU-file directs to the land boundary, network file, external forcing file, observation points, cross-sections and output files.

The MDU-file also contains all values for flow time -, flow geometry-, flow physical- and flow numerical parameters.

B.4. Input

There are several input files which are needed to run a computation in D-Flow FM. The Master Definition Unstructured File is the file which direct to all these files. The network, external forcing file and the open boundaries are necessary to run a computation. Next to these files there are some optional files which can be added to the computation. These files are the Land Boundary, Cross-sections and the Observation points.

B.4.1. Land Boundary

The Land Boundaries are lines which separates water from land. The Land Boundary can be used to make a network. The Land Boundary could also be showed in the output. The Land Boundary has an .ldb extension as is showed in Figure B-2.

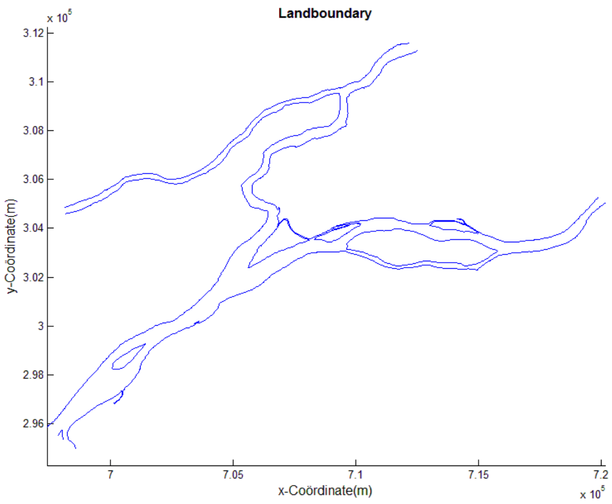

Figure B-2; Land boundary

B.4.2. Network

The network consists of net nodes connected by net links. The Bathymetry is stored in the net nodes. The flow discharges are calculated on the basis of the network. D-Flow FM calculates the discharge from network cell to network cell. The net links of the network needs a good orthogonality and a good smoothness to let the computations run as good as possible. The network can be curvilinear, consists of triangles or other multi angular shapes or of a combination of these. The network is stored in a NetCDF file with a _net.nc extension.

B.4.2.1. Curvilinear

A curvilinear grid can be created by splines (polylines which determines the shape of a curvilinear grid). The fineness of the grid can be determined by curvilinear grid parameters. An example of a curvilinear grid is shown in Figure B-3.

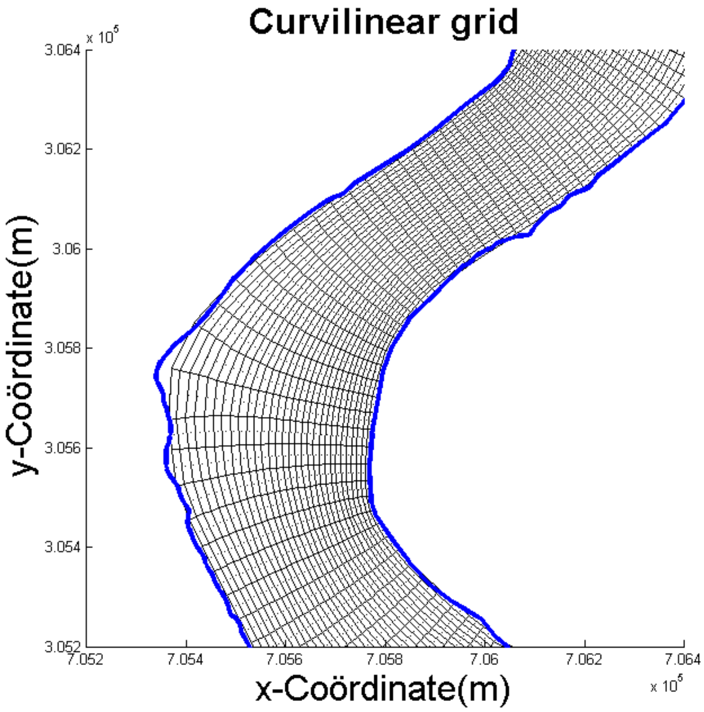

Figure B-3; Curvilinear Grid

B.4.2.2. Flexible Mesh

A triangular shapes network (Figure B-4) can be created by hand or by a polygon. When a polygon is converted to a net, the vertices a polygon will become net points. Other net points inside the polygon will be triangulated by D-Flow FM. The triangles can be connected to a curvilinear grid by hand.

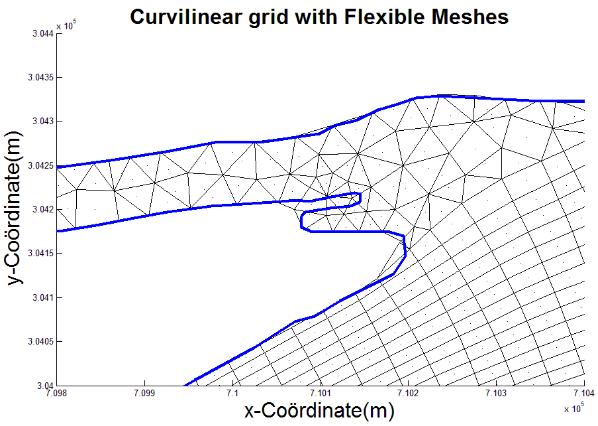

Figure B-4; Grid with triangles

B.4.2.3. Smoothness and Orthogonality

For a good computation the smoothness and orthogonality should be good enough. The net-links of a D-Flow FM network have to satisfy a good orthogonality and a good smoothness. The orthogonality is the cosine of the angle between a net-link and a flow-link (Figure B-5).The Flow-link is the link between two circumcenters of two connected cells. The smoothness is the ratio between the sizes of the areas of two connected cells. D-Flow FM requires this for computational reasons (See chapter B.5).

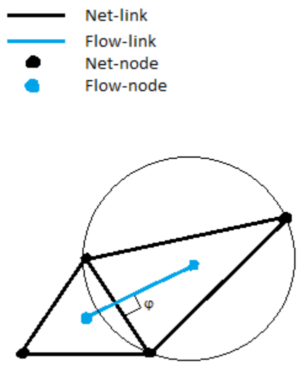

Figure B-5; Orthogonality

The value for the orthogonality can be display by a parameter called “Link orthogonality cosphi” (See Figure B-6).It is still a discussion point when the orthogonality is good enough for computation. But a value beneath 0.05 near land boundaries and a value beneath 0.01 in the middle of the river should be good enough (According to Wim van Balen).The orthogonality in the network in Figure B-6 is good enough for the computation.

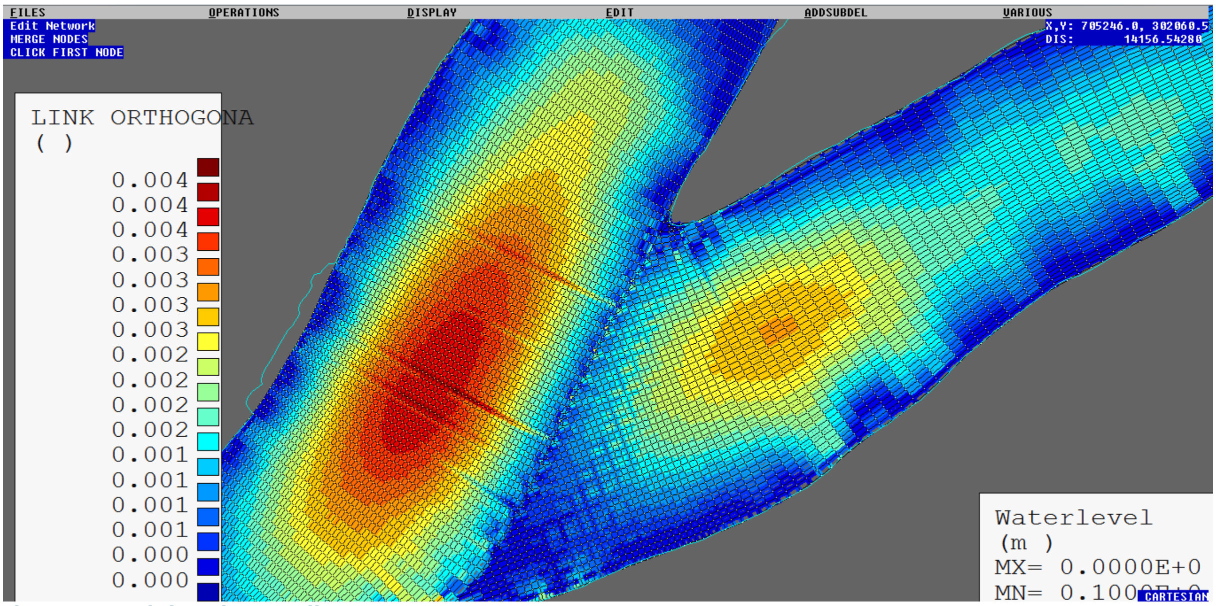

Figure B-6; Link orthogonality

The smoothness can be displayed by a “smoothness indicator” (Figure B-7). The smoothness is as important as the orthogonality for the computation. Though, when improving the orthogonality, the smoothness barely changes. That is why the smoothness should be optimal first, before improving the orthogonality of the network. There are no strict demands for the smoothness. It should be as close to one as possible.

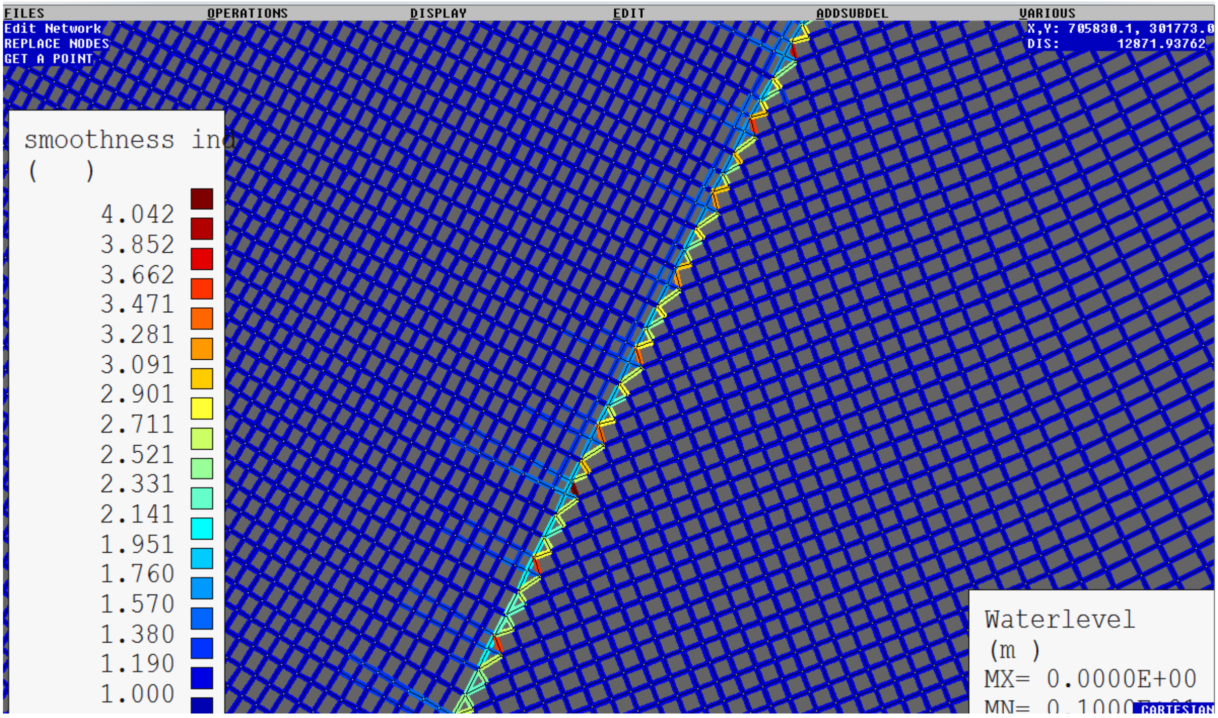

Figure B-7; Link Smoothness

B.4.2.4. Quality Network

The quality of the network doesn't just depend on the smoothness and the orthogonality. There are some other demands for a good computation. One of these is that small flow links are not allowed. Figure B-8 shows some almost too small flow links. The flow links are shown in white line. Flow links are links between flow nodes, shown in white dots. If a flow node lies outside a cell, it cannot be displayed. In that case a flow link is too small and is has to be removed.

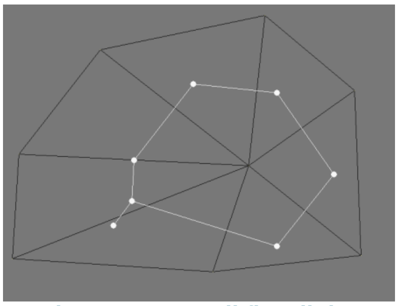
Figure B-8; Small flow links

Besides the computational demands there are some other demands that will improve the quality of the network. The network should be detailed enough for what the model is meant to. So, the level of detail depends on the mention of the model. The least important part of the quality of the network is the visual attractiveness. Although the orthogonality of the network in Figure B-9 is better than the orthogonality in Figure B-6, the network looks very messy. In is not a computational problem, but a bit of visual attractiveness is desired.

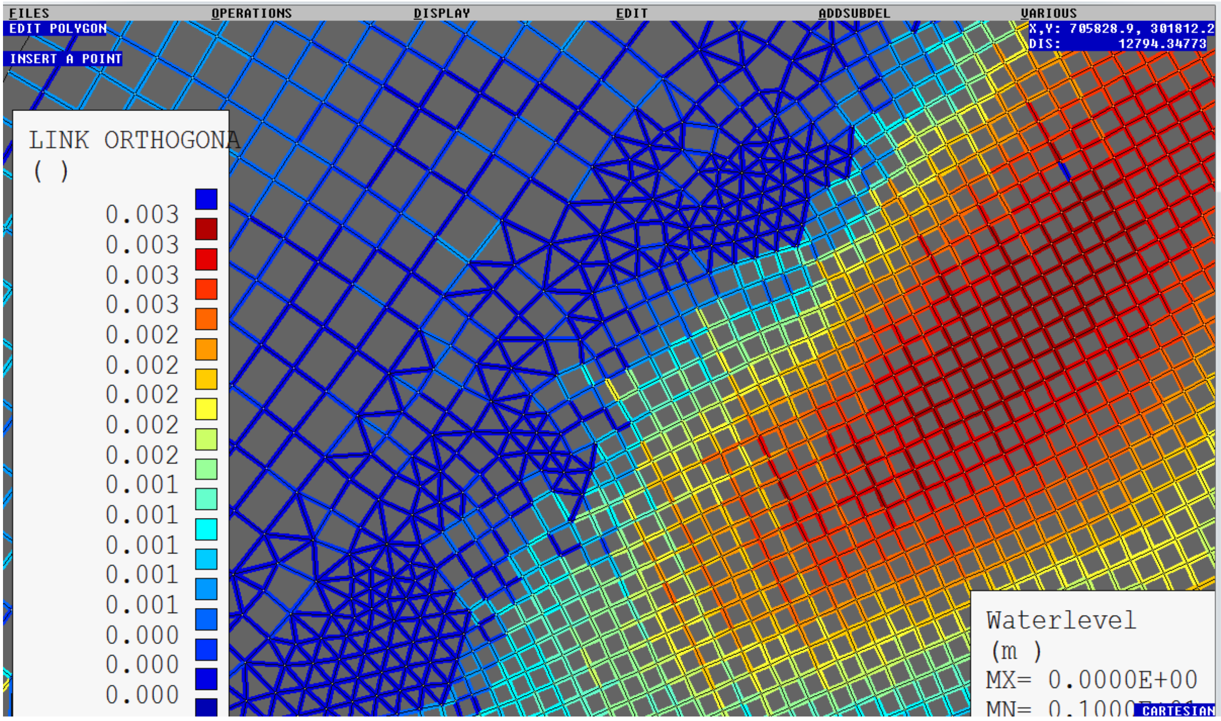

Figure B-9; Good orthogonality, but bad visual attractiveness

B.4.3. External forcing

The external forcing file is the file that controls all the external forces like, boundary conditions, wind, rain, dams etc. The file directs to the open boundary locations and conditions. The external forcing file indicates the kind of boundary conditions and the interpolation method of the boundary conditions. The external forcing file is file with an .ext extension.

B.4.3.1. Open boundaries

The open boundaries are each stored in at least two files. One of the files is a polyline file which contains the locations of the vertices of the polylines. The other file is a component file which contains the boundary conditions. Each vertex of the polylines could have its own component files. The boundary conditions at polylines are interpolated from the vertices of the polylines. If there is only one component file, the boundary conditions are uniform across the line. The polylines file has the extension .pli and the component files have the extension .cmp.

B.4.4. Observation points

Observations points are points in the network where all data during the simulations are stored. Data like velocity over time will be stored in the observation points. Observation points are stored in a file with an _obs.xyn extension.

B.4.5. Cross-sections

Cross-sections are lines crossing the rivers. As like the observations points, data during the simulations is stored in the cross-sections. The most important data gathered by cross-sections is discharge data. Cross-sections are polylines stored in a file with an _crs.pli extension.

B.5. Computation

The computation happens in the same interface as the development of the network is done. It is possible to follow the computation while it is running. This makes it possible to end a computation if it seems that something went wrong by the input or during the computation.

The computation is a very technical story which will not completely be explained in this report. For a full technical reference see Technical Reference of D-Flow FM (Deltares, 2012). What is worth to mention is that D-Flow FM uses a staggered grid to make computations. Therefore the discharge goes from flow node to flow node and not from net node to net node where the bathymetry is stored.

B.5.1. Staggered Grid

D-Flow FM uses a staggered grid (See Figure B-10) (Skamarock et al., 2010) to store data of velocity and for example, pressure, at different places of a net cell. The pressure for example is stored in the center of a control volume (net cell), while the flow velocity is stored in the net cell faces. This is the reason why a good orthogonality is necessary to get good computation results. If the flow link does not have an angle with the net link from 90° exact discharge from net cell to net cell cannot be calculated correctly.

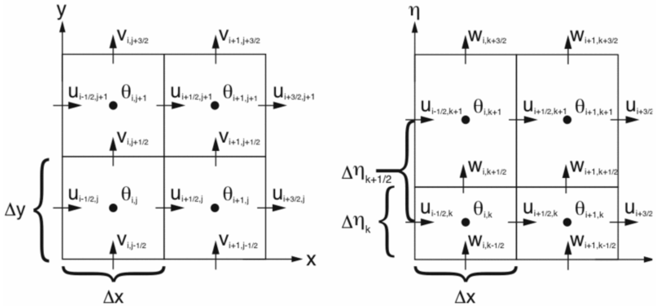

Figure B-10; Staggered grid

B.6. Output

There are several kinds of output files which can be created by D-Flow FM. The most important ones are the map and history files. Map-files contain information gathered at time steps which are determined beforehand. This could be, for example, water level data of the whole area. History files contain information gathered at certain locations. This could be, for example, the discharge at cross-sections during the model run. Other files that could be created by D-Flow FM are snapshots, Delwaq (Water Quality and Ecology) files and Flow geometry-files.

B.6.1. Quickplot

Quickplot is part of Matlab which makes it possible to plot figure very quick. It is an easy feature for plotting you need fast insight in the model computations. For analyzing the results, Quickplot is not extensive enough. Besides, Quickplot cannot open history files. Therefore, Matlab is needed.

B.6.2. Matlab

Matlab is needed for extensive analyzing of the computed model results. The Open Earth Repository contains a lot of tools which could be used to analyze computed model results. These tools give easy access to the desired computed model results out of the output files.

Appendix C Conversion Tool

The conversion tool for the conversion of a D3D model to a D-Flow FM model is available in the Open Earth Tools (Koningsveld, et al., 2011). These Open Earth Tools (OET) are as the name implicates open for everyone to use. OET is an initiative from several Dutch companies, Deltares is one amongst them.

The conversion tool converts al the computational depended files. This means that files that are not important to run a computation are not converted. Those files can be added the way the programmer would like it. Once the OET is available in Matlab, the conversion tool can be started by pressing ddd2dfm. The openings screen is shown in Figure C-1.

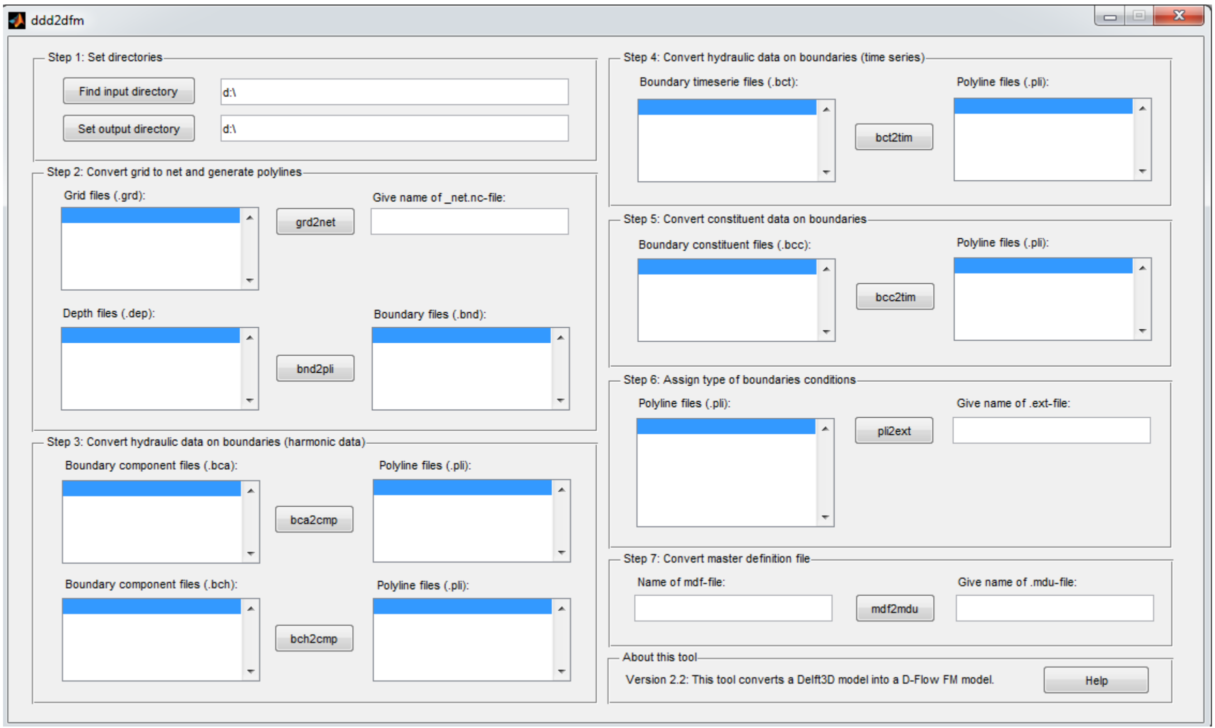

Figure C-1; Conversion tool

The conversion tool can now convert a D3D model to a D-Flow Fm model in five steps.

Step 1:
The first step is to set the input and the output directory. All the files most be available in one single directory, otherwise the conversion tool will not work.

Step 2:
The Grid (.grd file) will be, together with the Depth (.dep) file converted to a Network (_net.nc) and a sample file (.xyz). The Network will contain the bathymetry already, the sample files are not needed to run the computation, it is an extra file which can be used to change the bathymetry of the net.

Step 3:
The third step is generating the open boundary conditions from boundary and boundary component files. These two files will be converted to multiple files, two for each boundary. Each boundary will have a file which contains the location of the files (.pli), the other file will have information about the values of the open boundary (.cmp).

Step 4:
The fourth step is to convert data out of the polylines files to the external forcing file (.ext). The external forcing file will invoke the open boundaries. Since D3D does not use such a file, the external forcing file has to be created from the polylines files.

Step5:
The last step is to convert the master definition file (.mdf) to the master definition unstructured file (.mdu). All data that are necessary for the computation will be converted from the .mdf to the .mdu file. The .mdu file also contains information which invokes other files that cannot be converted such as the observation point file and the cross-sections file. This information should be added manually if observation and cross-sections will be added.

Appendix D Structures

There are three structures that possibly will be place in the Danube River. Two of them will be placed in the Bala branch, the other one just before the Epurasu branch. All three structures will have a short introduction in this appendix. The three structures that possibly will be placed in the Danube River are:

- Bala bottom sill after phase III
- Bala guiding wall and bank protection Turcescu
- Epurasu dyke with opening cunete

The bathymetry of samples V10 at Critical points 01 and 02 is shown in Figure D-1. Critical point 01 and 02 are both critical points because the discharge distribution is not as in should be. The discharge distribution at CP01 and CP02 are both in disadvantage of the Lower Danube branch. The implementation of the three structures is a possible solution for that problem.

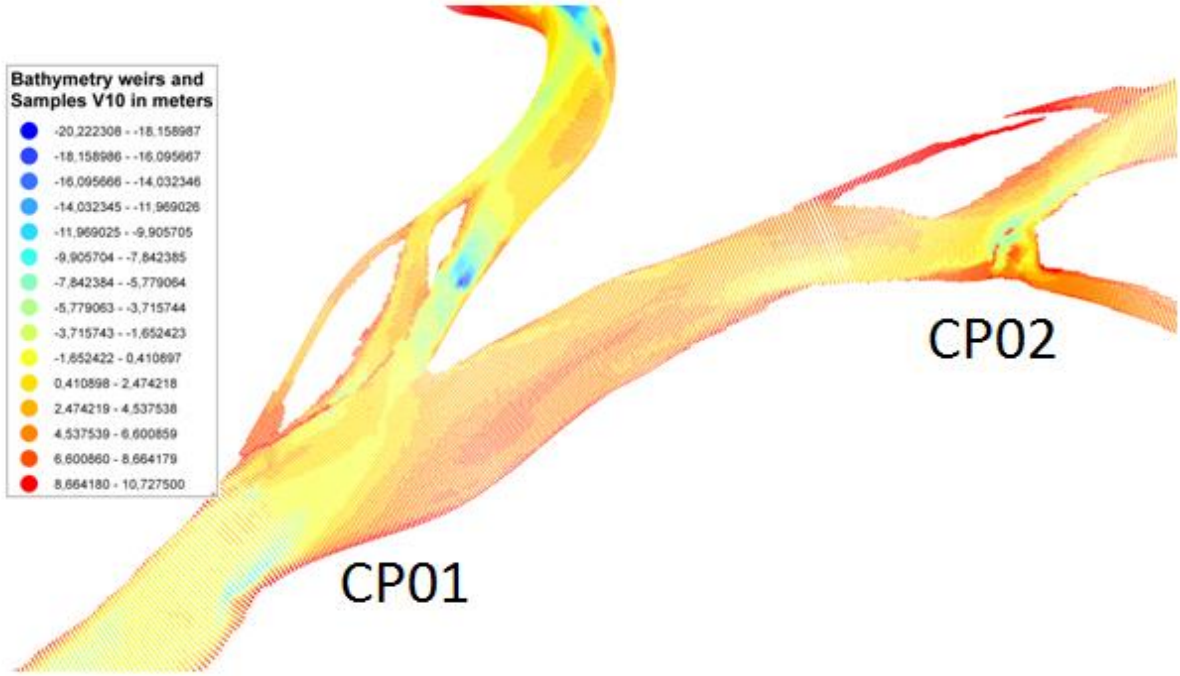

Figure D-1; Bathymetry of samples V10 and Critical points 01 and 02

D.1. Bala bottom sill after phase III

The first structure is a low increase of the bottom level in the Bala branch. The bottom level at a part of the Bala branch increases to 0,22 meter with a slope. The slope has a maximum angle of 1:1.5 near the top of the structure. The Bala bottom sill after phase III is shown in Figure D-2.

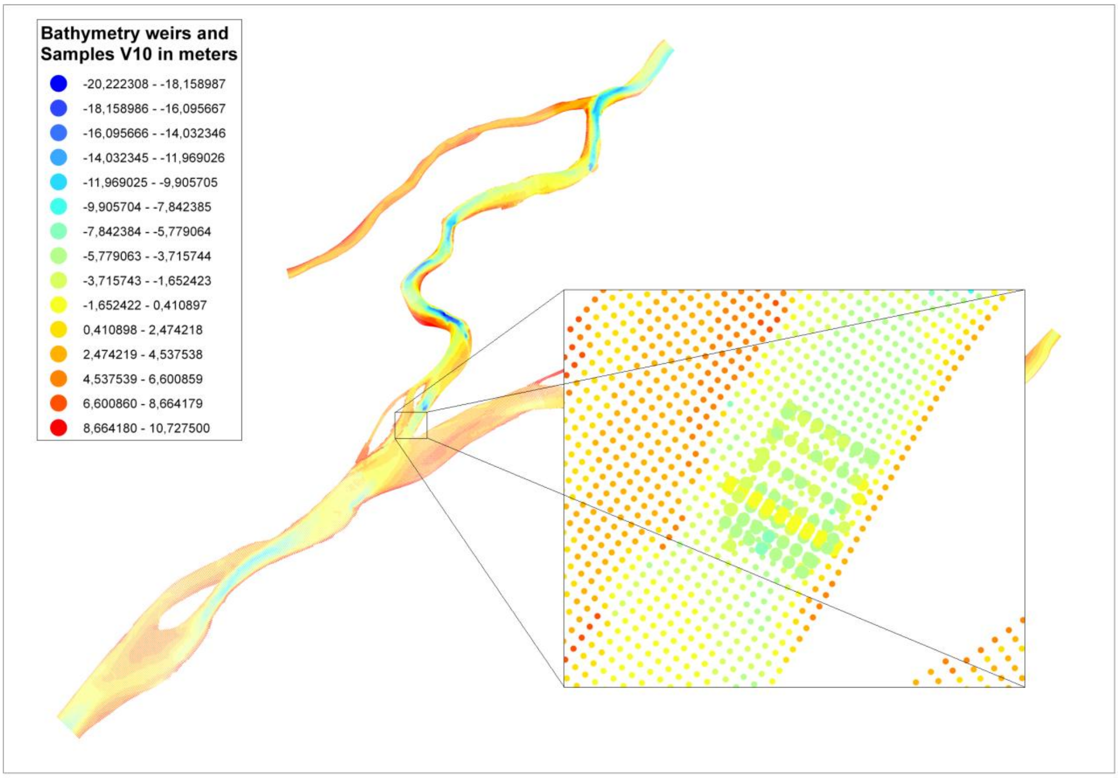

Figure D-2; Bala bottom sill after phase III

D.2. Bala guiding wall and bank protection Turcescu

The second structure consists of two parts. The first part is a guiding wall at the left side of the Bala/Upper Danube branch. The second part is a bank protection at the right side of the Bala branch. The guiding wall prevents water to flow through the left side of the islands in the Bala branch. The Bala guiding wall and bank protection Turcescu is shown in Figure D-3.

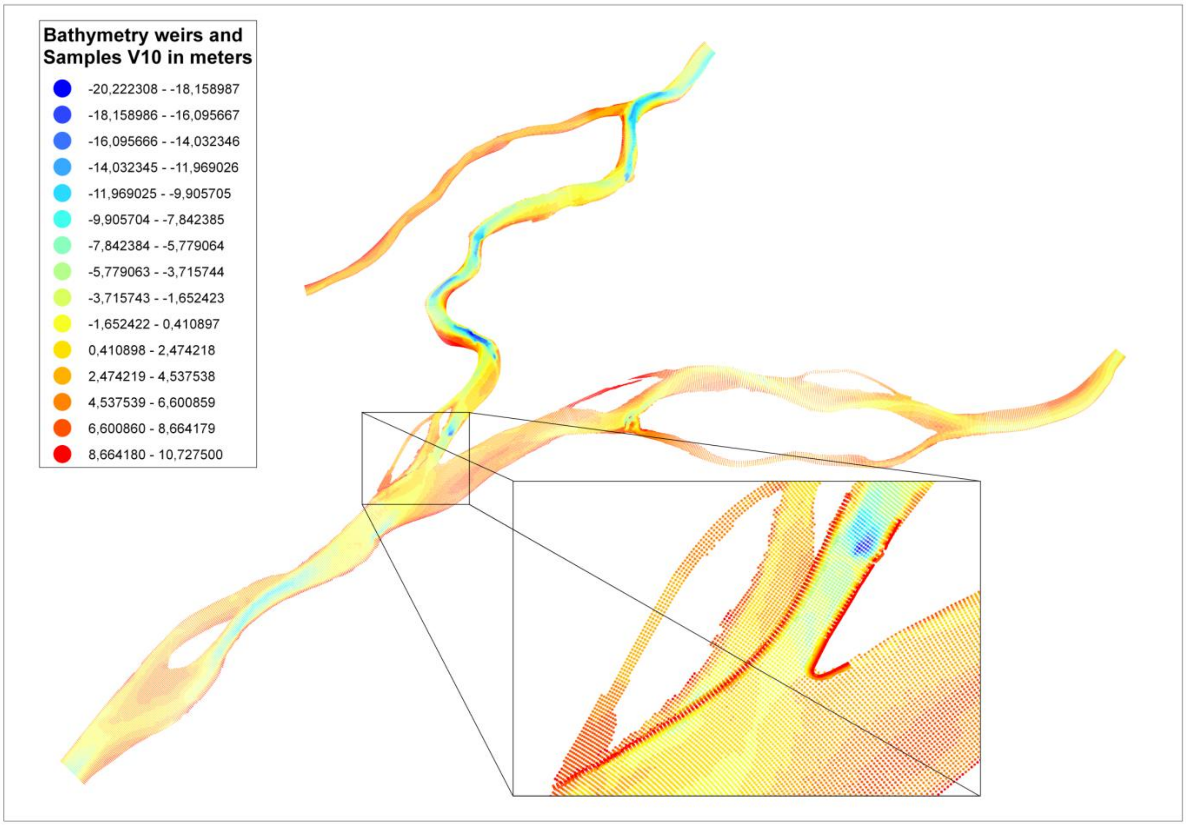

Figure D-3; Bala guiding wall and bank protection Turcescu

D.3. Epurasu dyke with opening cunete

The last possible structure is a dyke with opening before the Epurasu branch. This dyke prevents a high discharge in the Epurasu branch. This should increase the discharge in the Lower Danube branch. The Epurasu dyke is shown in Figure D-4.

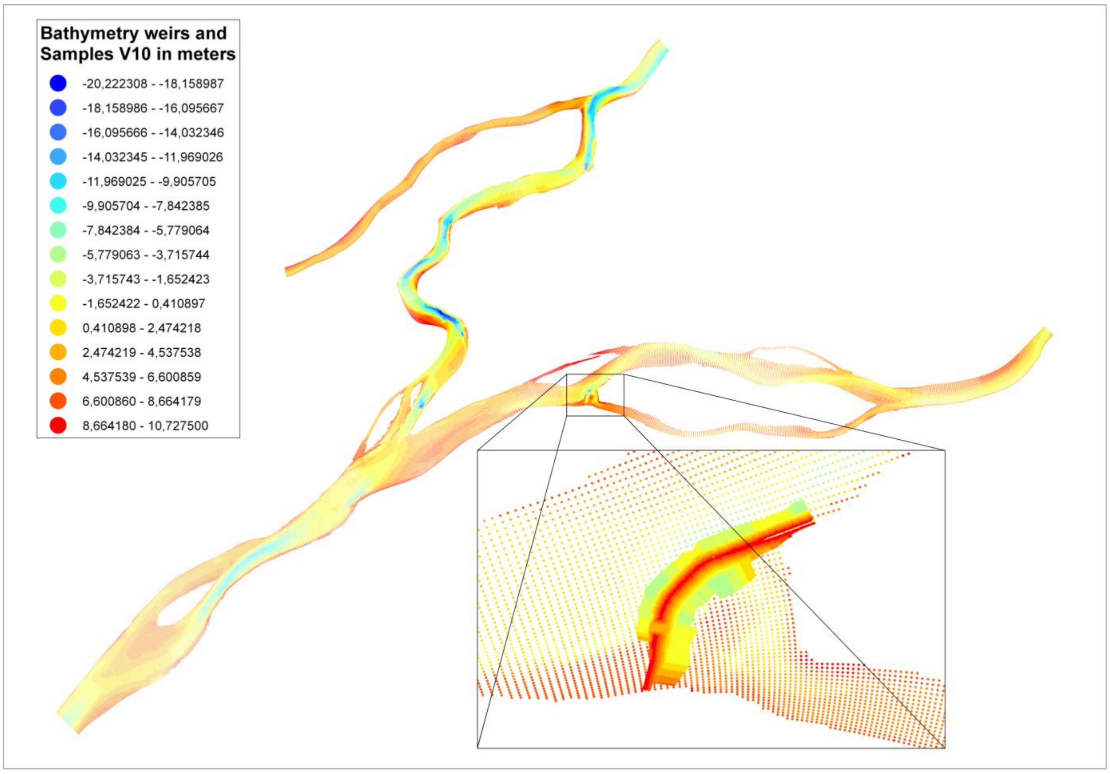

Figure D-4; Epurasu dyke with opening cunete

D.4. Bala structures

Figure D-5 shows the Bala bottom sill after phase III and the Bala guiding wall and bank protection Turcescu. These structures will probably be placed together with the Epurasu dyke with opening cunete.

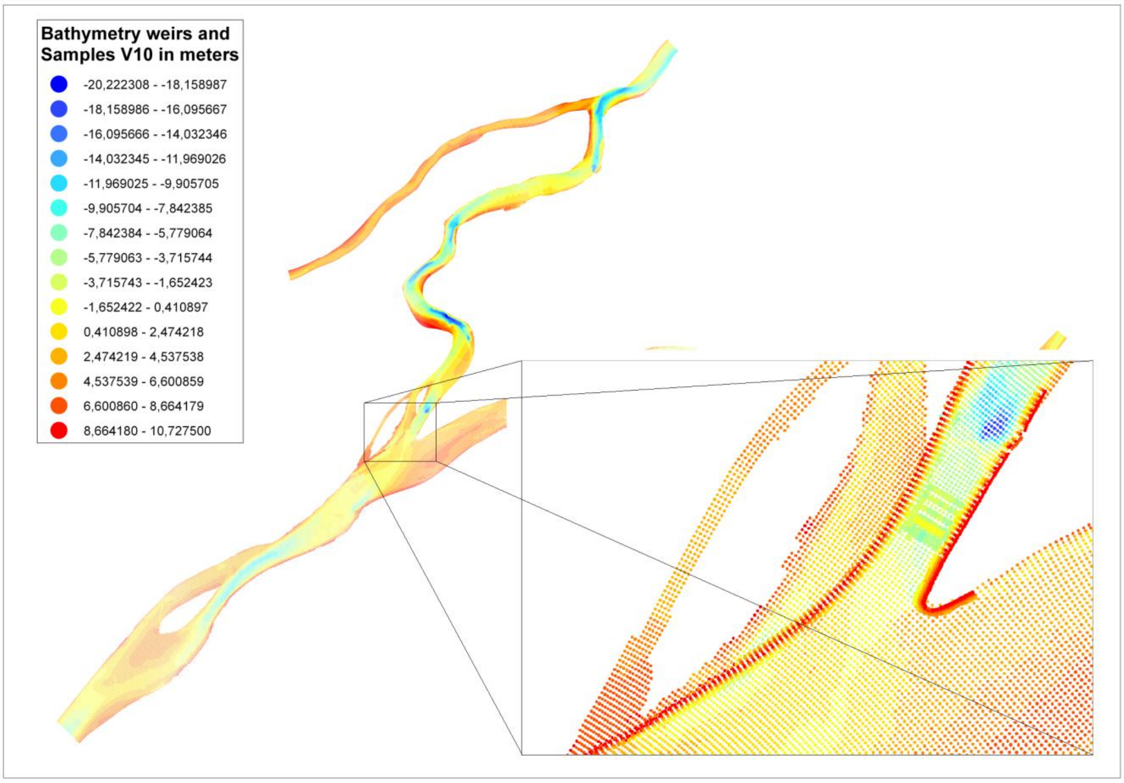

Figure D-5; Bala guiding wall and Bala bottom sill

Appendix E Analysis different models with structures

E.1. Grid analysis

The analysis exists of eight models. Four different grids have been used. Each grid has been used twice, once without structures and once with structures. This appendix contains 2 figures for each model, one figure for the whole model and one figure with a small part of the Bala branch. Each figure of the whole model contains a red rectangle which indicates the location of the figure with the small part of the Bala branch. The following grids have been used for the analysis.

- Delft3D-Flow model
- D-Flow Flexible Mesh conversion
- D-Flow Flexible Mesh Detail CP0102
- D-Flow Flexible Mesh Detail CP0102 1*1

The Delft3D model is the originally developed model. This model has been used for the validation of the bathymetry. The D-Flow Flexible Mesh conversion is a conversion of the Delft3D model. The model is converted by a conversion tool (See Appendix C). The grid looks different than the Delft3D model; dry points in the Delft3D model have been removed. Dry points are not allowed in D-Flow FM, all grid points should have a bottom level value. The points that have been removed in the conversion did not have a value in the Delft3D model, which is the reason that there is no difference between the models.

The D-Flow Flexible mesh Detail Cp0102 has a finer grid at critical points one and two. The rest of the grid is coarser that the original model. The model has also some more improvements. While dry points have been included in the D3D model, the grid boundaries are not equal to the land boundary. Figure E-1 shows an example of an improvement. The left side of Figure E-1 contains the D-Flow conversion model without dry points and the right side contains the D-Flow FM Detail CP0102 model.

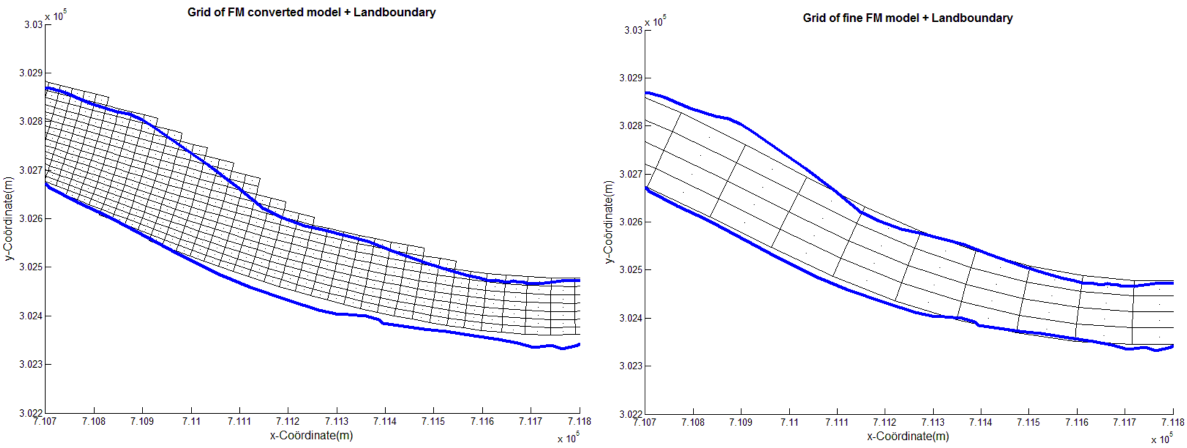

Figure E-1; Conversion model and improvement in Detail Cp0102 model

D-Flow Flexible Mesh Detail CP0102 1*1 has a one by one meter grid cell size at the location of the Bala bottom sill. The earlier mentioned grid D-Flow Flexible mesh Detail Cp0102 is used to make this grid. It is refinement at the location of the Bala bottom sill to cell sizes of one by one meter. There is one extra figure for the last model. The grid is too fine to see anything on the figure with the smaller part of the Bala branch. Therefore there is another figure with an even smaller part of the Bala branch. The size of this figure is indicated in Figure E-9.

E.1.1. Delft3D model

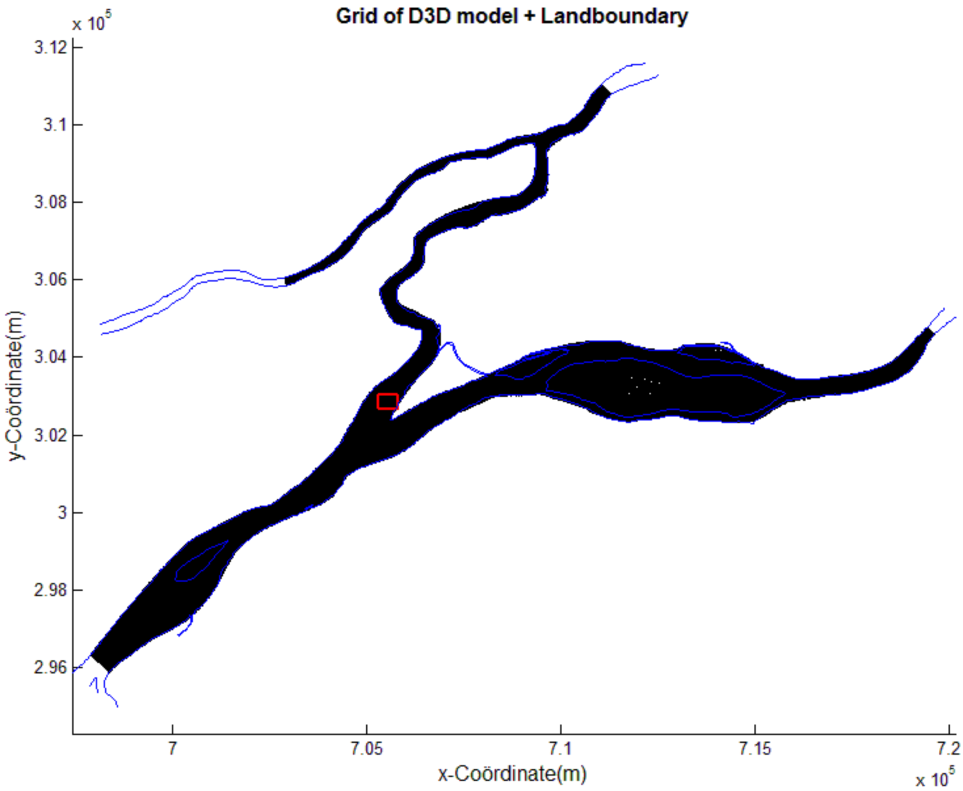

Figure E-2; Delft3D-Flow model

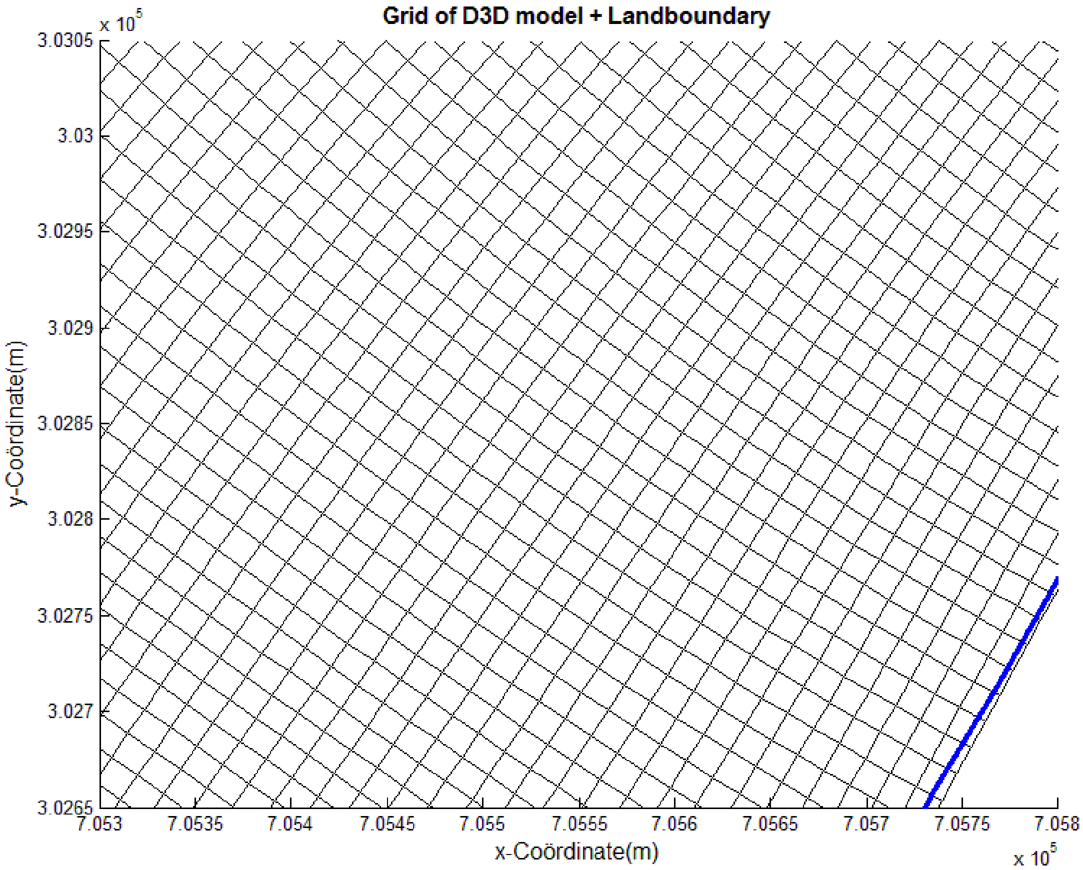

Figure E-3; Delft3D-Flow model at beginning of the Bala branch

E.1.2. D-Flow Flexible Mesh conversion

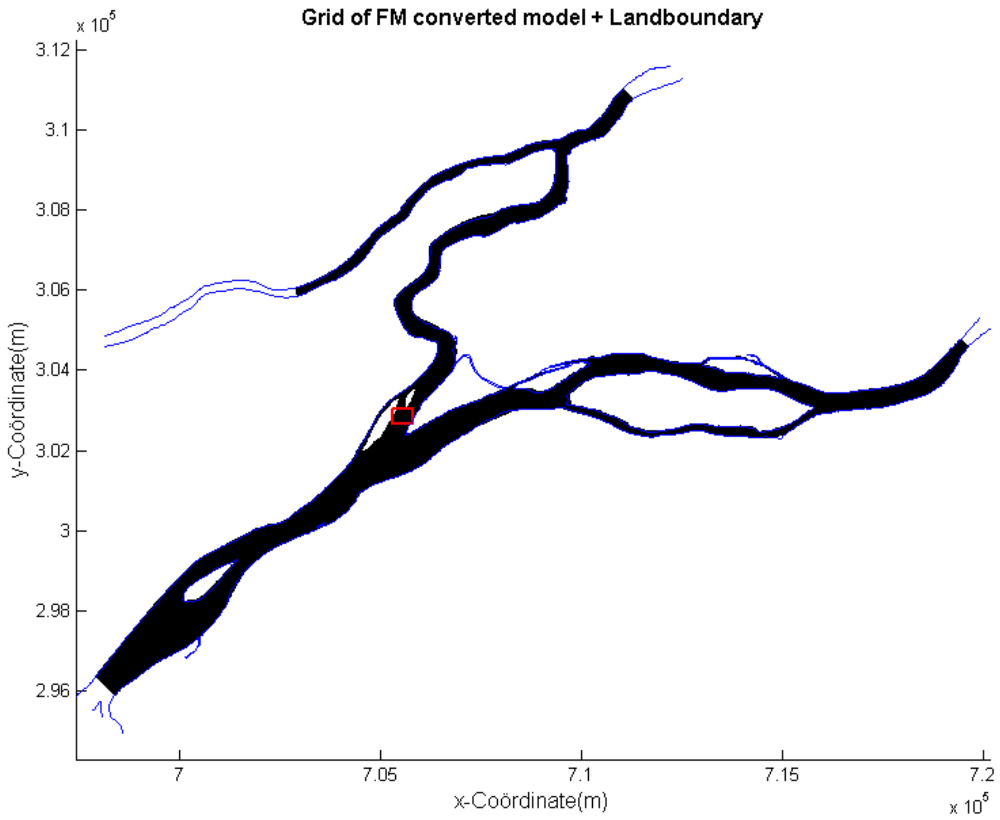

Figure E-4; D-Flow FM conversion model

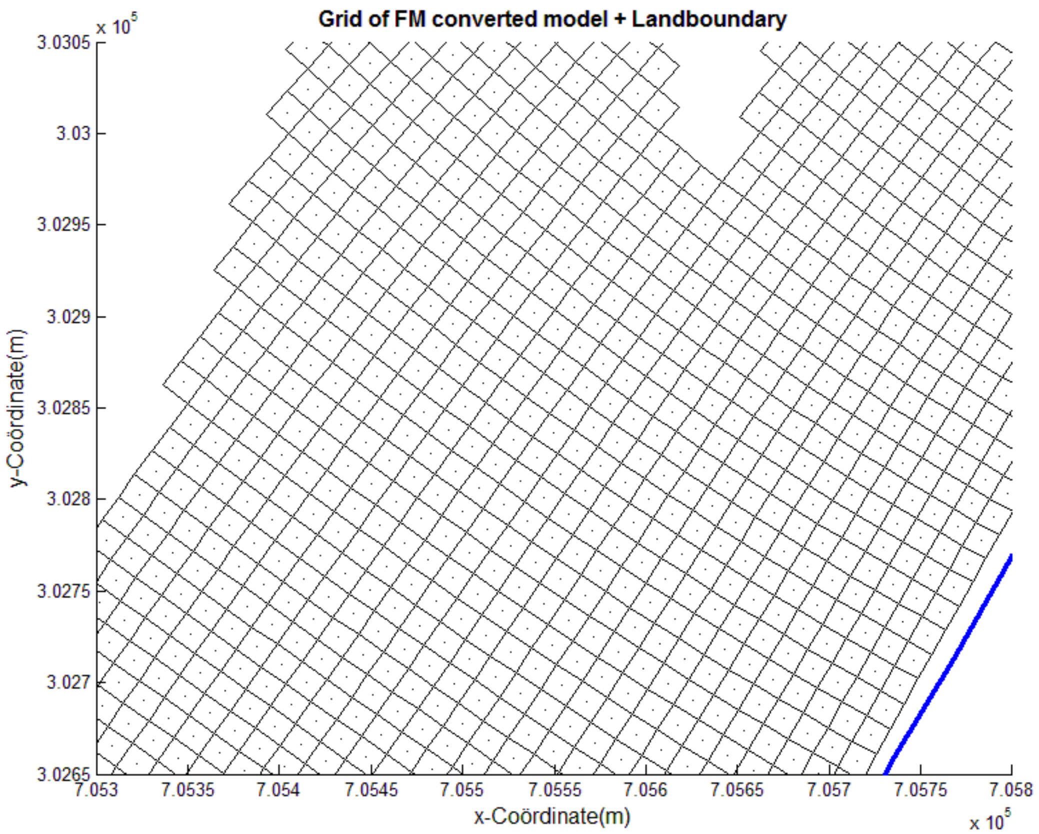

Figure E-5; D-Flow FM conversion model at the beginning of the Bala branch

E.1.3. D-Flow Flexible Mesh Detail CP0102

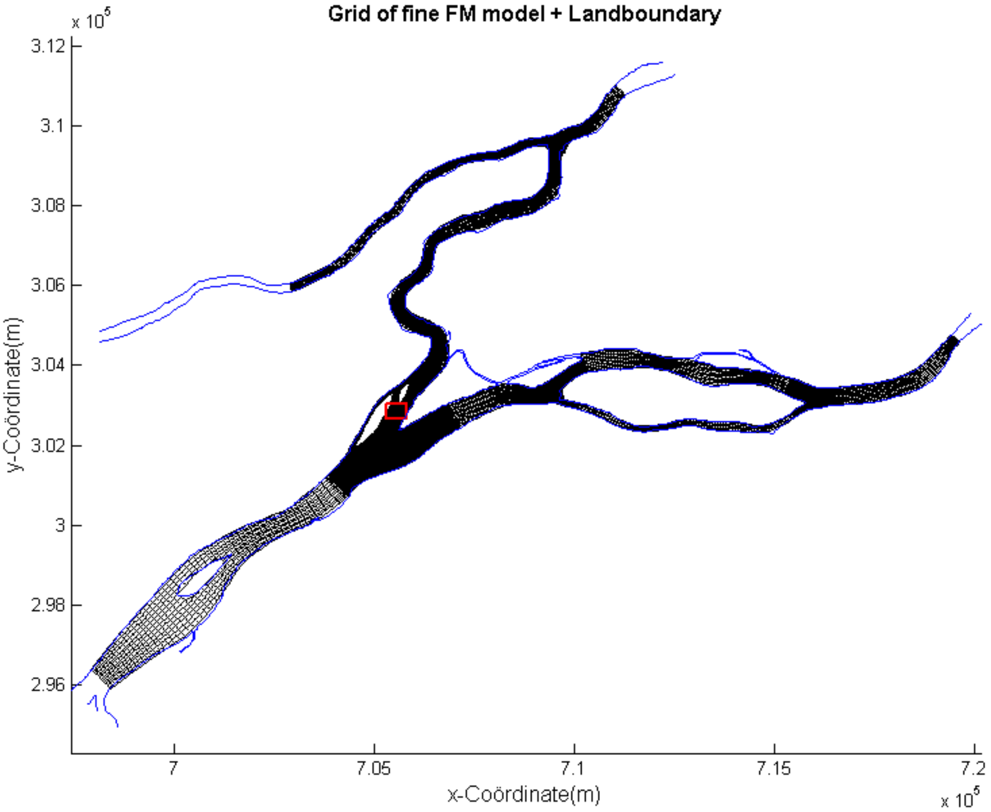

Figure E-6; D-Flow FM Detail Cp0102

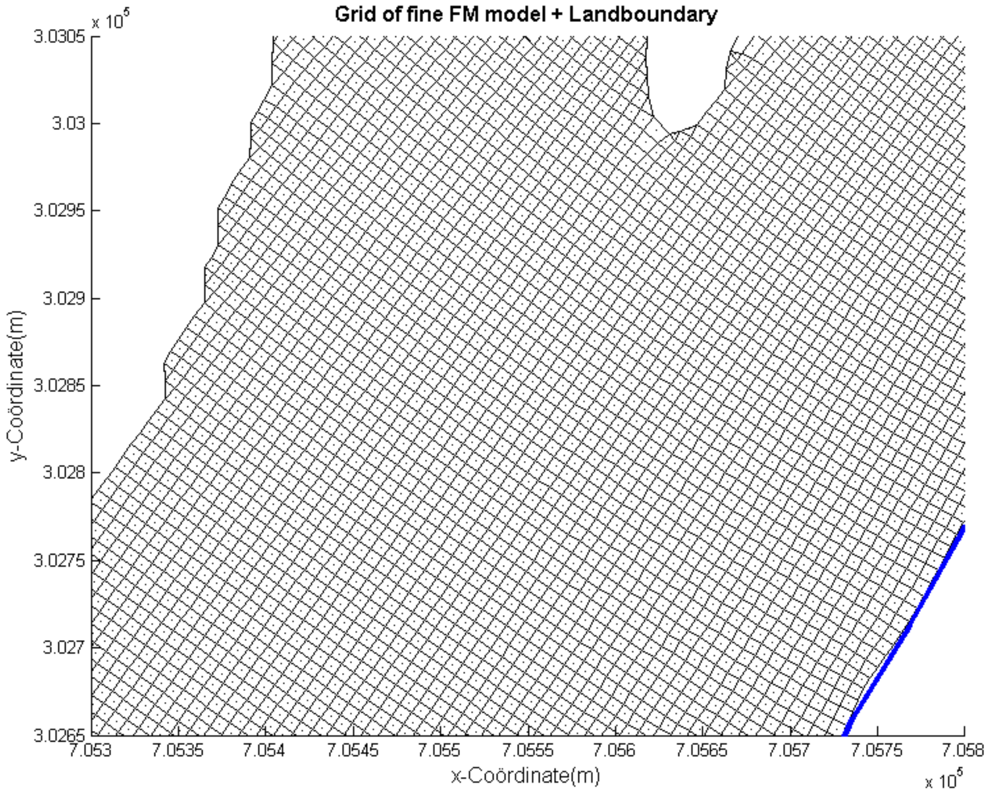

Figure E-7; D-Flow FM Detail Cp0102 model at the beginning of the Bala branch

E.1.4. D-Flow Flexible Mesh Detail CP0102 1*1

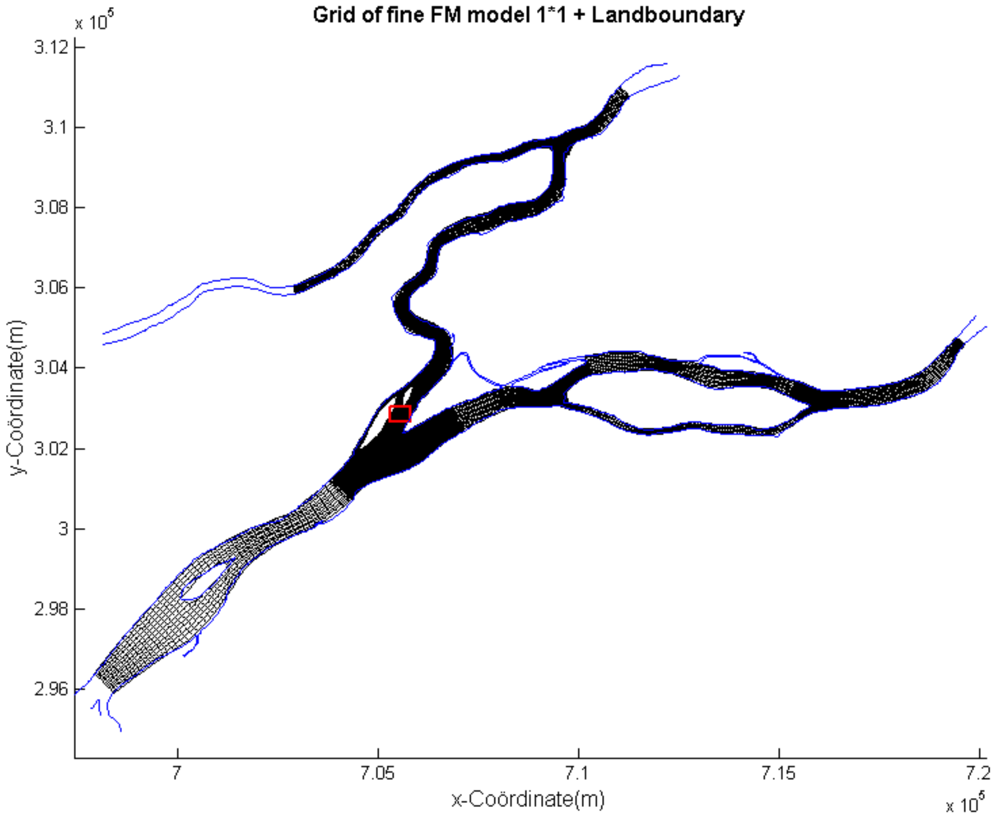

Figure E-8; D-Flow FM Detail Cp0102 1*1 model

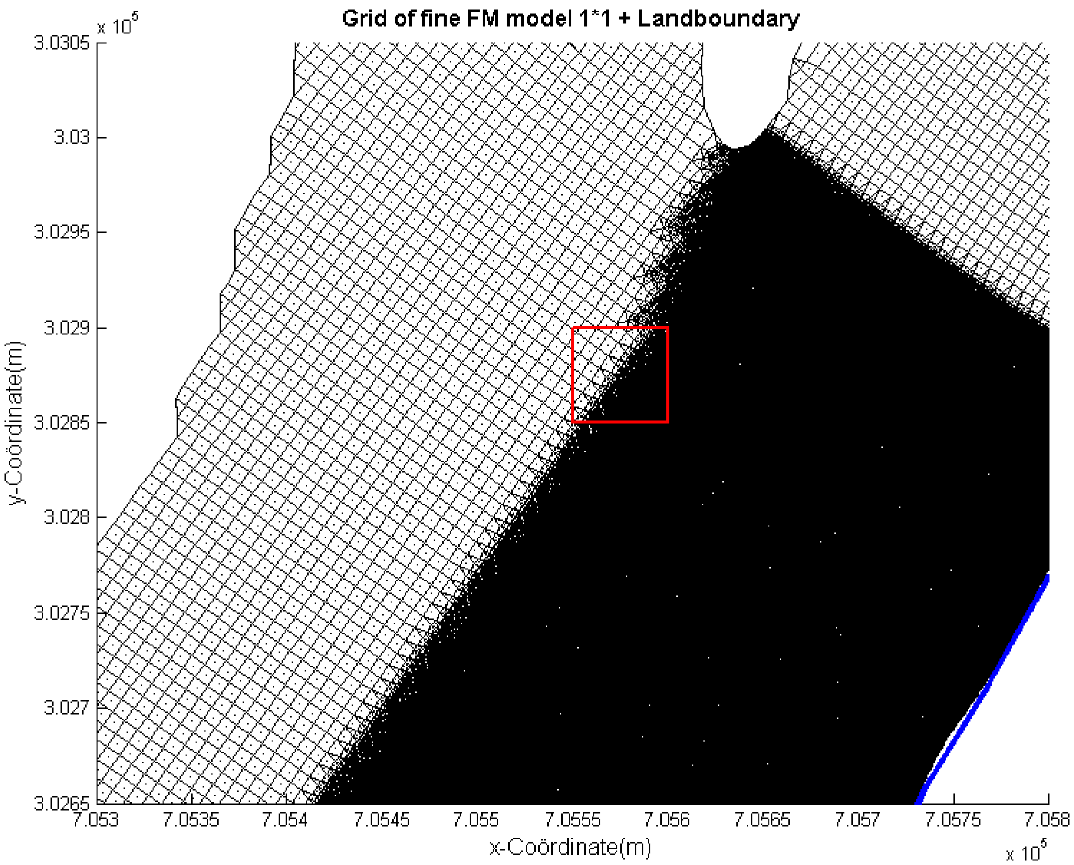

Figure E-9; D-Flow FM Detail Cp0102 1*1 model at the beginning of the Bala branch

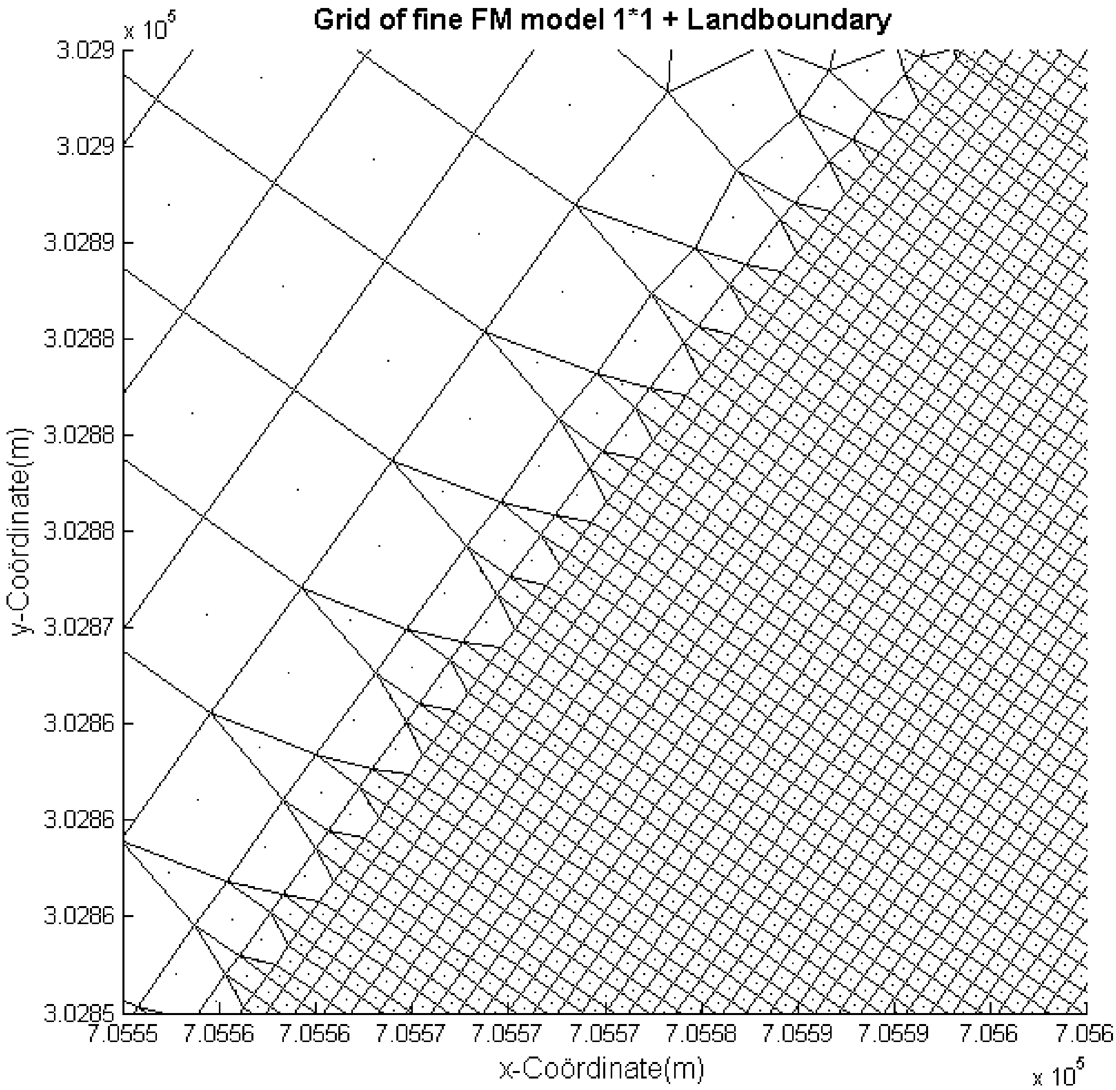

Figure E-10; D-Flow FM detail Cp0102 1*1 model, transition zone from coarse to 1*1 cells

Appendix F Results analysis

F.1. Bathymetry without structures

The samples used in this chapter of the analysis are the samples V10 discussed in chapter 3.2.1. The samples are interpolated onto the net cell corners in each grid. The grids that are used for the analysis are shown in chapter 3.3 and Appendix E.

F.1.1. Discharge

The discharges at cross-sections in the computed model results of the models without structures are shown in Figure F-1. The discharge at the cross-sections Danube_up01 and Borcea (Upper) are equal in each computed model result. These are the cross-sections close to the open boundaries. These cross-sections lay upstream of the bifurcations in the study area of the Danube. The discharge should be equal to the discharge at the open boundary and that seems to be true, since the discharge at the open boundary in the Danube branch was 5080 m^3/s and the discharge at the open boundary in the Epurasu branch was 371 m^3/s.

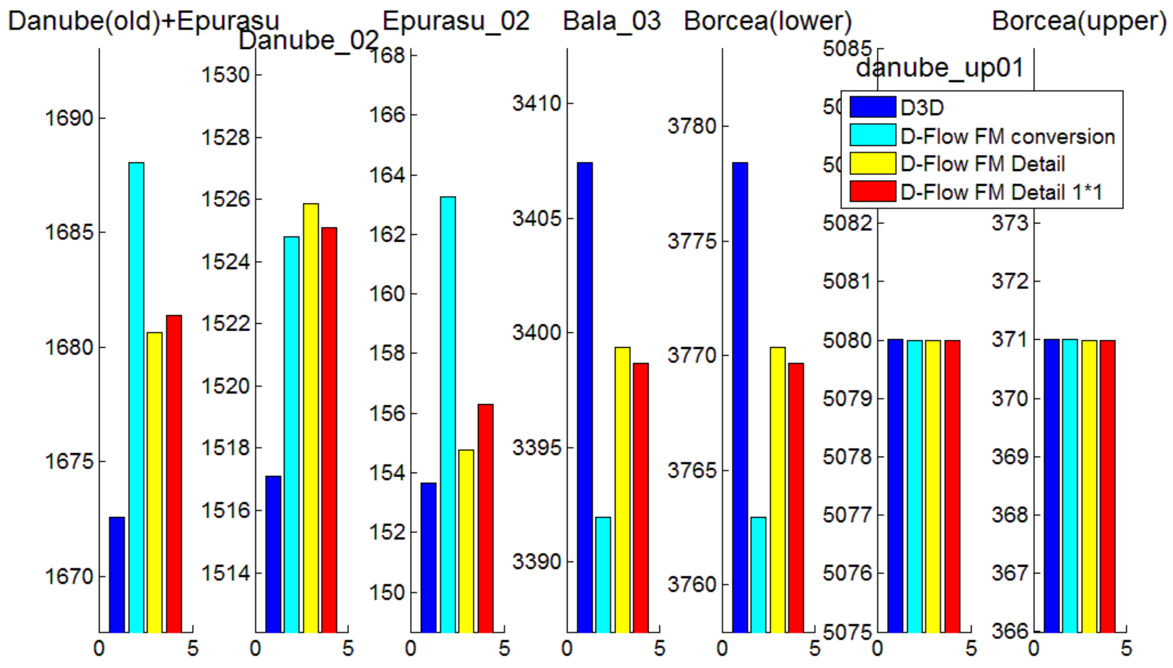

Figure F-1; Discharge at cross-sections in models without structures

The other cross-sections lie downstream of bifurcations and it seems that the discharge distribution differs in the different models. The biggest difference occurs at the bifurcation between the Danube branch and the Bala branch in the D3D model and the D-Flow FM conversion model. The comparison between these two models is already made in chapter 4, so there is no use to make this comparison again.

The other models, the D-Flow Fm Detail model and the D-Flow FM Detail 1*1 model, differ from the D3D model and the D-Flow FM conversion model. The discharges at some cross-sections are exactly the average of the D3D model and the D-Flow FM model. The only exceptions to this rule are the cross-sections Danube 02 and the upstream cross-sections Danube_up01 and Borcea (Upper). As mentioned before the discharge at the cross-sections Danube_up01 and Borcea (Upper) are equal in all computed model results. The discharge at the Danube 02 cross-section in the D-Flow FM Detail model, the D-Flow FM Detail 1*1 model and the D-Flow FM conversion model are almost equal.

The detailed models, D-Flow FM Detail and D-Flow FM Detail 1*1, are almost equal to each other; this is not very surprising, since there are little differences between these models. The more detailed part of the D-Flow FM Detail 1*1 model occurs on the location of the possible implementation of the structures. Therefore, more differences between these models are expected in the comparison of the model with structures.

The differences are very small, as said before the biggest difference occurs between the computed model results of the D3D model and D-Flow FM conversion model. There is a difference of 15 m^3/s. The differences between the detailed models and the other models have a maximum of 8 m^3/s, this is small compared with the total discharge of ~1525 m^3/s at the Danube 02 cross-section. This is just a relative difference of:

$$\frac{8}{1525} * 100 = 0{,}52\%$$

So, the discharges differ, but there are no outstanding differences. The grid and the difference in computation between D3D and D-Flow FM seem to have effect on the discharge distribution. The D-Flow FM conversion model differs from the D3D model and the detailed models differs from the D-Flow FM conversion model. The next chapter will discuss the difference in water level at observation points.

F.1.2. Water level

The previous chapter showed that the differences in computation in D3D and D-Flow FM with a different level of detail have just a small effect on the discharge distribution. This chapter will discuss the differences in water levels at observation points. The water levels at observation points are shown in Figure F-2.

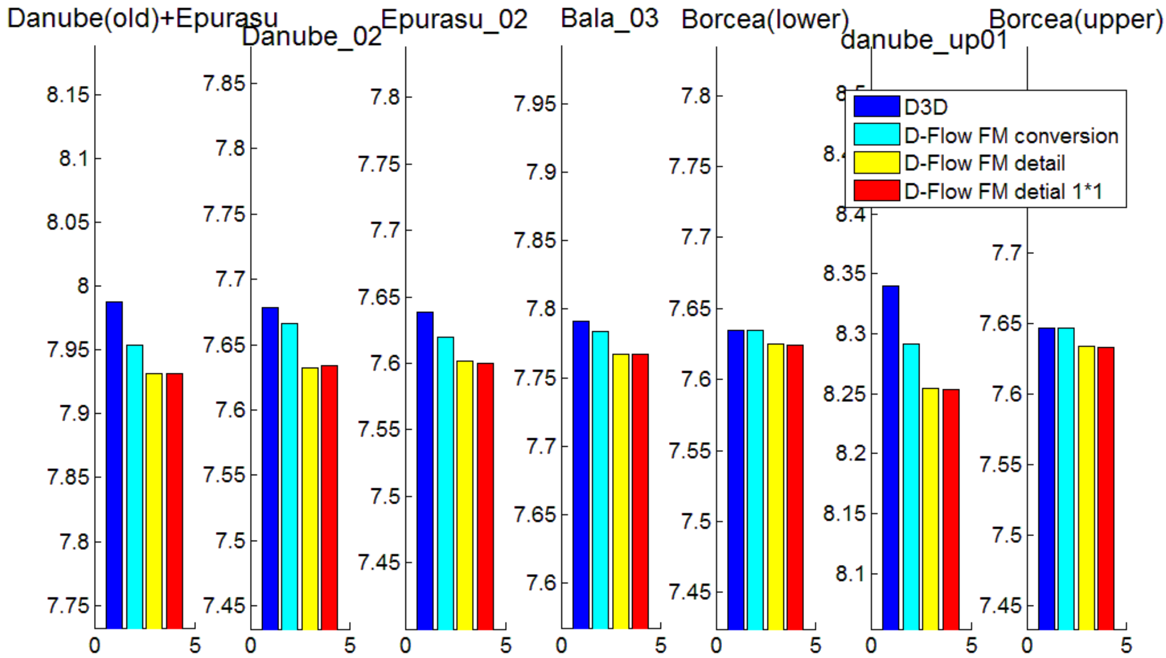

Figure F-2; Water level at observation points in models without structures

It seems from Figure F-2 that the water level at observation points in D3D is generally higher than the water level at observation points in D-Flow FM. A higher level of detail seems to have effect on the water level at observation points as well. The detailed models generally have lower water levels at observation points than the D-Flow FM conversion model.

The biggest difference occurs near the upstream boundary in the Danube branch at the observation point Danube Up01. But the difference between the D3D model and the conversion model are not bigger than 4 centimeter. The largest differences between the detailed models and the D-Flow FM conversion model are also smaller than 4 centimeter. This difference also occurs near the upstream open boundary in the Danube branch. The water levels at the downstream open boundaries are fixed, that is why the biggest differences occur at the upstream open boundary.

F.1.3. Velocity

Since the differences between the models in discharge and water level seemed small, it is easy to say that the differences in velocities are also small. The velocities are the average velocity at a cross-section. The velocities are averaged over the width and the height at the cross-sections. The average velocities at cross-sections are displayed in Figure F-3.

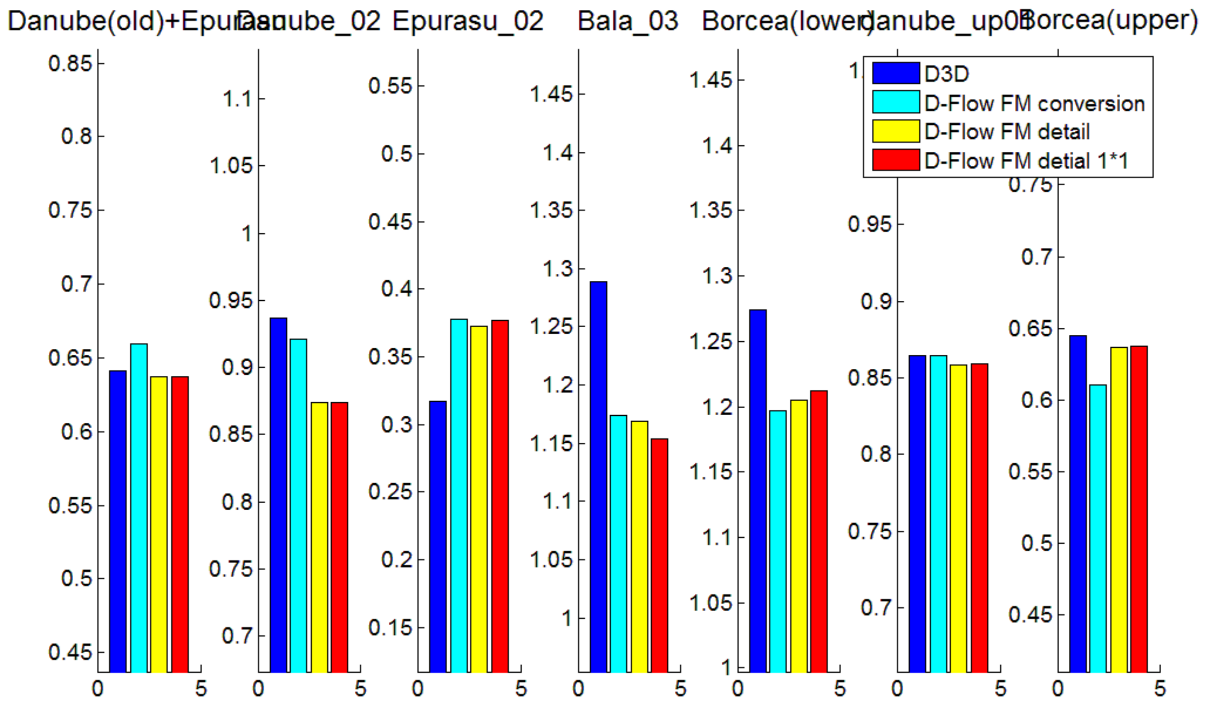

Figure F-3; Average velocity at cross-sections in models without structures

The D3D model seems to have higher velocities at most cross-sections. The only cross-sections that have a lower velocity in the D3D model are the Epurasu 02 cross-section. All other cross-sections have a higher average velocity in D3D than in the D-Flow FM models or the average velocity are approximately equal. The difference in computation (Chapter 2.2) seems to cause the biggest difference in the average velocity at cross-sections.

The velocities in the D-Flow FM models are approximately equal to each other. The average velocity in the D-Flow FM conversion model at the cross-sections Danube (Old)+ Epurasu and Danube 02 are lower than the detailed models. The velocity at the Borcea(Upper) cross-sections in the D-Flow FM conversion model is a little bit lower than in the detailed models.

The relative differences between the models in velocity are higher that the relative differences in the water level of the discharge, but still the relative difference are not very large. The largest difference occurs at Bala 03 cross-sections between the D3D model and the D-Flow FM model. Here the average velocity in the D3D model is approximately 10% higher than the velocity in the D-Flow FM models.

F.2. Bathymetry with structures

The differences between models without structures were relatively small. It is interesting to know what the effect is of the implementation of the structure in the Bala branch and the Epurasu branch on the different models. The differences between models with structures will be discussed in this chapter. The models used in this chapter are exactly the same as the models used in the previous chapter, only difference is the bathymetry. The bathymetry used in this chapter is samples V10 and the implementation of the structures in the Epurasu branch and the Bala branch. See chapter 3.2.2 for more information about this bathymetry.

The same computed model results as in the comparison in the previous chapter will be compared. The discharge at cross-sections will be compared first, after that the water level at observation points will be compared and at last, the average velocity at cross-sections will be compared.

F.2.1. Discharge

The discharge at cross-sections in the models with structures is shown in Figure F-4. At first sight, the differences seem to be larger than the differences in the comparison between models without structures.

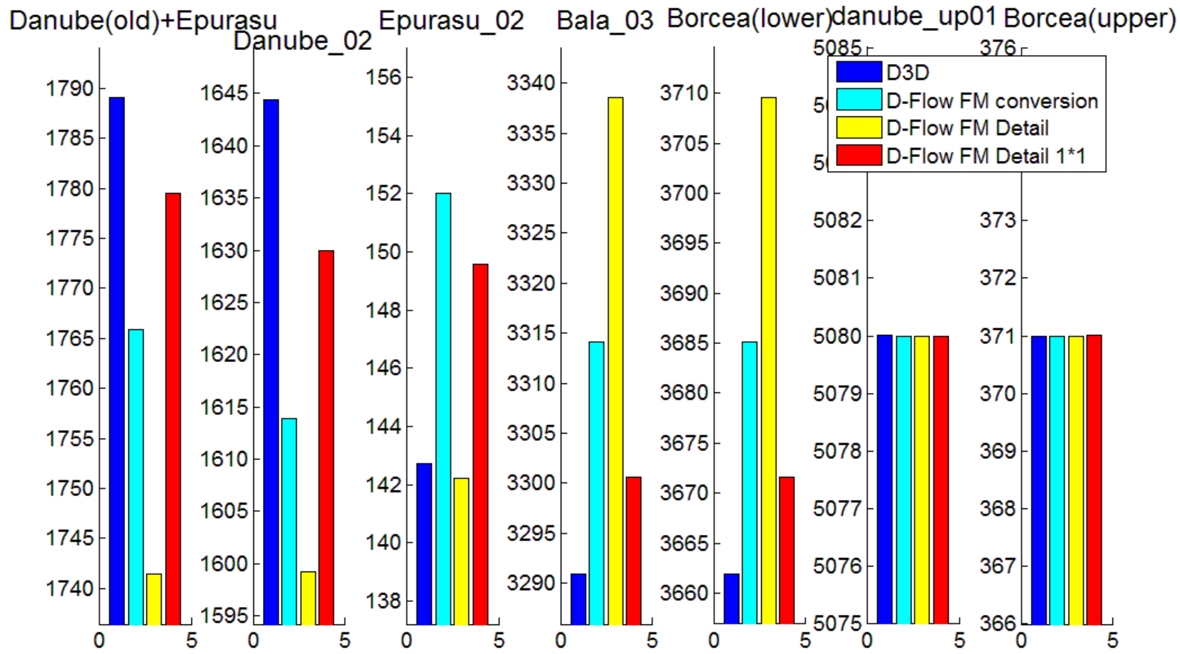

Figure F-4; Discharge at cross-sections in models with structures

While the computed model results of the D-Flow FM Detail model with bathymetry without structures and the D-Flow FM Detail 1*1 model with bathymetry without structures were almost similar, the D-Flow FM Detail model with bathymetry with structures differs a lot from the D-Flow FM Detail 1*1 model with bathymetry with structures. It is not surprising that there are larger differences between these models in the comparison with structures. The detailed part of the D-Flow FM Detail 1*1 model is located at the location of the Bala bottom sill. A more detailed part at locations with steep slopes could provide different discharge than a less detailed part. This is different for a flat bathymetry; the level of detail does not make a large difference in the discharge.

The largest difference occurs between the D3D model and the D-Flow FM Detail model at the cross-section Danube (Old) + Epurasu. The discharges at the cross-section Danube (Old) + Epurasu in the D3D model are approximately 47 m^3/s higher than the discharge in the D-Flow FM Detail model. The relative difference between these model at the cross-sections Danube (Old) + Epurasu is:

$$\frac{47}{1741} * 100 = 2{,}7\%$$

This is a notable difference, in fact, all the discharge at cross-section of the D-Flow FM Detail model are notable. Where the other three models are approximately equal to each other, the D-Flow FM Detail model is different from the other models. This does not count for the Epurasu 02 cross-section and the cross-section near the open boundaries. The discharges at those cross-sections in the D-Flow FM model are more equal to the discharge at those cross-sections in the other models.

F.2.2. Water level

It seemed from comparing the models with structures that the D-Flow FM Detail model was different from the other models. This chapter will discuss the differences between the models without structures in water levels at observation points. This is displayed in Figure F-5.

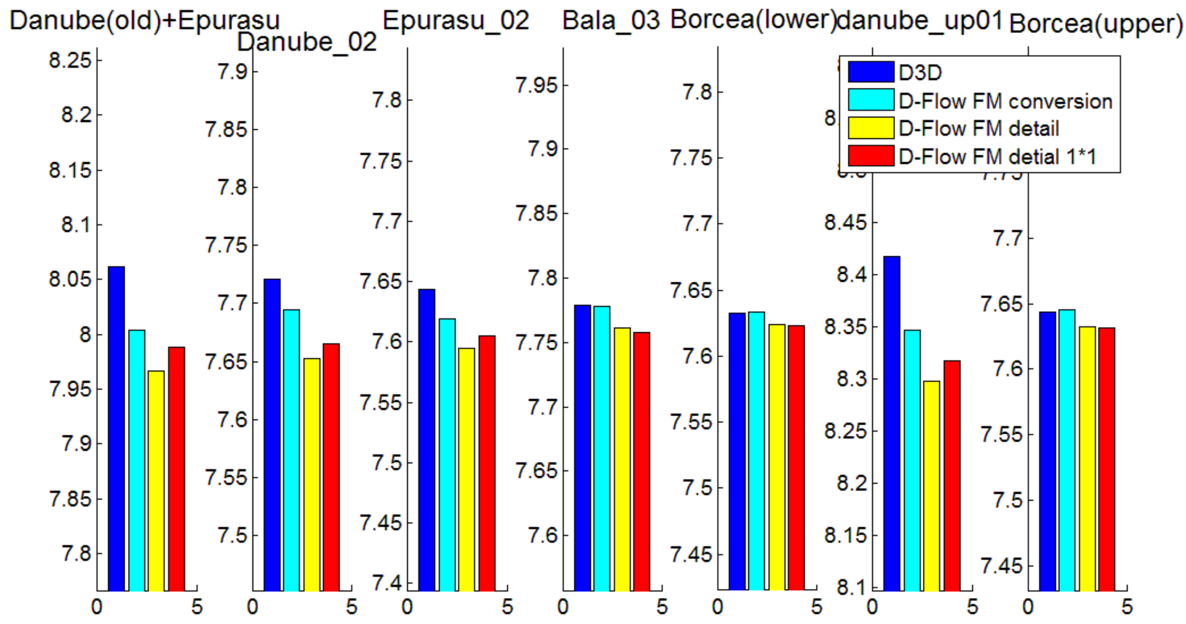

Figure F-5; Water level at observation points in models with structures

While the D-Flow FM Detail model showed the biggest deviation in discharges, the biggest deviation in water level is caused by the D3D model. Especially, the water level at the upstream observation points Danube Up01 in the D3D shows a big difference between the D3D model and the other models. The largest difference is the difference between the D3D model and the D-Flow FM model at the observation point Danube up01. This difference is approximately 12 centimeter.

There is a similarity between the comparison of the water level and the discharges. For example, at the cross-sections where the discharge in the D-Flow FM Detail model is higher than the D-Flow FM detail 1*1 model, the water level at observation points in the D-Flow FM detail model is also higher than the water level in the D-Flow FM detail 1*1 model. This is conversely for cross-sections where the discharge in D-Flow FM detail is lower than the discharge in the D-Flow FM detail 1*1 model. This counts also for the comparison of the water level and the discharges in the other models.

F.2.3. Velocity

Now the differences in discharges and water levels between the models with structures have been this discussed, the differences in averaged velocity could be discussed. The average velocities at cross-sections are shown in Figure F-6.

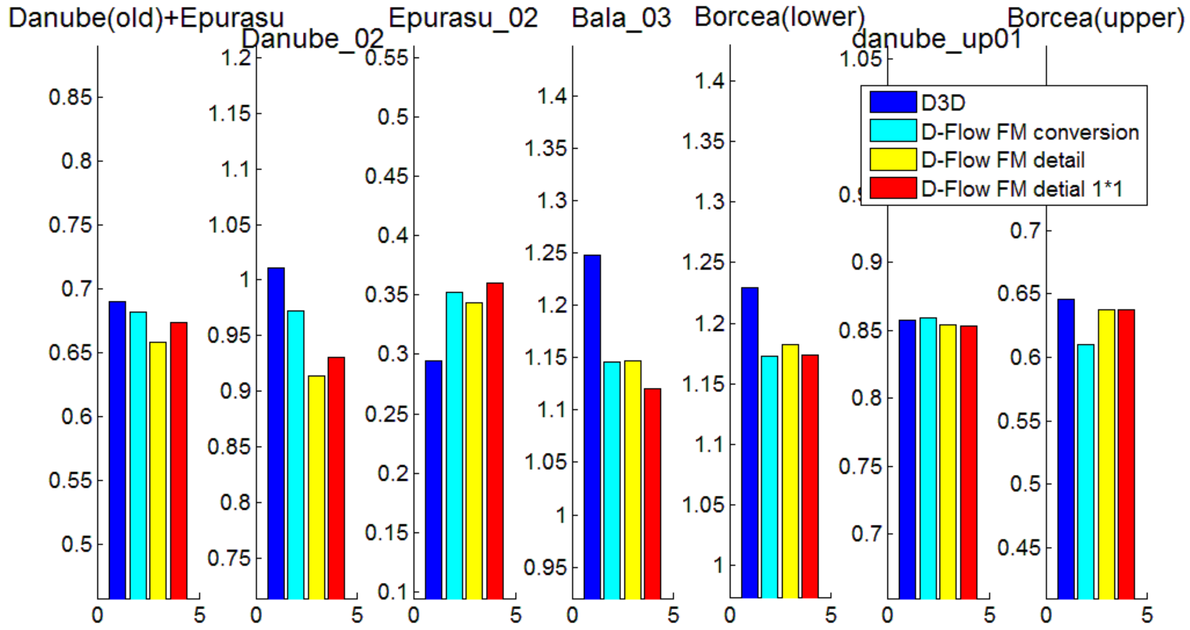

Figure F-6; Average velocity at cross-sections in models with structures

Generally the average velocity at cross-sections is higher in the D3D models, except for the Epurasu 02 cross-sections. The velocity at the Epurasu 02 cross-sections in the D3D models is lower than in the other models. The maximum difference between the D3D model and a D-Flow FM model is approximately 0,13 m/s at the Bala 03 cross-sections, while the average velocity in the D-Flow FM Detail 1*1 is only 1,12 m/s. This is a relative difference of:

$$\frac{0.13}{1.12} * 100 = 11{,}6\%$$

The average velocities at cross-sections in the D-Flow FM models are almost equal. There are only small differences, except for the cross-sections Danube 02 and Borcea (Upper). The average velocity at the cross-sections Danube 02 in the D-Flow FM conversion model is higher than the other D-Flow FM model, while the average velocity at the cross-section Borcea (Upper) in the D-Flow FM conversion model is higher than the other D-Flow FM models.

F.3. Difference between structures and without structures

Now the different models have been compared for the situation without structures and for the situation with structures, it is interesting to compare the difference between the models with structures with the models without structures. In fact, the effect of the implementation of the structures in different models will be compared in this chapter. The models will be compared with a table. For each model, first the models without structures is displayed, then the models with structures and at last the differences between this models.

F.3.1. Discharge

The difference in discharge at cross-sections (See Figure 3-1 for the cross-sections) is displayed in Table F.1. Since the discharge upstream are fixed, the difference between the models with structures and the models without structures at different cross-sections are connected to each other. Below the connection between the differences at cross-sections are displayed.

$$\text{Difference at } \mathbf{Danube}\ (\mathbf{Old}) + \ \mathbf{Epurasu} \ = -\text{Difference at } \mathbf{Bala\ 03} \\ = -\text{ Difference at } \mathbf{Borcea}\ (\mathbf{Lower})$$

$$\text{Difference at } \mathbf{Danube}\ (\mathbf{Old}) + \ \mathbf{Epurasu} \ = \text{Difference at } \mathbf{Danube\ 02} + \text{Difference at } \mathbf{Epurasu\ 02}$$

It does not make sense to discuss all cross-sections here, therefore the differences at the Danube (Old) + Epurasu cross-sections and the Epurasu 02 cross-sections will be discussed. Since the differences at the Epurasu 02 cross-sections depends on the difference at the Danube (Old) + Epurasu, the relative differences, with respect to the difference at the Danube (Old) + Epurasu cross-section, at the Epurasu 02 cross-sections will be discussed.

	Danube(Old) + Epurasu	Danube 02	Epurasu 02	Bala 03	Borcea lower	danube up	Borcea upper
D3D							
With	1789,1	1644,4	142,73	3290,9	3661,9	5080	371
Without	1672,6	1517,1	153,67	3407,4	3778,4	5080	371
Difference	116,5	127,3	-10,94	-116,5	-116,5	0	0
D-Flow FM conversion							
With	1765,9	1613,9	152,03	3314,1	3685,1	5080	371
Without	1688	1524,8	163,25	3392	3763	5080	371
Difference	77,9	89,1	-11,2	-77,9	-77,9	0,0	0,0
D-Flow FM Detail							
With	1741,4	1599,2	142,21	3338,6	3709,6	5080	371
Without	1680,6	1525,9	154,75	3399,4	3770,4	5080	371
Difference	60,8	73,3	-12,5	-60,8	-60,8	0,0	0,0
D-Flow FM Detail 1*1							
With	1779,5	1630	149,56	3300,6	3671,6	5080	371
Without	1681,4	1525,1	156,31	3398,7	3769,7	5080	371
Difference	98,1	104,9	-6,8	-98,1	-98,1	0,0	0,0

Table F.1; Discharges and difference in discharge between models without structures and models with structures in m^3/s

At the Danube (Old) + Epurasu cross-section the implementation of the structures has the biggest effect in the D3D model and the lowest effect in the D-Flow FM Detail model. The difference at the Danube (Old) + Epurasu cross-section is in the twice as large in the D3D model compared with the D-Flow FM Detail model. The relative differences at the Epurasu branch with respect to the difference at the Danube (Old) + Epurasu cross-sections are calculated below.

$$Relative\ difference\ D3D = \frac{10,94}{116,5} * 100 = 9,4\%$$

$$Relative\ difference\ D - Flow\ FM\ Conversion = \frac{11,2}{77,9} * 100 = 14,4\%$$

$$Relative\ difference\ D - Flow\ FM\ Detail = \frac{12,5}{60,8} * 100 = 20,6\%$$

$$Relative\ difference\ D - Flow\ FM\ Detail\ 1 * 1 = \frac{6,8}{98,1} * 100 = 6,9\%$$

The relative difference at the cross-section Epurasu 02 is highest in the D-Flow FM Detail model, while the D-Flow FM Detail 1*1 shows the lowest relative difference. There relative difference in the D-Flow FM Detail is 3 times as large as the relative difference in the D-Flow FM Detail 1*1 model. This is partly caused by the differences at the Danube (Old) + Epurasu cross-section, since the effect of the structures is relatively small in the D-Flow FM detail model. The large relative difference is also partly caused by the absolute difference in discharge at the Epurasu 02 cross-sections.

F.3.2. Water level

It seems from the previous chapters 5.1.2 and 5.2.2 that the water level at observation points in the computed model results of the D3D model is generally higher than in the other models. Even when the discharge at cross-section in different models was the same. The D3D model will probably also have larger differences between the model with bathymetry without structures and the model with bathymetry with structures.

A higher discharge in the model with bathymetry with structures in comparison with the model with bathymetry without structures at a cross-section will probably give a difference in water level at observation points below zero. Higher discharges will have higher water levels. Since the difference in water level at observation is calculated by the water level at observation points in the models without structures minus the water level at observation points in the models with structures, a higher water level in the models with structures will mean a difference lower than zero. The discharge at cross-sections in the models with structures were higher at the cross-sections Danube (Old) + Epurasu and Epurasu 02 in comparison with the models without structures. Therefore the difference in water level at the observation points with the same name generally is below zero and the difference at the other observation points will generally be above zero. The difference in water level at observation points are displayed in Table F.2.

	Danube(Old) + Epurasu	Danube 02	Epurasu 02	Bala 03	Borcea lower	danube up	Borcea upper
D3D							
With	8,0617	7,7209	7,644	7,7792	7,6324	8,4176	7,6436
Without	7,9874	7,6782	7,6381	7,7915	7,6347	8,3396	7,6468
Difference	0,0743	0,0427	0,0059	-0,0123	-0,0023	0,078	-0,0032
D-Flow FM conversion							
With	8,0033	7,6947	7,6194	7,7783	7,6336	8,3472	7,6455
Without	7,9536	7,6662	7,6194	7,7839	7,6346	8,2916	7,647
Difference	0,0497	0,0285	0	-0,0056	-0,001	0,0556	-0,0015
D-Flow FM Detail							
With	7,9665	7,6525	7,5942	7,7611	7,6240	8,2978	7,6325
Without	7,9315	7,6323	7,602	7,767	7,6249	8,2541	7,6338
Difference	0,0350	0,0202	-0,0078	-0,0059	-0,0009	0,0437	-0,0013
D-Flow FM Detail 1*1							
With	7,9887	7,6648	7,6051	7,7574	7,6228	8,3180	7,6313
Without	7,9317	7,6336	7,6003	7,7667	7,6242	8,2537	7,6333
Difference	0,057	0,0312	0,0048	-0,0093	-0,0014	0,0643	-0,002

Table F.2; Water level and difference in water level between models without structures and models with structures in m

What was stated above the table seems largely right. The difference at observation points in the D3D models is higher than in the other models. Also the difference at the observation points Danube (Old) + Epurasu and Epurasu 02 are below zero and the difference at other observation points are above zero. This counts for every observation point, except for Epurasu 02. The difference at the Epurasu 02 is very small in all models. The difference is in all models smaller than 1 centimeter or larger than -1 centimeter.

There are barely notable differences in the water level at observation points between the models without structures and the models with structures. The biggest difference occurs upstream at the Danube up observation point between the D3D models. This difference is just a difference of 7 centimeter. The difference between the D-Flow models without structures and the D-Flow models with structures at the observation point Danube up is 5,5 centimeter, 4,4 centimeter and 6,4 centimeter. The differences between these value are very small.

F.3.3. Velocity

The difference in average velocity at cross-sections between the models without structures and the models with structures is displayed in Table F.3. The differences between the models with structures and the models without structures are very small. The biggest difference is the difference in D3D at the Danube 02 cross-sections. This difference is 0,07 m/s in advantage of the model with bathymetry with structures. The difference between models with structures and models without structures is already very small. Comparing these differences gives even smaller differences. The largest difference at a cross-section between the effect of the implementation of the structures in a model and the effect of the implementation of the structures in another model is just 0,033 m/s.

	Danube(Old) + Epurasu	Danube 02	Epurasu 02	Bala 03	Borcea lower	Danube up	Borcea upper
D3D							
With	0,69023	1	0,29454	1,2477	1,2292	0,85755	0,64541
Without	0,64113	0,93722	0,31727	1,2888	1,2736	0,86436	0,6448
Difference	0,0491	0,07348	-0,02273	-0,0411	-0,0444	-0,00681	0,00061
D-Flow FM conversion							
With	0,68189	0,97184	0,35249	1,1455	1,1728	0,85954	0,6104
Without	0,65964	0,92103	0,37744	1,1737	1,1973	0,86434	0,61052
Difference	0,02225	0,05081	-0,02495	-0,0282	-0,0245	-0,0048	-0,0001
D-Flow FM Detail							
With	0,65817	0,91415	0,3433	1,1472	1,1824	0,85448	0,6373
Without	0,63749	0,87351	0,37275	1,1685	1,2047	0,85854	0,63703
Difference	0,02068	0,04064	-0,02945	-0,0213	-0,0223	-0,00406	0,00027
D-Flow FM Detail 1*1							
With	0,67336	0,93105	0,36018	1,1202	1,1741	0,85302	0,63773
Without	0,637	0,87376	0,3771	1,1537	1,2119	0,85897	0,63733
Difference	0,03636	0,05729	-0,01692	-0,0335	-0,0378	-0,00595	0,0004

Table F.3; Average velocities and difference in average velocity between models without structures and models with structures in m/s