A comparison between the Tygron Geodesign Platform and Delft3D: A case study

Bachelor Thesis Report Civil Engineering

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Preface

This report was written as part of the research for my bachelor study for Civil Engineering at the University of Twente. In this research I have set up a Delft3D model from scratch to compare this to an already existing model in Tygron. This report contains the process of the research and my findings concerning the Tygron software.

I would like to thank everybody that helped me in the process of this bachelor thesis project. Especially I would like to thank Jesse Jager and Sido Grin from Aveco the Bondt for helping me set up my research plan and supervising during the research. Also I would like to thank Matthijs Gensen from the University of Twente for his supervision on this project. I would also like to thank the developers of Tygron for helping me where needed on the Tygron software and for the open discussions about improvements.

I would also like to wish the reader of this report a lot of reading pleasure. For any questions regarding this research report you can reach me via e-mail:
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Abstract

This research shows a comparison between the results of a flood propagation model in the Tygron Geodesign Platform (from here on called Tygron) and in Delft3D. Tygron is multifunctional software that is designed to make quick but well informed decisions. It is relatively new software and it has not yet been properly validated. To give an overview of the performance of Tygron, a comparison is done with Delft3D. Delft3D is more established software and has been tested and validated extensively.

The comparison between Tygron and Delft3D is done according to a case study. This provides a realistic as well as a comparable situation. The case area is a peak storage area in the south-western point of Haarlemmermeer. The inflow discharge is controlled during the whole simulation and the water flows through ditches in the area and later flood the plains. The simulations are compared on flow velocity, water depth and water direction. The model in Tygron was available from the start. The model in Delft3D was set up specifically for this research.

The research results show a number of differences between Tygron and Delft3D. The water depth in the area shows the expected behaviour for both Tygron and Delft3D. The differences between Tygron and Delft3D are minimal and not significant for the vast majority of model purposes. Considering flow velocity, there are two anomalies. The expectation for the flow velocity pattern is that the highest velocity occurs in the middle of a channel. This is the location where the effect of surface friction is at its minimum. However, Tygron does not show this pattern, but rather a slightly deviating pattern. Delft3D does show the expected flow velocity pattern. The second anomaly in flow velocity is the occurrence of flow velocity peaks at the edge of the channels. These flow velocity peaks only seem to occur at the cell between a wet and a dry area and do not significantly affect the flow around it. Delft3D does not show these flow velocity peaks. The comparison of the flow direction shows a last anomaly in the results from Tygron. From the beginning of the simulation, the flow direction seems to alternate on an irregular distance. This suggests that the water is already moving. This leads to believe that there is something wrong with the initial state of the simulation in Tygron. This phenomenon is also not shown by Delft3D.

Considering that the development of Tygron is young, and considering the other applications Tygron can be used for, it shows great potential as modelling software. The water module can already be used for predictions of water depths in relatively simple environments. For local and detailed predictions of flow velocity and direction however, the software still needs improvement before it can be used effectively.

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Introduction

A large part of the Netherlands ground level is below sea level. This brings with it challenges to protect the Netherlands against flooding and it causes the consequences of a flood to be disastrous. To manage the risk of a flood, many assessments of water safety in the form of dike quality are/ done. Also, spatial measures are taken to reduce the consequences and therefore reduce the risk of floods (Hoekstra, 2013). To manage the spatial measures, floods are simulated using flood propagation models.

The use of computational flood propagation models dates back to the sixties of the twentieth century (Alcrudo, 2004), and model software has improved since. Nowadays supercomputers are constantly running to simulate floods all around the Netherlands and the rest of the world. The Tygron Geodesign Platform (from here on called Tygron) is a platform which has an implemented flood propagation model, called the Flooding Module. In this module, simulations can be done to give a visual representation of the consequences of a flood. The flooding module is not yet officially released and also not yet properly validated. Therefore Aveco de Bondt is interested in a comparison between Tygron and other modelling software, to see on what aspects the results from Tygron differ from an already established software package. In this research, a comparison will be done between Tygron and Delft3D. The research question that will be answered in this research is as follows:

What differences in water height, flow velocity and flow direction are present between the results from a simulation in Tygron and a simulation in Delft3D on a planned inflow in a peak storage area?

1. Tygron and Delft3D

This chapter will provide a description of Tygron and of Delft3d. The governing equations and the grid types will be discussed. Other differences in the two software packages will be highlighted throughout the report if relevant.

1.1. Tygron Geodesign Platform

Tygron is multifunctional software that is designed to make quick but well informed decisions (Tygron, 2019). It aims to be easy and quick to use and to give a clear overview of the situation and possible consequences. This makes it a suitable platform to discuss measures with stakeholders and let them participate in decision making. The software consists of several modules, all specific to a certain subject. One of these modules is the flood module, that is used to simulate water propagation.

The flood module in Tygron is a 2D model using the two-dimensional Saint-Venant equations (Tygron, 2019). The model divides a user selected area into a number of square cells, ranging from 0,25m^2 to 100m^2, creating a structural grid (Tygron, 2019). The cells in the grid are given their characteristics, like surface height and roughness, using open data to be able to solve the equations for the water flow for any given scenario.

Aveco de Bondt is currently working with the preview of the flooding module in Tygron. They intend to use the platform to show the consequences of floods. For this application the simulation needs to result in a rough estimation of reality. The main factors that are important for this application are the area that floods, the resulting water level and the evacuation times per area.

Another example of an application that Aveco de Bondt uses Tygron for, is the simulation of peak storages. For this, a more detailed simulation is needed, which includes water levels and local water velocities. This is needed to take soil erosion of the flooded area into account.

1.2. Delft3D

Delft3D is a more established simulation software package developed by Deltares (Delft3D, 2019). Extended testing and validating is done on the software (Melger, 2019) and it is widely used all over the world. Delft3D is able to carry out simulations of flows, sediment transports, waves, water quality, morphological developments and ecology (Deltares, 2014) and, like Tygron, consists of a number of modules, each specialised in one subject.

Delft3D is able to compute both the three-dimensional, as well as the two-dimensional Saint-Venant equations (Deltares, 2014a). Considering the exceptional computational power needed for solving the three-dimensional Saint-Venant equations (Teng et al., 2017), for most practical purposes of the flood simulation, a two-dimensional approach is sufficient (Alcrudo, 2004). The grid used in Delft3D is either a structured or unstructured grid. A structured grid consists of rectangular grid cells, whereas an unstructured grid can have either rectangular or triangular grid cells or both. While the grid in Tygron is automatically generated, the grid in Delft3D is set up manually dependent on the model area and its specifications. In Delft3D all information needed for the computation of a flood simulation is added manually into the model. Every grid cell is then given its characteristics based on the input data.

2. Method

The aim of the research is to see whether the results from Tygron are valid. Since a real-life experiment is in this case not possible, a simulated situation will be recreated in other software; Delft3D. This means that a comparison between Tygron and Delft3D will be done according to a case study. This provides a realistic, yet comparable situation. The case area is described in detail in chapter 3. It is crucial that any differences shown in this comparison are the result of differences in the software and not in the model. Therefore a strict division between what is the same and what is different in both models is needed.

The physical area will be implemented in exactly the same way. The bathymetry, roughness coefficients and culvert locations in Delft3D will be identical in both simulations, since this is a digital representation of the same physical area. Certain modelling choices however, will be made independently from each other. This is done because some modelling choices are software specific. Something that works good in Tygron may not work in Delft3D or the other way around. To prevent copying modelling mistakes or software specific modelling philosophies, modelling choices will be made independently from each other. These modelling choices include grid type and properties, time frame settings and numerical parameters.

For the case area, an already existing model in Tygron, constructed by Aveco de Bondt, is used. The model in Delft3D is set up based on this already existing model. The model in Tygron is not altered for this research.

The results following from both software packages will be compared on water depth, flow velocity and flow direction. These three characteristics will be a representation of the whole flow process.

3. The case area

To prevent flooding in the water system in Rijnland (Figure 3.1), Hoogheemraadschap Rijnland is planning to install a peak storage area in the south-western point of Haarlemmermeer as part of a larger package of measures. The peak storage area should have a storage volume of 1,000,000 m^3 of water. For this, a dike will be placed together with accompanying ditches on either side of the dike, as shown in Figure 3.2.

In case the peak storage area needs to be activated, water will be let in through a given discharge time-series in the south-western corner to fill the ditches in the area in four hours' time. After four hours, the full discharge of 15 m^3/s should be reached and the area should fill up in the following twenty hours.

The resulting bathymetry of the area, including the dike and ditches, is given in Figure 3.3. To stop waves from the inlet and ensure steady flow through the ditches, a weir is installed in the basin with a height of 1.4m with respect to the bottom of the basin, as shown in Figure 3.3A. The initial water level in the area is at -6,02m NAP, which means that there is an initial water depth of roughly one meter in the ditches. The water-inlet is situated in the south-western corner of the peak storage area. The inflow is determined using a time-series discharge, which is given in Figure 3.4. The discharge slowly rises to 15m^3/s in a time-span of four hours, and will remain at 15 m^3/s until the peak storage area is filled.

In the case area, three different types of surface are present; waterways, grasslands and crops. The Manning coefficients given to these crops by Aveco de Bondt are 0.04 (Waterways), 0.08 (Grasslands) and 0.09 (Crops). According to Chow (1959), these are rather high values for the corresponding surface types. These higher Manning values imply a high level of surface friction. This may cause a great difference in flow velocity between high and low water depths, for example the middle and the edges of a channel. To ensure a proper comparison between Tygron and Delft3D, these Manning values will be used nonetheless. The layout of the surface areas is shown in Figure 3.5.

Finally, three culverts are installed in the area. Their location is shown in Figure 3.6. The culverts allow for a free flow between two water bodies. They are cylindrical culverts with a diameter of one meter and a length of 8.94m (Culvert 1), 18.02m (Culvert 2) and 18.68m (Culvert 3). The height at which they are installed determines the threshold for flow through the culverts. The height of both endpoints of the culverts is the same as the highest surface height of the two grid cells in which the endpoints are located. This is the same as in reality. The Manning coefficient that is used for the culverts is 0.014. This is also a rather high value (Chow, 1959), which will decrease flow velocity through the culverts. However, as long as both models use the same value, there should be no differences.

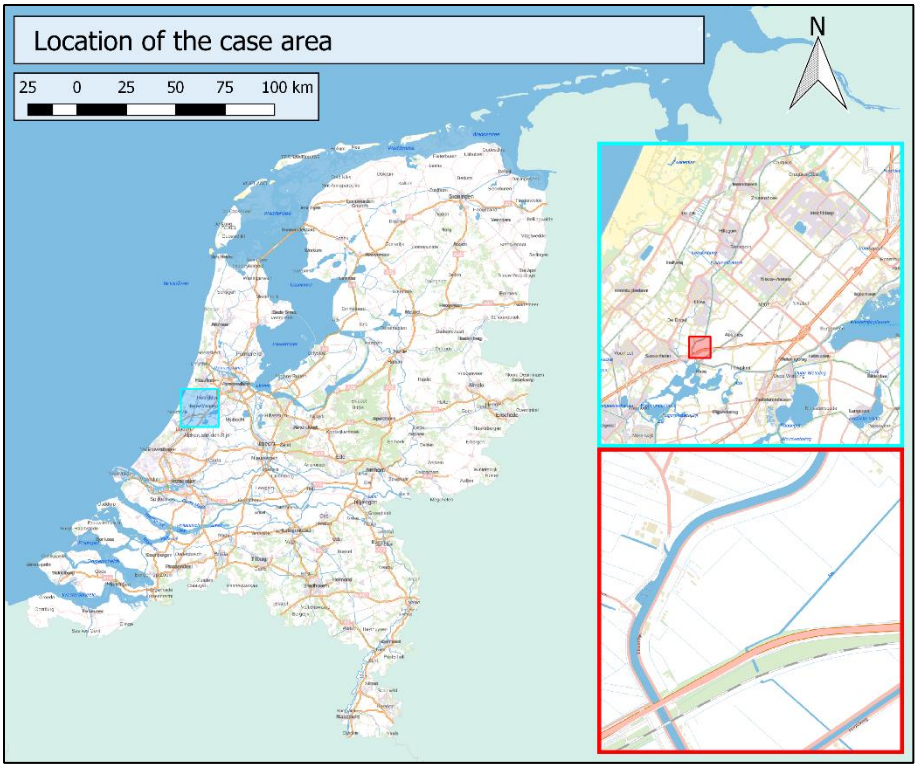


Figure 3.1: Location of the case area.

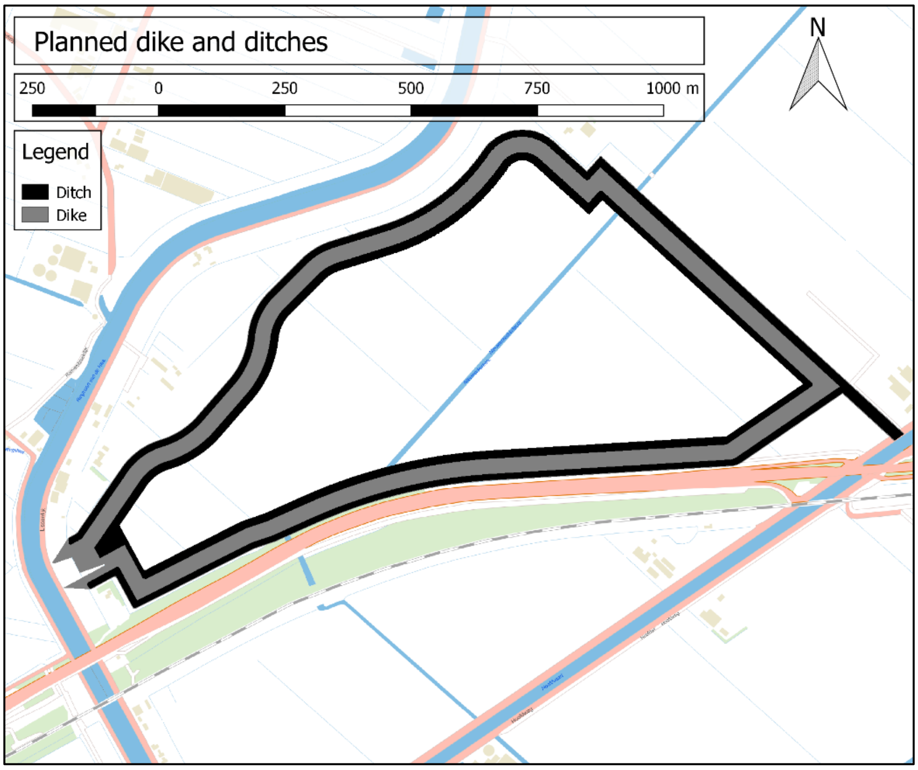


Figure 3.2: Planned dike and ditches in the case area

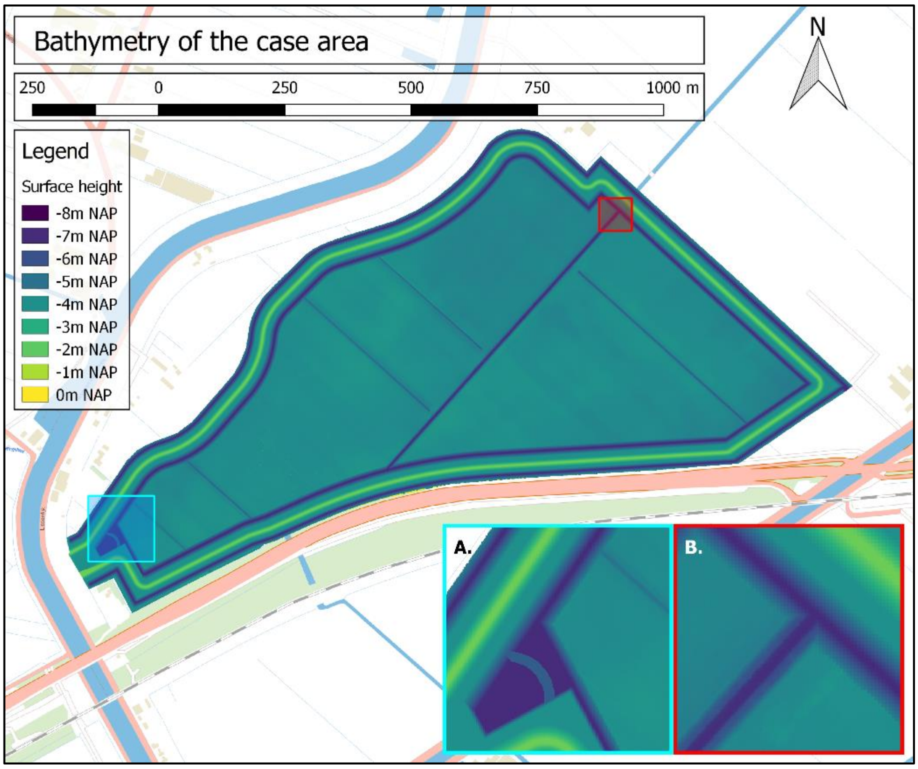


Figure 3.3: Bathymetry of the case area. (A: The inlet location with installed weir, B: Connection between the already existing and the installed ditch)

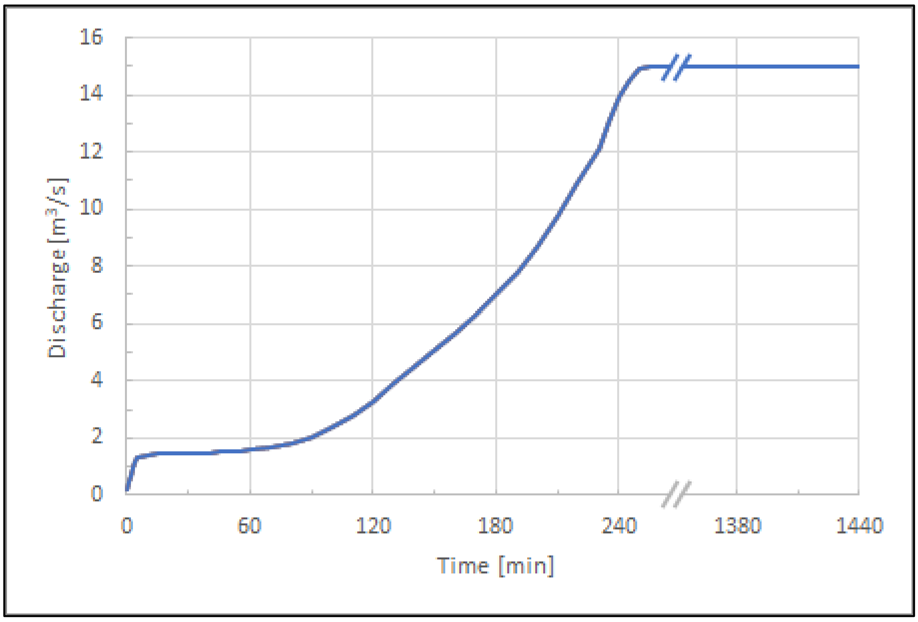


Figure 3.4: Time series of inflow discharge.

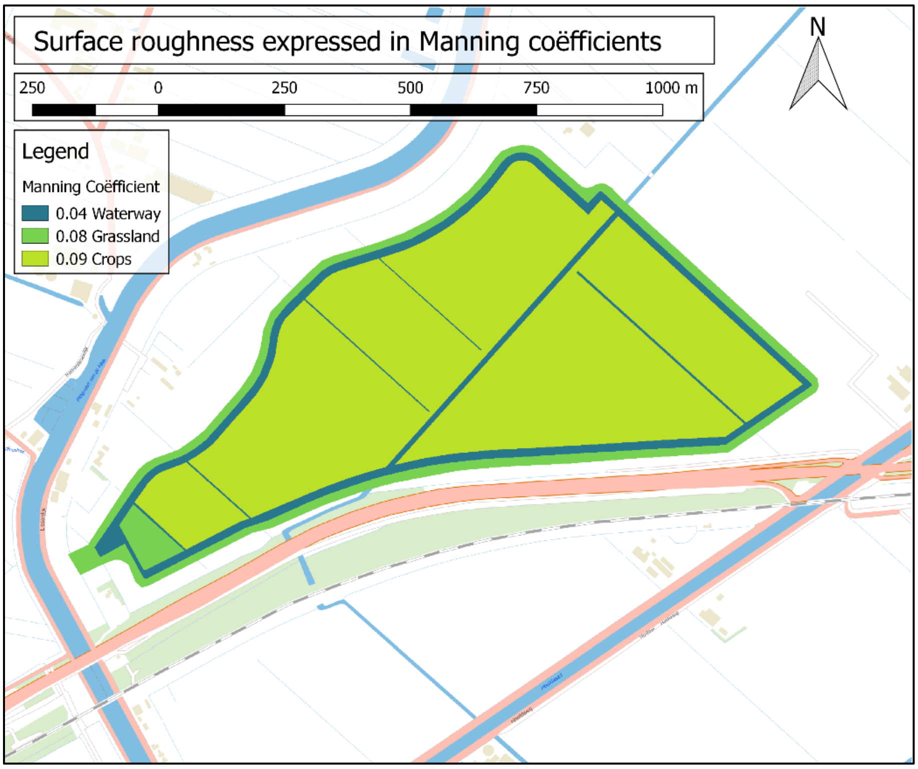


Figure 3.5: Surface roughness expressed in Manning coefficients.

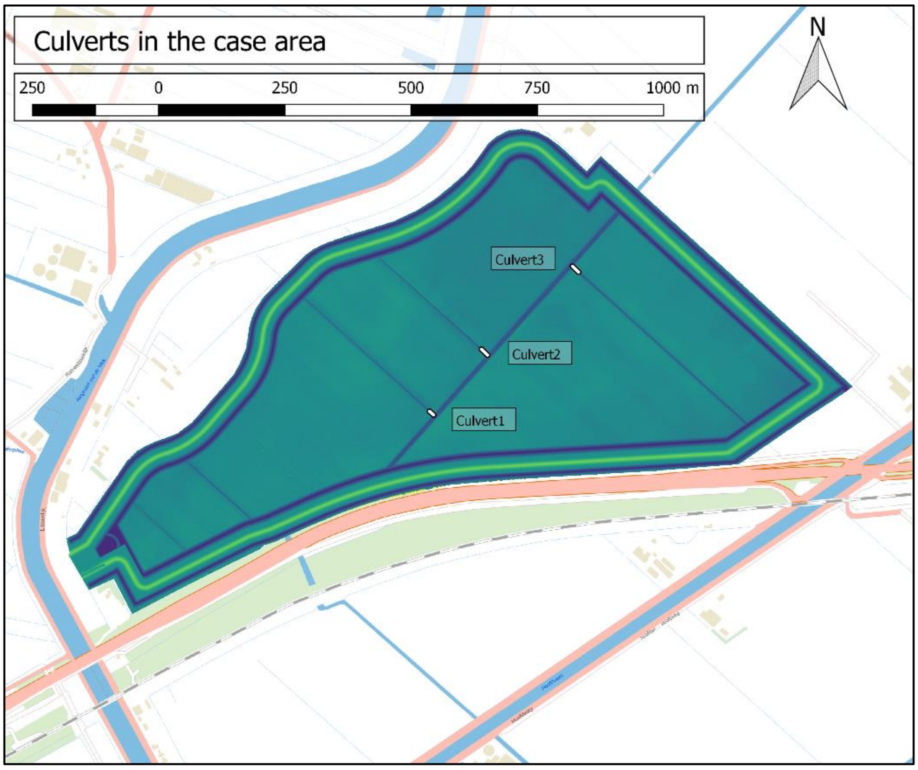


Figure 3.6: Culverts in the case area.

4. Models in Tygron and Delft3D

A description of the models in both Tygron and Delft3D is given in this chapter. It describes only the differences between the two software packages that are relevant to this research.

4.1. Tygron

The model in Tygron is set up by Aveco de Bondt and was not altered for this research. It was set up by implementing the case area described in chapter 3. Some parts that are specific to the Tygron model will be elaborated on in this paragraph, to emphasize the potential differences between Tygron and Delft3D. These consist of the grid type, the discretization of the surface height to the grid, the implementation of the inflow discharge and the determination of the timestep of the model.

Tygron uses a structural grid with square grid cells with an edge length of 0,5m. This grid is oriented parallel to the equator, which means that the horizontal lines are slightly curved to account for the curvature of the earth. The surface height of the case area is transferred to the grid by taking four elevation points in the corners of a grid cell, and determining the linear slope in both the x- and the y-direction. Using this, the elevation in the centre point is calculated (Tygron, 2019). Using this method, the surface area will not include sudden jumps in surface height, since two adjacent grid cells always share the two corner points. This process is visualised in Figure 4.1.

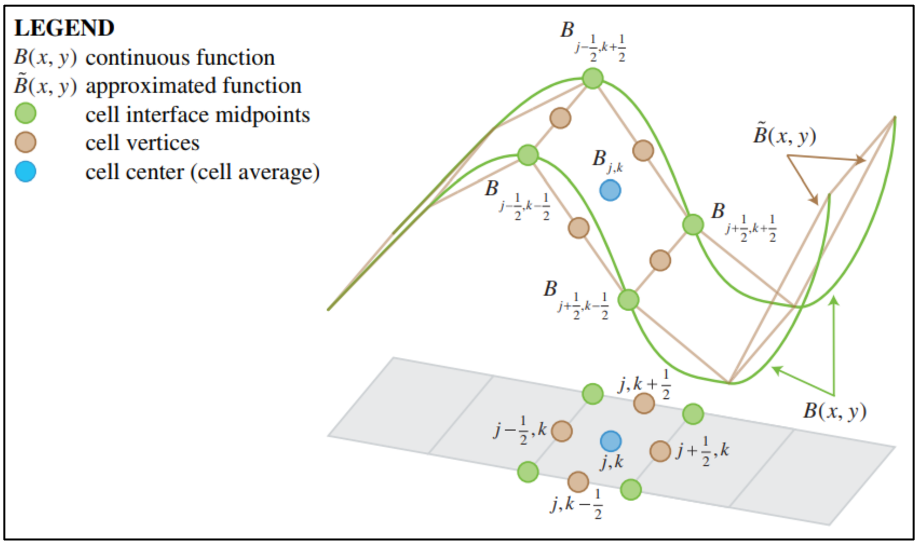


Figure 4.1: Discretization of surface height to computational grid in Tygron. Figure from (Tygron, 2019))

Since the required inflow discharge is too large to be let in with a singular inlet, the inflow discharge in Tygron is separated into six inlet points, located in a straight line in the south-west corner of the case area. These points virtually generate water in a given cell. The six points all have their own unique time-series, which are slightly out of synchronisation to decrease the effect of unwanted wave occurrence. The individual and total discharges are given in Figure 4.2.

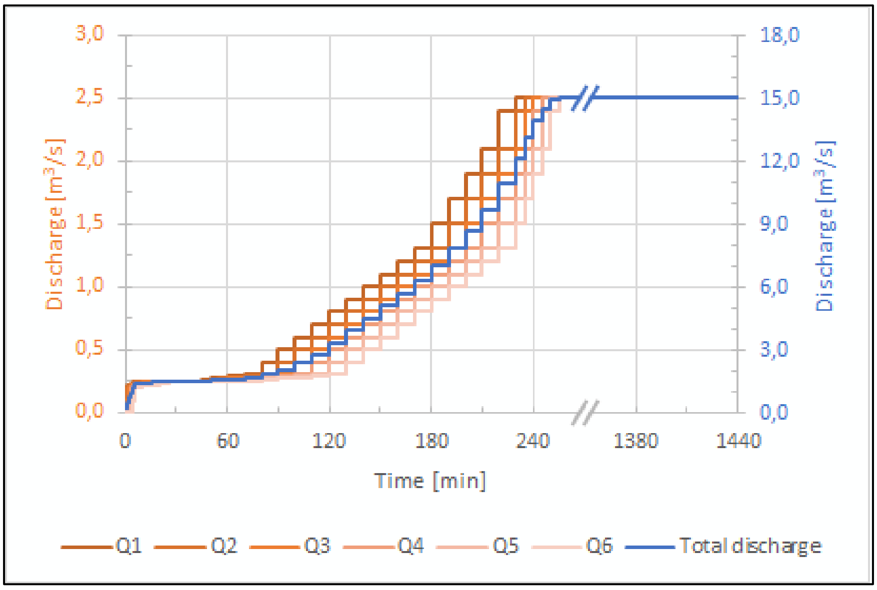


Figure 4.2: Inflow discharge in Tygron, with individual inlet points (Q1-Q6) on left axis and the total discharge on right axis.

Tygron uses an adaptive timestep. For every timestep in the Tygron simulation, the software determines the size of the timestep so that the Courant number is kept smaller than 0.25 for all active computational cells. In other words, at all times the timestep is one fourth of the time it takes for the fastest flowing particle to travel one cell distance. This is illustrated in the equation below.

$$\Delta T = \min(\frac{\partial x}{4a}, \frac{\partial y}{4b}) \quad \text{(eq.1)}$$

In which:
ΔT is the computational time-step in seconds
Δx is the grid-size in the x direction
Δy is the grid-size in the y direction
a is the maximum velocity in x-direction
b is the maximum velocity in y-direction

4.2. Delft3D

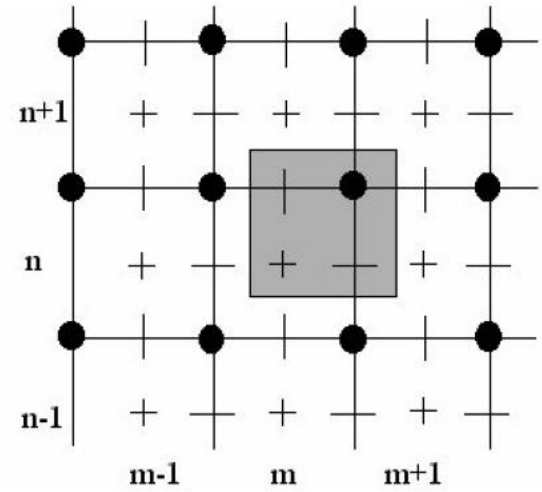
The model in Delft3D is set up from scratch, specifically for this research. Like the model in Tygron, it is set up by implementing the case area described in chapter 3. Some parts that are specific to the Delft3D model will be elaborated on in this paragraph, to emphasize the potential differences between Tygron and Delft3D. Since the generation of the grid is an important part of the simulation in Delft3D, this is given extra attention. In addition to that, the implementation of the inflow discharge and the determination of the timestep are elaborated on in this paragraph.

4.2.1. Computational grid

In Tygron, the grid is generated automatically with the grid cell size as the only input parameter. In Delft3D, generating a proper grid is an important part of the simulation, which is why this is explained in more detail.

Delft3D has a number of possibilities for generating a grid. As described in chapter 1, the software supports both a structured grid as well as an unstructured grid. However, to generate an unstructured grid, a separate package is needed which is not implemented into the base version of Delft3D. Therefore, for this application, only a structured grid is used. The advantage of an unstructured grid would be that the grid cells can be placed optimally for every individual location, because it is not bound to a fixed structure.

However, because the simulation in this research mostly consists of a flat floodplain, the flow is not fixed in a certain direction like it is in a channel or river, which is why the grid cell orientation is not crucial. The consequences of the limitation to a structured grid is therefore minimal.



	Legend:
Full lines	The numerical grid
Grey area	Items with the same grid indices (*m,n*)
+	Water level, concentration of constituents, salinity, and temperature
–	Horizontal Velocity component in *u*-direction (also called *m*-direction)
|	Horizontal velocity component in *v*-direction (also called *n*-direction)
●	Depth below mean water level

Figure 4.3: Grid in Delft3D, figure from (Deltares, 2014)

Different types of data, listed in Figure 4.3, are stored in different locations in reference to the grid cells, this is called a staggered grid (Deltares, 2014a). A visualisation of the location of the data is given in Figure 4.3. Using a staggered grid, the pressure gradient in the cell can be estimated more accurately (Ketabdari, Saghi, & Rezaei, 2010), this leads to a more accurate representation of reality.

The accuracy of the simulation depends on a number of grid specific properties (Deltares, 2014b). These properties include orthogonality, smoothness, aspect ratio, grid cell size and the Courant number. The orthogonality of a grid describes how the grid cells are placed against each other. It is defined as the angle between the line connecting the cell centres (blue lines in Figure 4.4), and the line connecting grid cell corners (red lines in Figure 4.4) (Deltares, 2014a). The closer this angle is to 90°, the better. The smoothness of a grid is defined as the ratio between the areas of two adjacent grid cells. A smoothness value of 1.0 is the optimum, since this implies the exact same grid area between two adjacent grid cells. The aspect ratio of a grid cell is the ratio between the vertices in the x-direction to the vertices in the y-direction. A square grid cell has an aspect ratio of 1.0, since the vertices in both directions are exactly the same length. The closer the aspect ratio is to 1.0, the better. The edge length determines how fine the grid is, the smaller the edge length, the finer the grid, and the more detailed the simulation.

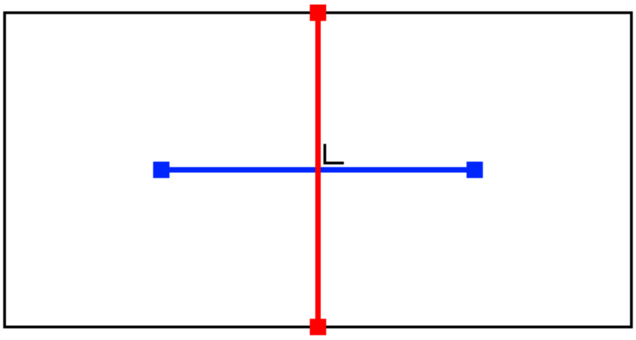


Figure 4.4: Grid orthogonality in a structured grid.

Finally, the Courant number, or CFL (Courant-Friedrichs-Lewy number), is a dimensionless number that describes the stability of a simulation. It was first introduced in 1928 by Richard Courant, Kurt Friedrichs and Hans Lewy in (Courant, Friedrichs, & Lewy, 1928). It describes the amount of grid cells that a particle travels in one timestep. To maintain stability in the simulation, this can usually not exceed one grid cell. Delft3D uses a slightly altered version of the Courant number, which is determined using the following equation.

$$CFL = 2\Delta T\sqrt{gH}\sqrt{\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}} \qquad \text{(eq.2)}$$

In which:
ΔT is the computational time-step in seconds
g is the gravitational acceleration
H is the total water depth
Δx is the grid-size in the x direction
Δy is the grid-size in the y direction

In general, the Courant number is advised to be smaller than ten at all times (Deltares, 2014a). The equation above implies that the finer the grid, the larger the courant number. Also, the larger the timestep, the larger the courant number. Therefore, when a finer grid is used, the timestep should be decreased to meet the courant number recommendations.

According to equation 2, the courant number is affected by the water depth. While the timestep of the simulation is a global variable, the water depth usually varies in space. This makes the CFL condition a variable that is grid cell specific. To maintain an optimal Courant number all over the simulation, the change in water depth could be countered by a change in grid cell sizes. For example, a finer grid could be used along the ditches, since the water depth will be higher in these grid cells. This method of an unstructured grid, however, is not possible for this research, as described earlier in this paragraph.

For this simulation, a structured grid with square grid cells of one by one meter is chosen. A grid with square grid cells meets the recommendations of orthogonality, smoothness and aspect ratio by definition, which makes it a good choice for the simulation. If the resolution in the transverse direction is too low, the physical processes are not accurately simulated (Bomers, Schielen, & Hulscher, 2019). Since the ditches are only ten meters wide at the most narrow location, therefore a grid this fine is needed for a sufficiently accurate representation of the flow. The grid is placed on an angle so that it is perpendicular to the inflow boundary. This enables an inflow boundary that is closest to reality, and also places the grid cell orientation in the ditches optimally considering the limitation to the structured grid. In contrary to the grid in Tygron, the grid in Delft3D does not compensate for the curvature of the earth, since the area is too small for this to make a significant difference. A visualisation of the grid is given in Figure 4.5.

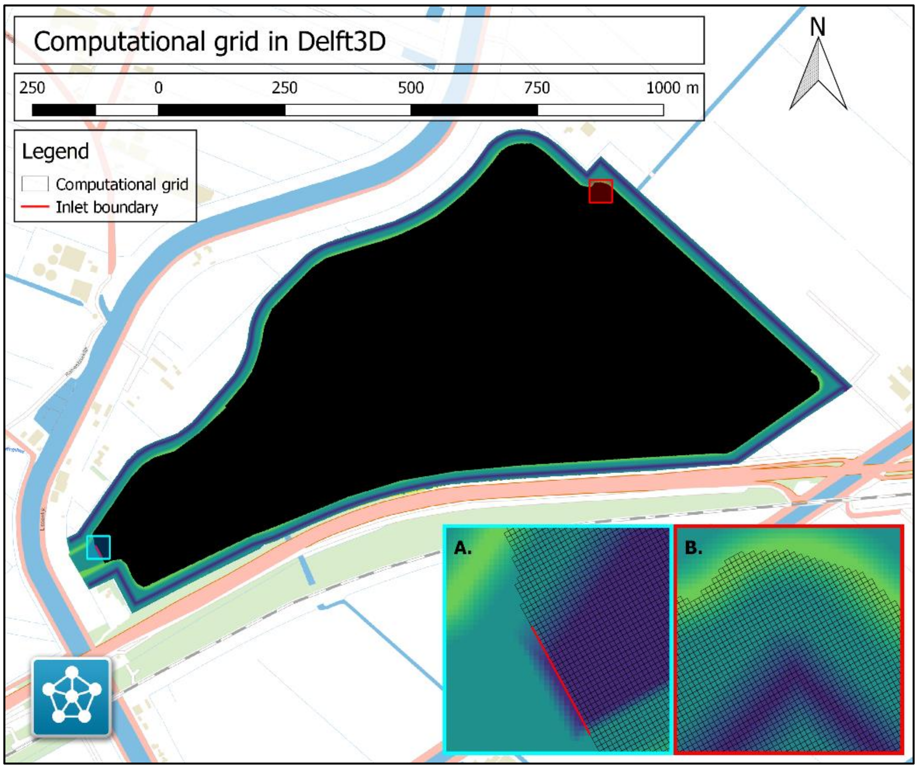


Figure 4.5: The computational grid in Delft3D.

4.2.2. Model

The inflow discharge for Delft3D, given in Table 4.1, is fitted to the inflow discharge described in chapter 3. Delft3D interpolates the inflow discharge linearly between specified timepoints. This creates a constant and smooth inflow curve, that fits the given inflow timeseries, shown in Figure 4.6.

Table 4.1: Time series of inflow discharge in Delft3D.

Timestep [hh/mm/ss]	Discharge [m^3/s]
00 00 00	00.00
00 05 00	01.35
00 10 00	01.40
01 30 00	02.00
02 00 00	03.30
03 00 00	07.00
03 50 00	12.00
04 00 00	14.00
04 05 00	14.50
04 15 00	15.00
08 00 00	15.00

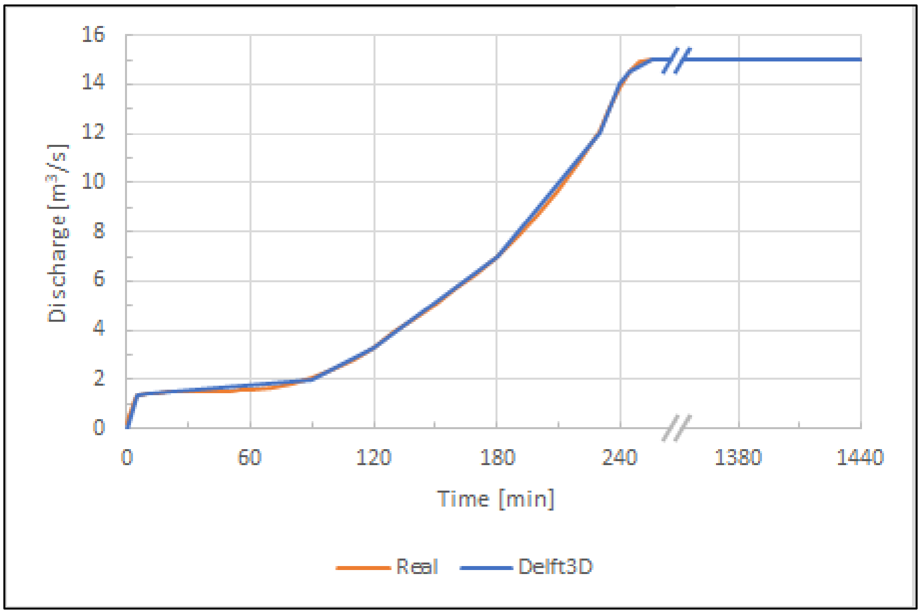


Figure 4.6: Time series of inflow discharge in Delft3D.

Delft3D works with a fixed timestep throughout the whole simulation (Deltares, 2014a). There are a number of restrictions to the time steps taken in a simulation, of which the courant number, described in paragraph 4.2.1, is the most important one. A timestep that is too large could make the simulation unstable, as well as reduce accuracy. For the chosen grid of one by one meter, a timestep of 0.15 seconds is sufficiently small. Smaller timesteps will result in a larger computation time. With the given bathymetry, this results in Courant numbers ranging from 1.8 to 7.0.

5. Results

In this chapter, the results from both simulations will be given in the form of coloured map figures and cross sections. The results are examined on all timesteps, but only relevant timesteps are given in this chapter. A list of visualisations of other timesteps is given in appendix A. As described in chapter 2, the comparison is made on water depth, flow velocity and flow direction. For every characteristic, first the expected behaviour is described, followed by the actual results of both Tygron and Delft3D. For some observations, a cross section is given to show detailed values. The locations of the cross sections are defined in Figure 5.1. Cross sections 1 shows the flow at the inflow boundary and the flow over the weir. Cross section 2 shows the flow through the narrowest channel in the area right after a bend in the flow. This is expected to show a slightly deviant pattern to a regular straight channel. Cross section 3 shows the flow through a bend and cross section 4 shows the flow through a straight channel without major disturbances in the flow.

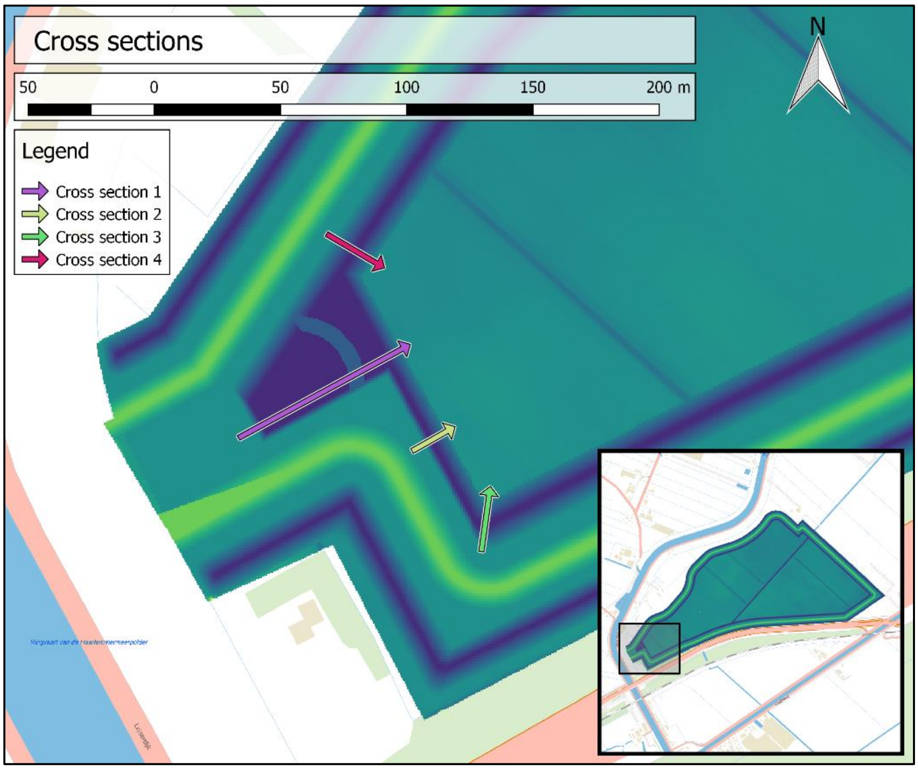


Figure 5.1: Four cross sections on key locations in the case area.

5.1. Water depth

The water depth in the region is expected to rise, starting at the inlet point in the south-west. Gradually the water depth will rise all throughout the ditches in the area. After roughly four hours, the ditches will have reached their volume capacity, and the plains will flood. This happens as expected in both Tygron and Delft3D (see appendix A.).

A visualisation of the difference in percentages in water depth between Tygron and Delft3D at eight hours, is given in Figure 5.2. It shows that most of the area is green, which means that the difference is close to 0%. The white spots in the figure are places that have not been flooded yet. However there are two observations that require explanation. The first of these are the blue parts in the figure. At the leading edge of the flood, it seems like Tygron shows a slightly higher water depth. Note however, that this is based on percentages. A small water depth will accentuate small differences. The blue spots are all located at low water depths. Nevertheless, it seems that the flood propagation in Tygron is slightly ahead of that of Delft3D. The other observation is the red lines along the ditches. These show a difference in water depth that is most likely caused by the difference in surface height after discretization, which is shown in Figure

5.3. From comparing Figure 5.2 and Figure 5.3, it is clearly visible that where the water depth in Delft3D is higher than in Tygron, also the surface height is lower than in Tygron. Due to the administration of the bathymetry to the grid cells, a slight displacement of the bathymetry may occur. While this may not significantly affect the final and global results, it may show high local differences in water depth.

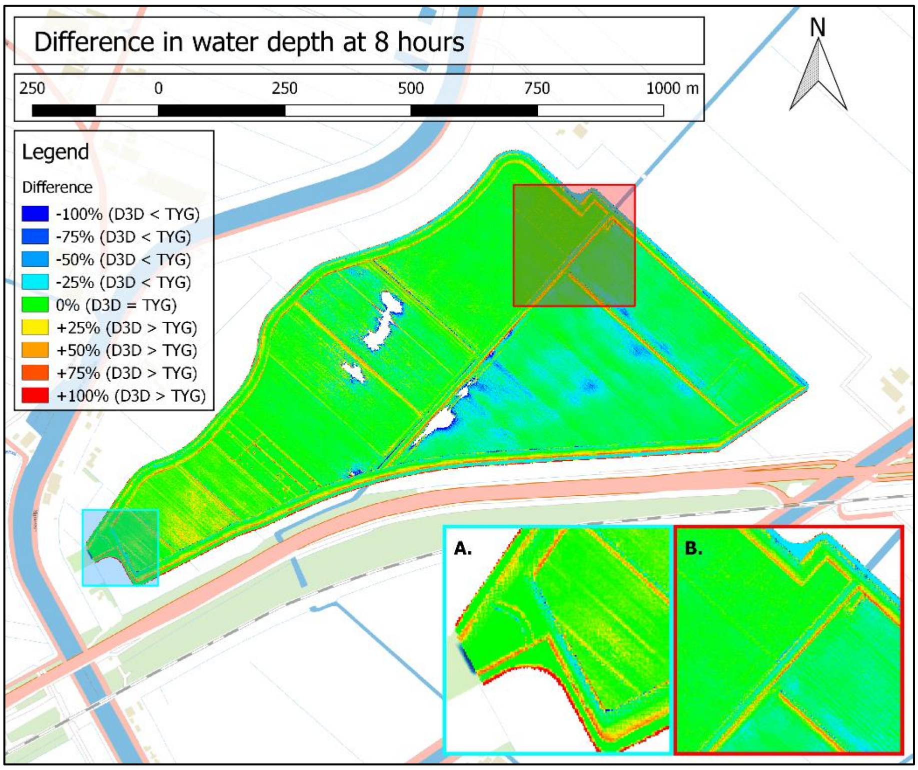


Figure 5.2: Difference in water depth between Tygron and Delft3D at 8 hours.

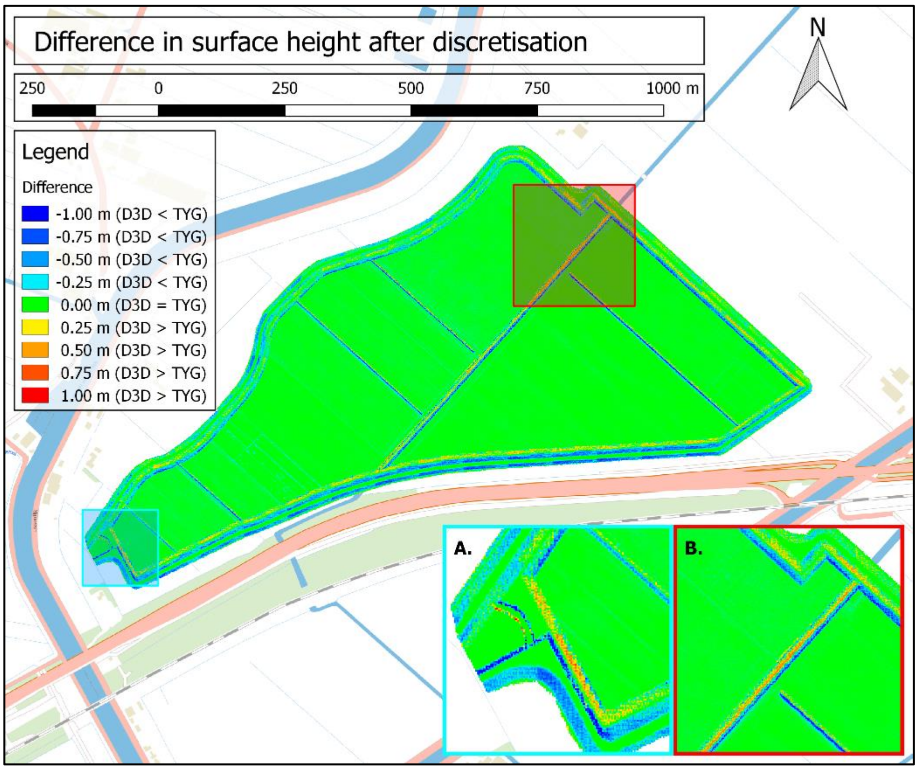


Figure 5.3: Difference in surface height after discretization of bathymetry to the grid.

5.2. Flow velocity

There are a few locations in the case area that should show deviant results in flow velocity to the rest of the area. These locations are the weir in the inflow basin, the most south-western ditch and bends in general. The weir is interesting because it is expected to show a higher flow velocity than the surrounding flow. A given discharge, determined by the inlet discharge, must flow through a smaller vertical area, which will make flow velocity increase. The same principle holds for the south-western ditch. This ditch is narrower than the other ditches in the area, thus prone to higher flow velocities. In bends, the flow velocity pattern depends on the location in the bend. Throughout most of the ditches in the case area, the flow velocity is expected to be the highest in the middle of the channel. This is the deepest part of the channel and also furthest away from both sides. Therefore the least amount of surface friction occurs in this part of the flow and thus the flow velocity will be highest. In some locations, like bends, the flow velocity may show a slightly deviating pattern due to other factors, like a change in direction, that influences the flow.

Both Tygron and Delft3D show the expected higher flow velocity on the weir and in the south-western ditch, shown in Figure 5.4 for Tygron and Figure 5.5 for Delft3D. In the bends however, there is a difference between Tygron and Delft3D. Tygron seems to show high velocities at the inner edge of the corner and low velocities at the outer edge. To further examine this, a cross section of the corner is shown in Figure 5.6. In this figure, Delft3D shows a slightly higher velocity towards the inner bend than towards the outside. Tygron shows a similar pattern, but with the maximum flow velocity further towards the inside of the bend. Also, Tygron shows a slight velocity peak towards the outside of the bend. Delft3D does not show such a velocity peak.

Many experiments have been done on the flow velocity through an open channel bend, for example (Chow, 1959), (Thandeswara & Seetharamiah, 1971) and (Duarte & Schleiss, 2009). All give the flow velocity through a bend in a channel with a rectangular cross sectional bed profile. They show that the flow velocity is indeed the highest towards the inside of the bend, depending on the angle of the bend and the location of the cross section in the bend. Comparing the results from Tygron to the results given in literature, Tygron shows valid results, apart from the velocity peak at the outer bend. However, the cross sectional bed profile in this channel is not rectangular, which has an effect on the flow velocity. Based on the available literature on this subject and the many factors which play a role in this situation, it cannot be determined whether Tygron or Delft3D shows better results. It can however be stated that the velocity peak at the outer bend is not valid.

Another observation on the results of Tygron is that higher flow velocities occur towards the edges of the channel rather than the inside. This is slightly visible in Figure 5.4 and clearly visible in Figure 5.7 as the darker lines at the edges of the channels. This phenomenon occurs throughout the whole of the simulation in Tygron. A cross sectional visualization of the phenomenon is given in Figure 5.8. This figure clearly shows that Delft3D gives the expected flow velocity pattern, where the flow velocity is the highest the furthest away from the channels' edge, because friction on the flow is the lowest at this point. Tygron however shows a decrease in flow velocity at the middle of the channel, and higher flow velocities towards the outside.

The last phenomenon that is visible all through the simulation is the occurrence of flow velocity peaks at the edge of the channel. An example of this is visualized in Figure 5.9. At both edges of the channel a peak in flow velocity occurs. This phenomenon seems to only occur at the very edge of a channel and does not significantly affect the flow velocities or water depths in the surrounding cells.

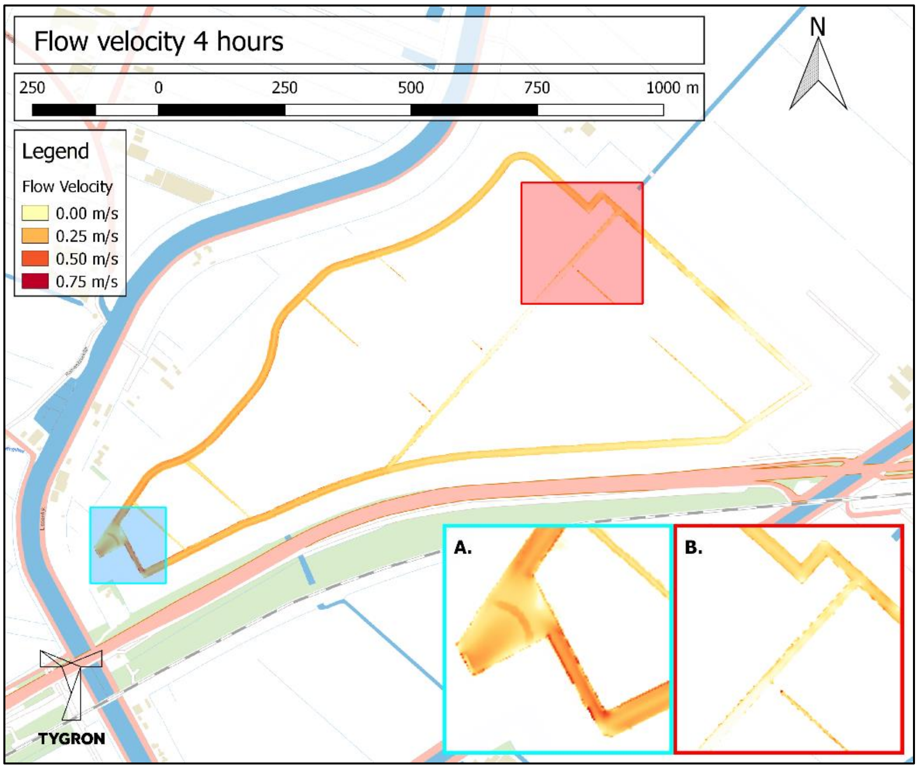


Figure 5.4: Flow velocity at 4 hours for Tygron.

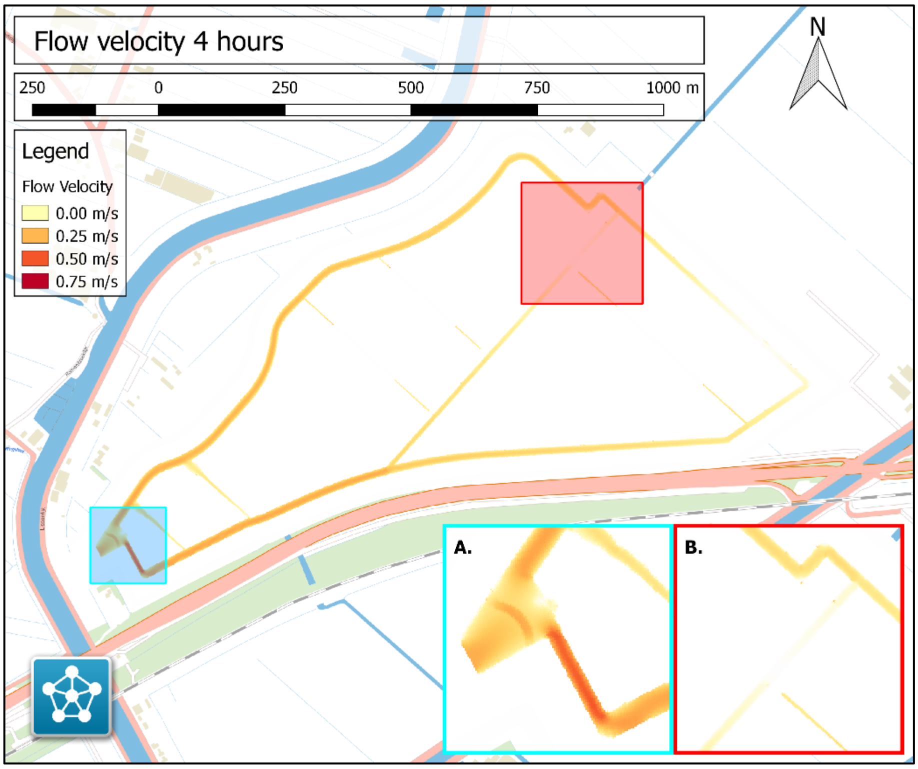


Figure 5.5: Flow velocity at 4 hours for Delft3D.

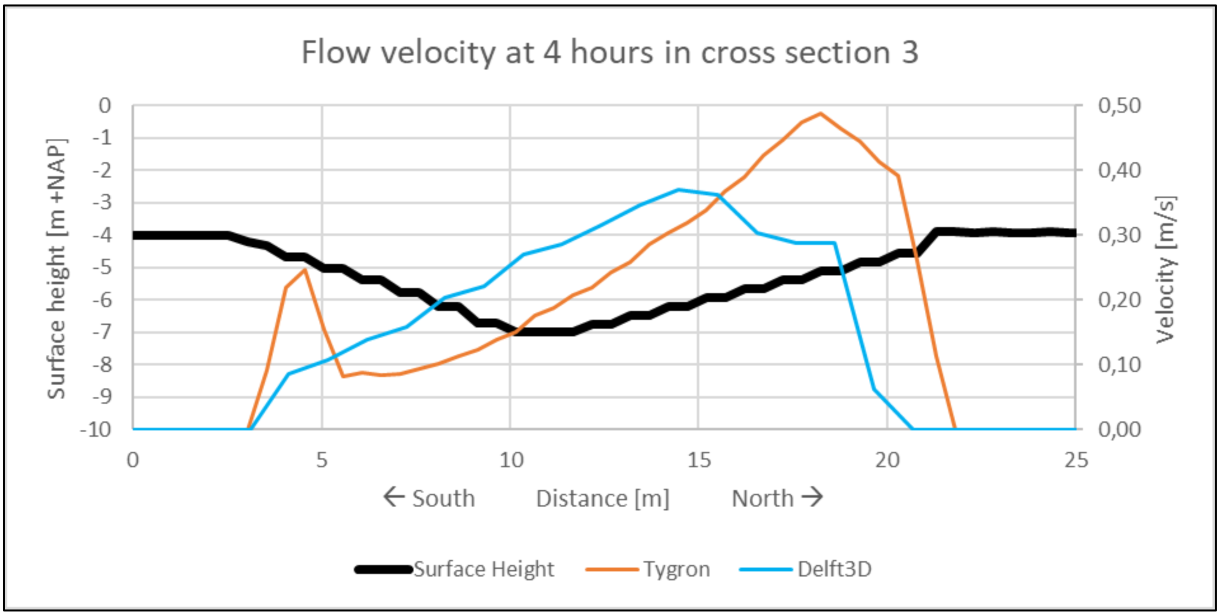


Figure 5.6: Flow velocity at 4 hours in cross section 3. (Surface height on left axis. Tygron and Delft3D flow velocities on right axis).

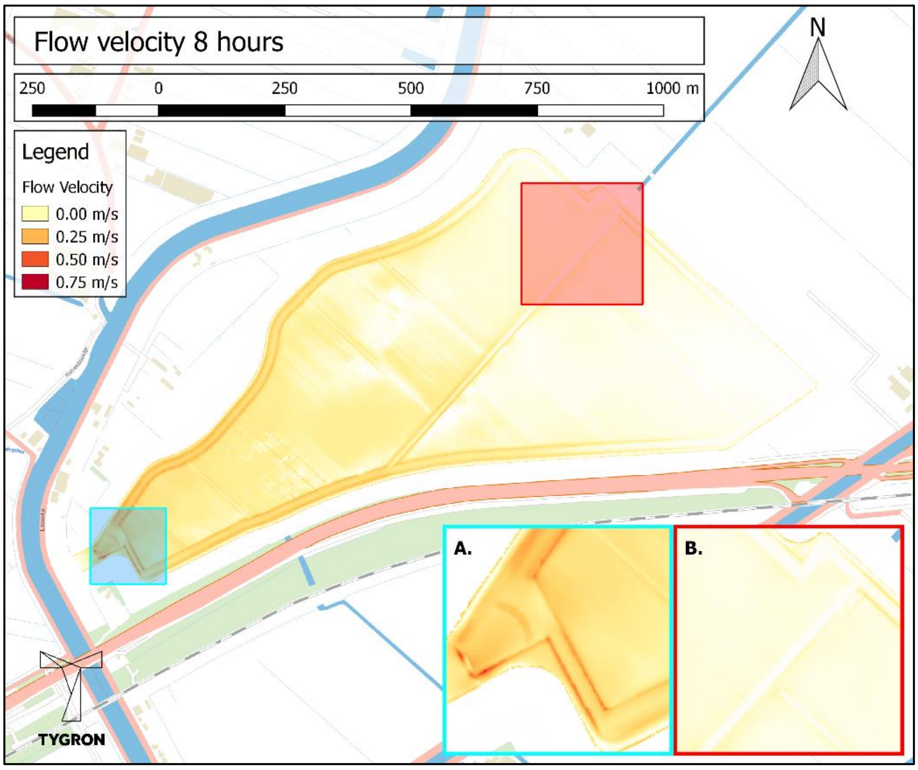


Figure 5.7: Flow velocity at 8 hours for Tygron.

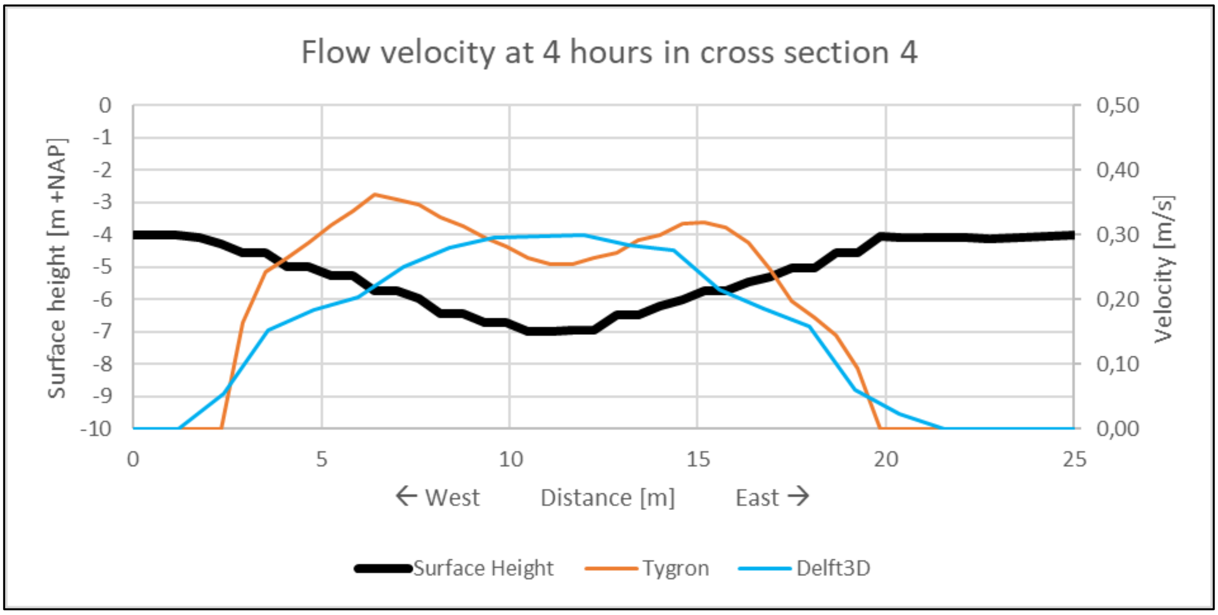


Figure 5.8: Flow velocity at 4 hours in cross section 4. (Surface height on left axis. Tygron and Delft3D flow velocities on right axis).

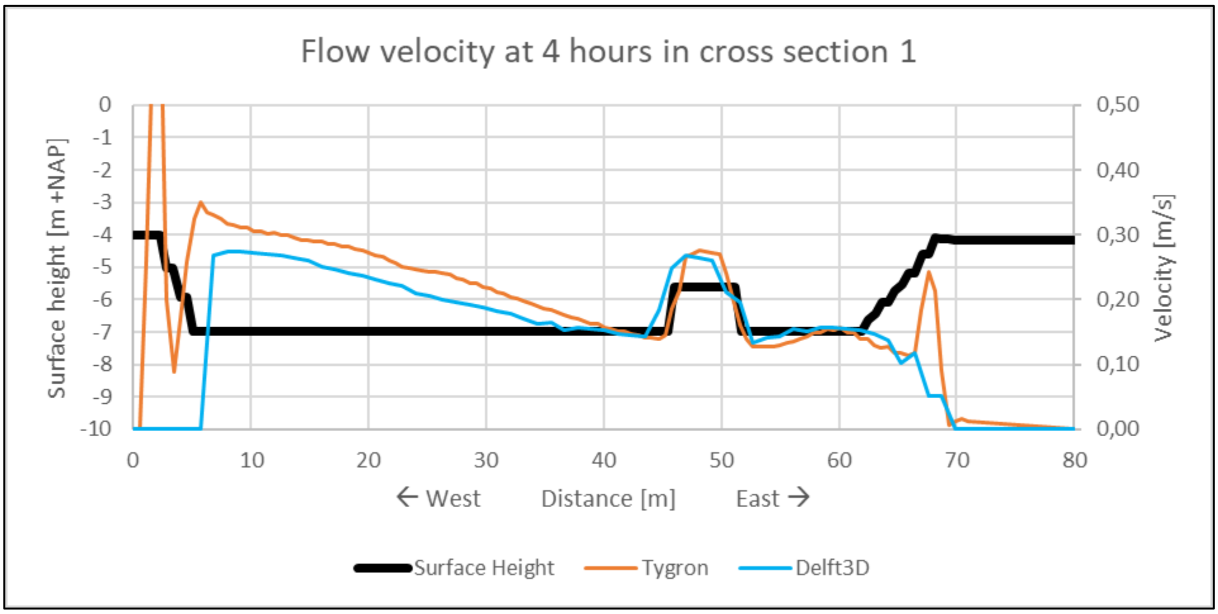


Figure 5.9: Flow velocity at 4 hours in cross section 1. (Surface height on left axis. Tygron and Delft3D flow velocities on right axis).

5.3. Flow direction

The direction of the flow is expected to follow the direction of the ditches for the majority of the simulation. Exceptions for this are the places where streams meet. Also, when the ditches have reached capacity and the plains start to flood, the flow direction will then depend on the locations at which the channels flood first and slight changes in the surface height.

In general, both Tygron and Delft3D show results conform the expectations. However at the start of the simulation, the results from Tygron show flow directions that are alternating on an irregular distance, as shown in Figure 5.10. This suggests that the water is already moving at this stage of the simulation. This is confirmed by Figure 5.11, which shows the flow velocities at one hour into the simulation. This phenomenon occurs from the very start of the simulation all throughout the area. Later in the simulation, when the inlet discharge takes effect, the irregular pattern seems to disappear and the expected pattern of the flow takes over. This leads to believe that the pattern is not caused by the inflow discharge, but rather the inflow discharge outweighs the irregular pattern, to result in the expected flow directions. Delft3D shows the expected flow directions from the start of the simulation (see Figure 5.12). It seems there is something wrong in the initial state of the simulation in Tygron.

Another observation in the flow directions is that, later in the simulation, the points where the flows meet differ between Tygron and Delft3D. These points can be identified by the point where the direction of the flow changes 180° in Figure 5.13 and Figure 5.14. According to the locations of the meeting points in Tygron, the flow velocity through the outer ditches is significantly higher than through the centre ditch. This is also the case in Delft3D, but to a lesser extent.

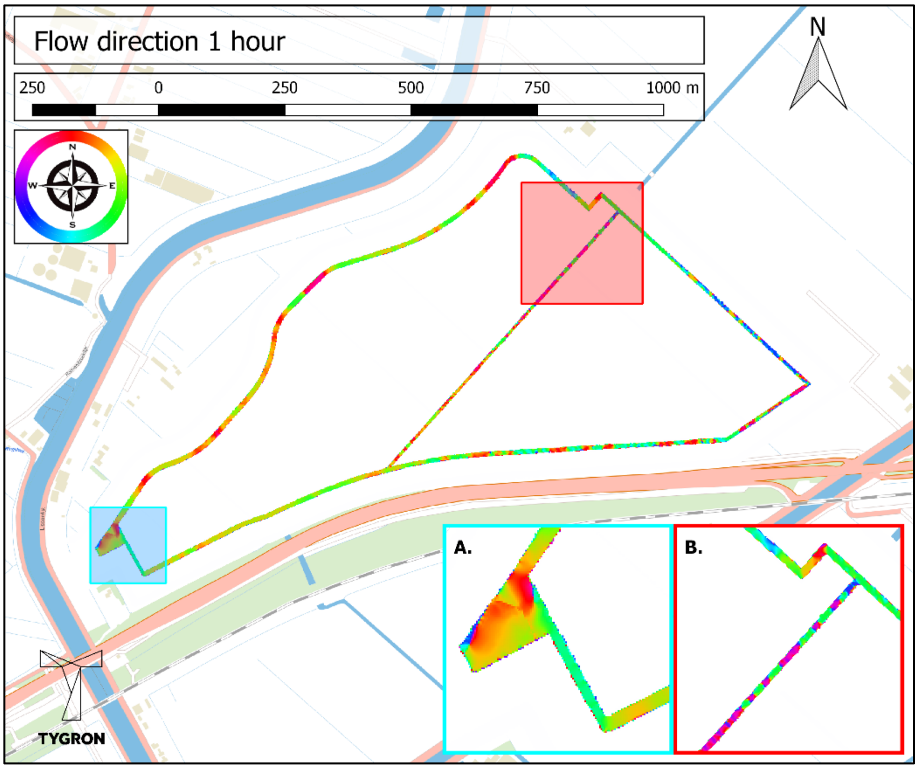


Figure 5.10: Flow direction at 1 hour for Tygron.

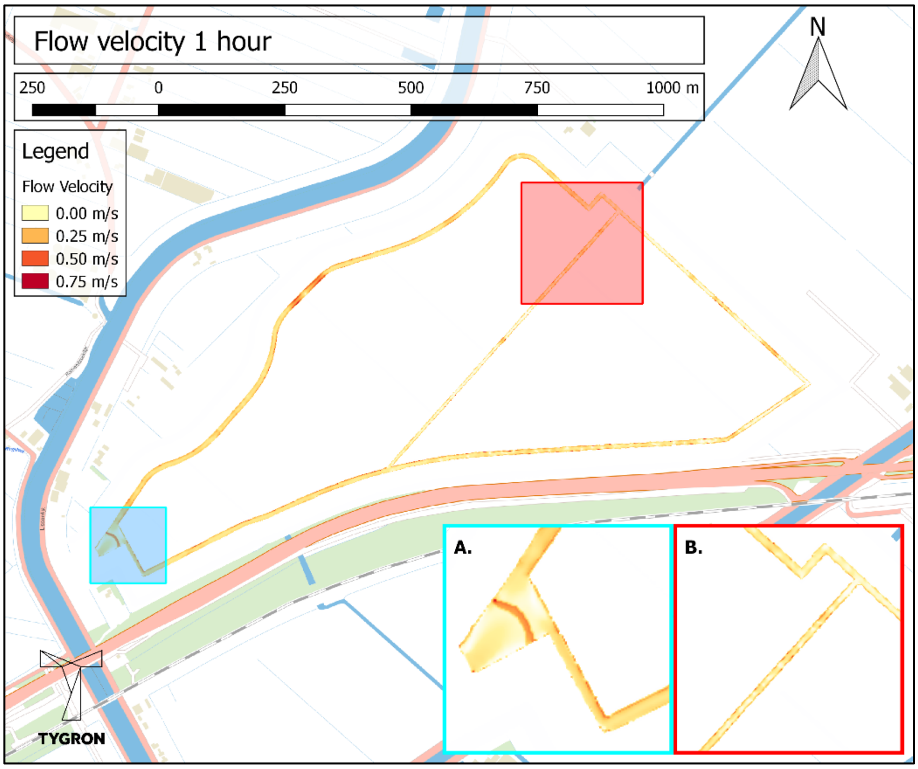


Figure 5.11: Flow velocity at 1 hour for Tygron.

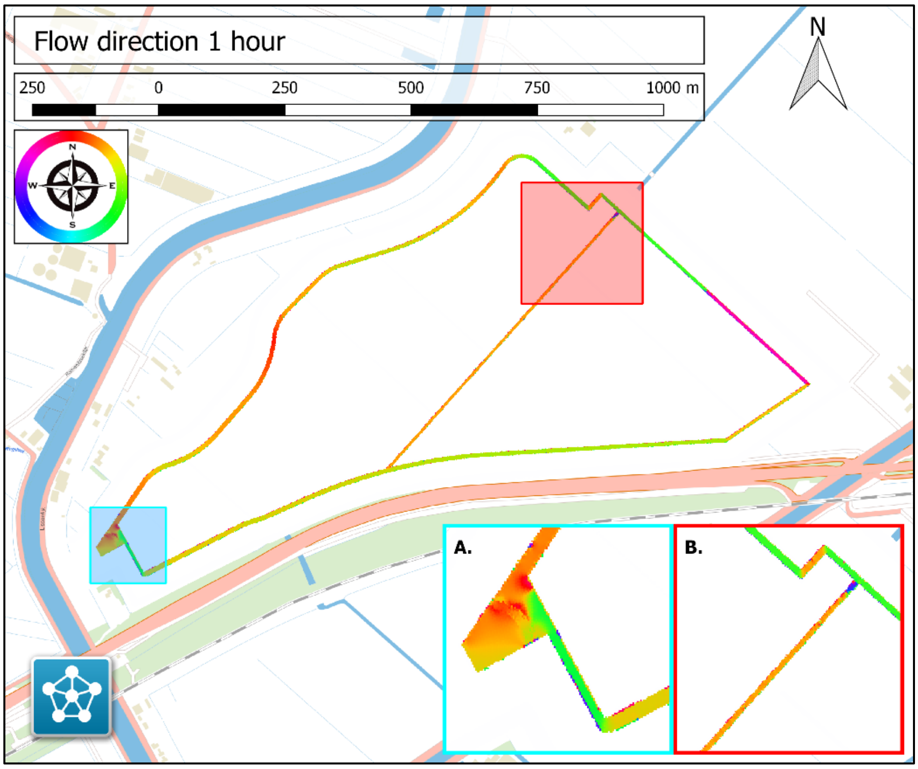


Figure 5.12: Flow direction at 1 hour for Delft3D.

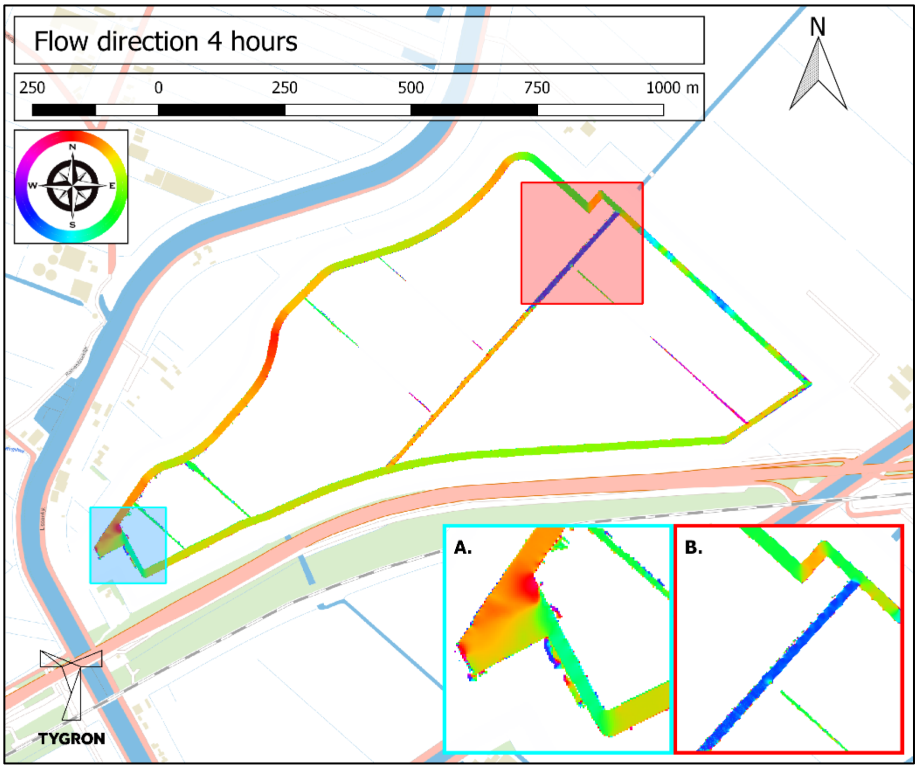


Figure 5.13: Flow direction at 4 hours for Tygron.

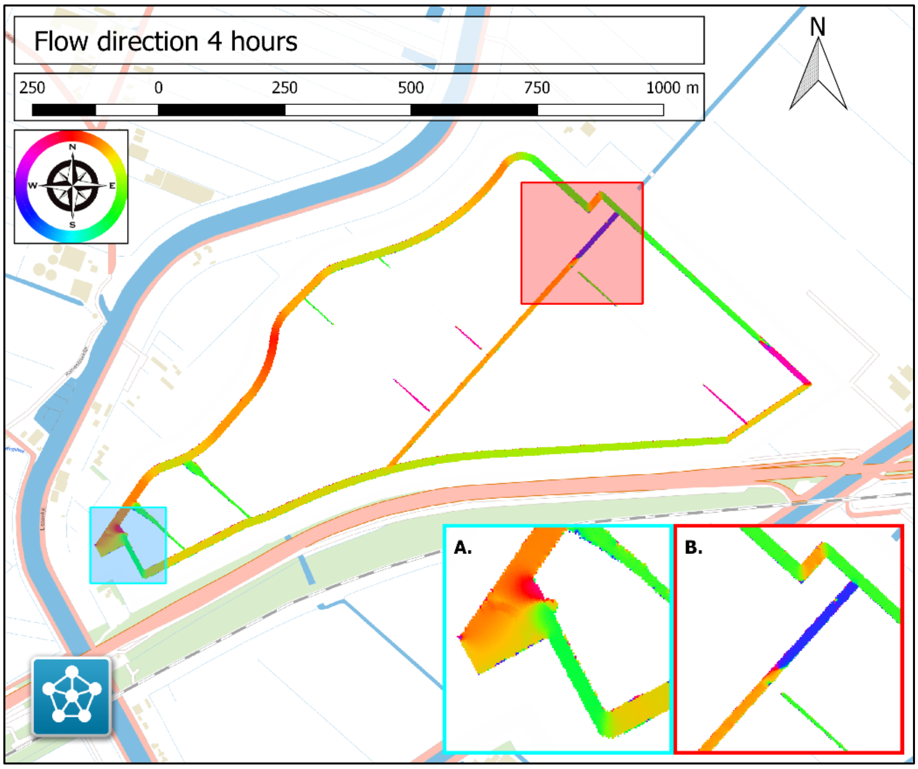


Figure 5.14: Flow direction at 4 hours for Delft3D.

6. Discussion

In this research the results from Tygron are compared to the results of Delft3D. In this chapter, first the main research and anything that may be of influence to the conclusions, will be discussed. After that, additional information will be shared that does not directly contribute to the research, but may be of interest to the reader.

The research was conducted according to a case study. The specific case that was used, was chosen for convenience. The case is a project that Aveco de Bondt was already working with, and the model in Tygron was readily available at the start of the research. Taking into account the short time available for this research, this model was chosen to perform the case study on. Another case area may give different results. A more diverse and complex case area may have been more suitable for this research, since it may have shown the relation between differences in the software and the complexity of the flow.

It is difficult to state that the results from the two models are comparable or whether one is better than the other. They are both a schematisation of reality, neither is actual reality. Therefore, this report cannot prove anything about the performance of Tygron, but it can and does make it highly plausible that one is more accurate than the other in a certain situation.

This research has not made use of the full potential of Delft3D. Delft3D is continuously improving software, supporting both an official base version as well as an open source version. It is built up from several different sub packages, each with their own specialty. Different applications of the software require different packages to function properly. For this research, only the official base version of the software was used. This saves a lot of time on the installation of the software, but limits the extend of the research. As a consequence of this, only a rectangular grid was used for the simulations. For the implementation of an irregular grid into the simulation, a separate package is necessary. This package is currently not implemented into the official base version. Also, the Tygron model uses a grid of 0,5m by 0,5m grid cells. With the current model and the computer used for the computations, this was not possible in Delft3D. Therefore the Delft3D model used a grid of 1m by 1m grid cells.

The impact of the limitations in Delft3D on the research is estimated to be low. The irregularities in the Tygron results are clear to see. Any unexpected behaviour was compared to literature and examined closely. An additional comparison with Delft3D using an irregular grid will not significantly change the conclusions of this research.

As mentioned above, Tygron uses a grid of 0,5m by 0,5m grid cells. However, the grid cell sizes can be changed to fit the model area. The impact of the grid cell size is discussed in appendix B. It seems that the flow velocities differ rather much between simulations with 0,5m grid cell size to 2m grid cell. These differences in flow velocities, however, have a minor effect on the water depths.

Towards the end of the research project, an influential update was carried out in Tygron. Because the software runs online, this happens automatically. There is currently no known way to change the version that Tygron runs on, so the data exported from the model is limited to the visualisations given in this report.

The impact and relevance of the differences between Tygron and Delft3D evidently depends on the purpose of the model. For most flood simulation models, the water depth is the most important result, because this shows whether a certain area will be flooded. The results found in this research show that Tygron can be used with acceptable certainty for these models. However, the case area used in this research is a rather simple one. It is possible that, in a more complex model area, the flow velocities have a larger impact on the water depth, which decreases the certainty of the results. To determine this, more research is needed with a more complex case area. For models with other purposes, for example to determine the soil erosion due to water velocities, Tygron is not yet completely suitable. Therefore, the validity of the model results should be examined for every model individually.

Apart from the comparison based on the research question of this research, there are also other aspects to compare Tygron and Delft3D on. One very relevant difference is the computation time. As previously mentioned, Tygron runs online. The model computations are carried out on a supercomputer through the cloud. This supercomputer was designed solely for the cause of running Tygron computations. Therefore the computations done by Tygron are very fast. The computation of twenty-four hours of the flow in the case area used for this research, takes a little over 20 minutes. Delft3D on the other hand, performs its computations locally on the computer it is installed on. The statistics of the computer that was used for this research is given in Table 6.1. On this computer, the computation of the first eight hours of the flow in the case area, takes roughly 48 hours. The incredibly short computation times with Tygron are a major advantage to the software because it allows for quick adaptations to the model. It is possible to reduce the computation time of Delft3D on this computer to be similar to Tygron, but it does involve a sacrifice in accuracy of the simulation. This is described in appendix C. The magnitude of the sacrifice depends on the size and characteristics of the case area.

Table 6.1: Computer properties.

Name	**HP EliteBook**
Processor	Intel(R) Core(TM) i5-6200U CPU @ 2.30GHz 2.40 GHz
RAM:	8 GB
Type of system	64-bits operating system, x64-processor

Another thing to note about Tygron is the time that the water module has been in development. The implementation of the two dimensional Saint-Venant equations started after the benchmark by Stowa in 2017 (Henckens & Engel, 2017). Before this, Tygron did not yet use the two-dimensional Saint-Venant equations for the computation of the flow. The development involving the two-dimensional Saint-Venant equations has only been going for one and a half year. While there are still a lot of things for Tygron to improve on, the software is improving rapidly and therefore shows great potential for the future.

Also, the water module is not the only module in Tygron. The software supports many other implementations, creating a complete spatial management software platform. These implementations include construction plans, stakeholder management and financial systems. These could all be reasons to use Tygron over other flood simulation software.

7. Conclusions and recommendations

Whether the results from Tygron are valid was determined using a comparison between Tygron and Delft3D. The comparison was done on water depth, flow velocity and flow direction, with use of a case study.

The water depth in Tygron shows the expected behaviour and is very similar to the results of Delft3D. There are minimal differences in water depth between Tygron and Delft3D that are not significant for the vast majority of model purposes.

Concerning flow velocity, Tygron shows two anomalies. The first of these is that the flow velocity pattern does not comply to the theoretical flow velocity pattern through an open channel. All throughout the area and the simulation, the flow in the middle of the ditches is lower than towards the outside of the ditches. Also, at the edge of the channels, flow velocity peaks are observed. This phenomenon only occurs on at the very edge of the channels and does not significantly affect the flow velocities or water depths in the surrounding cells. Delft3D shows neither of these two phenomena.

The flow direction results from Tygron show an anomaly as well. Right from the start of the simulation, flow velocities are alternating on an irregular distance. This suggests that the water is already moving in this area from the start of the simulation, while there is no inflow or outflow. This leads to believe that there is something wrong with the initial state of the simulation.

The reason for the deviant behaviour in Tygron is currently unknown, but it seems to have something to do with the way Tygron deals with small amounts of water in certain grid cells. This would explain both the strange behaviour at the edge of a channel and at the start of the simulation, when water depths are rather low. From the information gained in this research, it is not possible to point out the problem in the software. To identify the problem, more in depth research must be done with access to the Tygron source code. An analysis of all steps taken to produce a certain anomaly may result in the cause of the deviant behaviour.

Considering that the development of Tygron is young, and considering the other applications it can be used for, Tygron shows great potential as modelling software. The water module can already be used for predictions of water levels and water depths in relatively simple environments. For local and detailed predictions of flow velocity and flow direction however, the software still needs improvement before it can be used effectively.

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Appendix A – Results

This appendix shows the results of the simulations done in Tygron and Delft3D. The state of both simulations will be shown for the exact same timesteps. The timesteps that are shown are after one hour, after four hours and after eight hours. The results are given in water depth, flow velocity and flow direction. To optimally compare Tygron with Delft3D, a certain timestep will be given for both Tygron and Delft3D on one page.

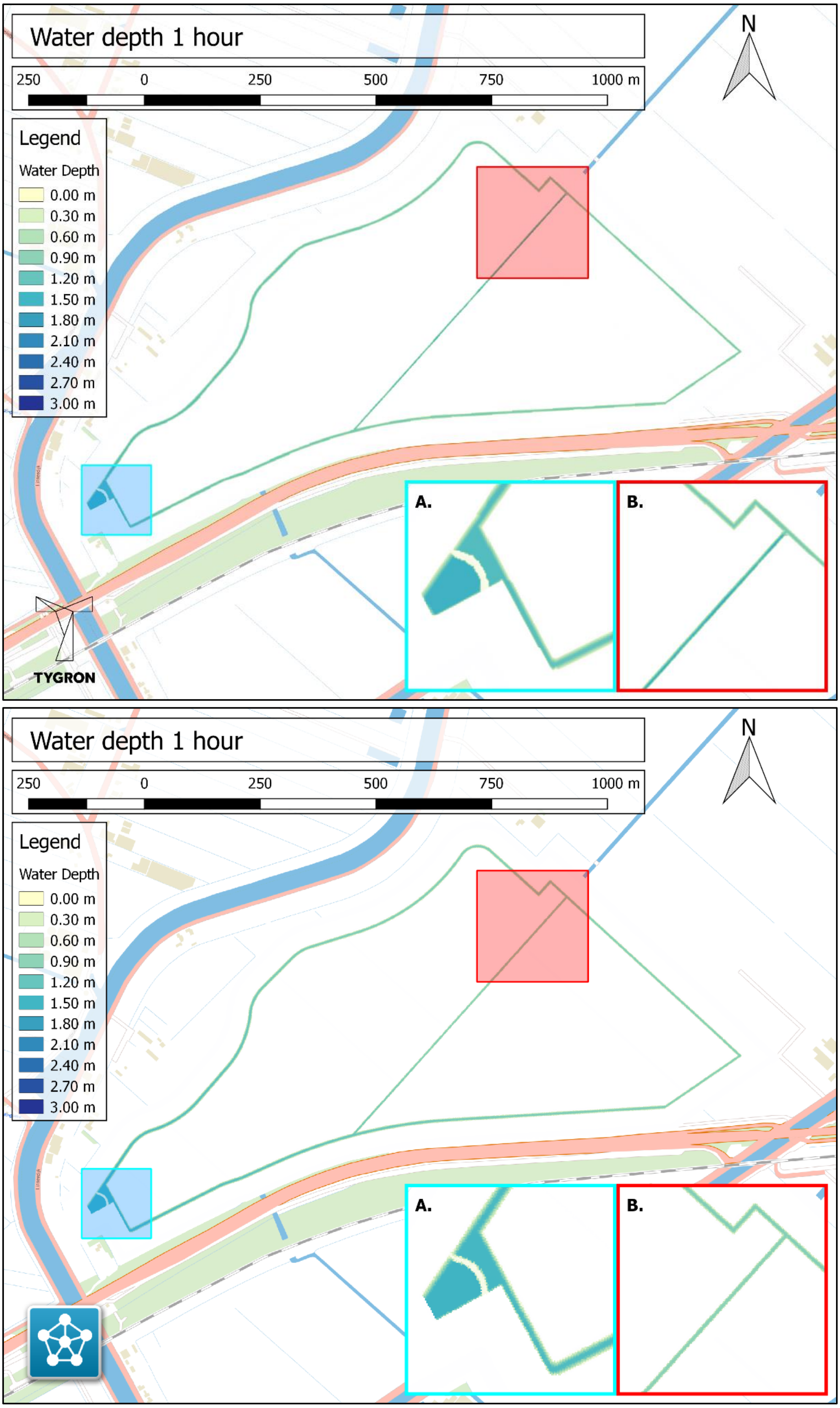


Figure A.1: Water depth at 1 hour for Tygron (top) and Delft3D (bottom).

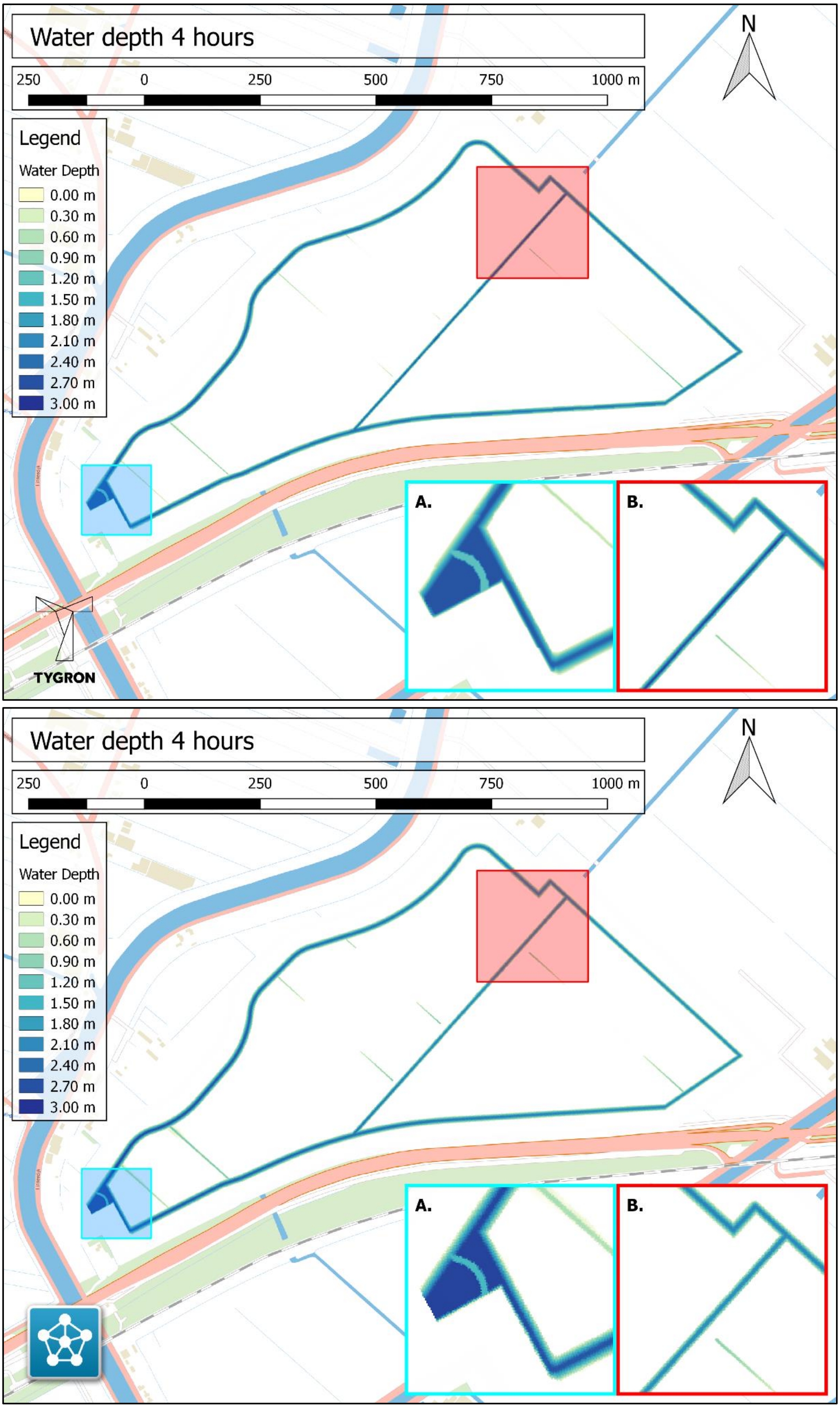


Figure A.2: Water depth at 4 hours for Tygron (top) and Delft3D (bottom).

Figure A.3: Water depth at 8 hours for Tygron (top) and Delft3D (bottom).

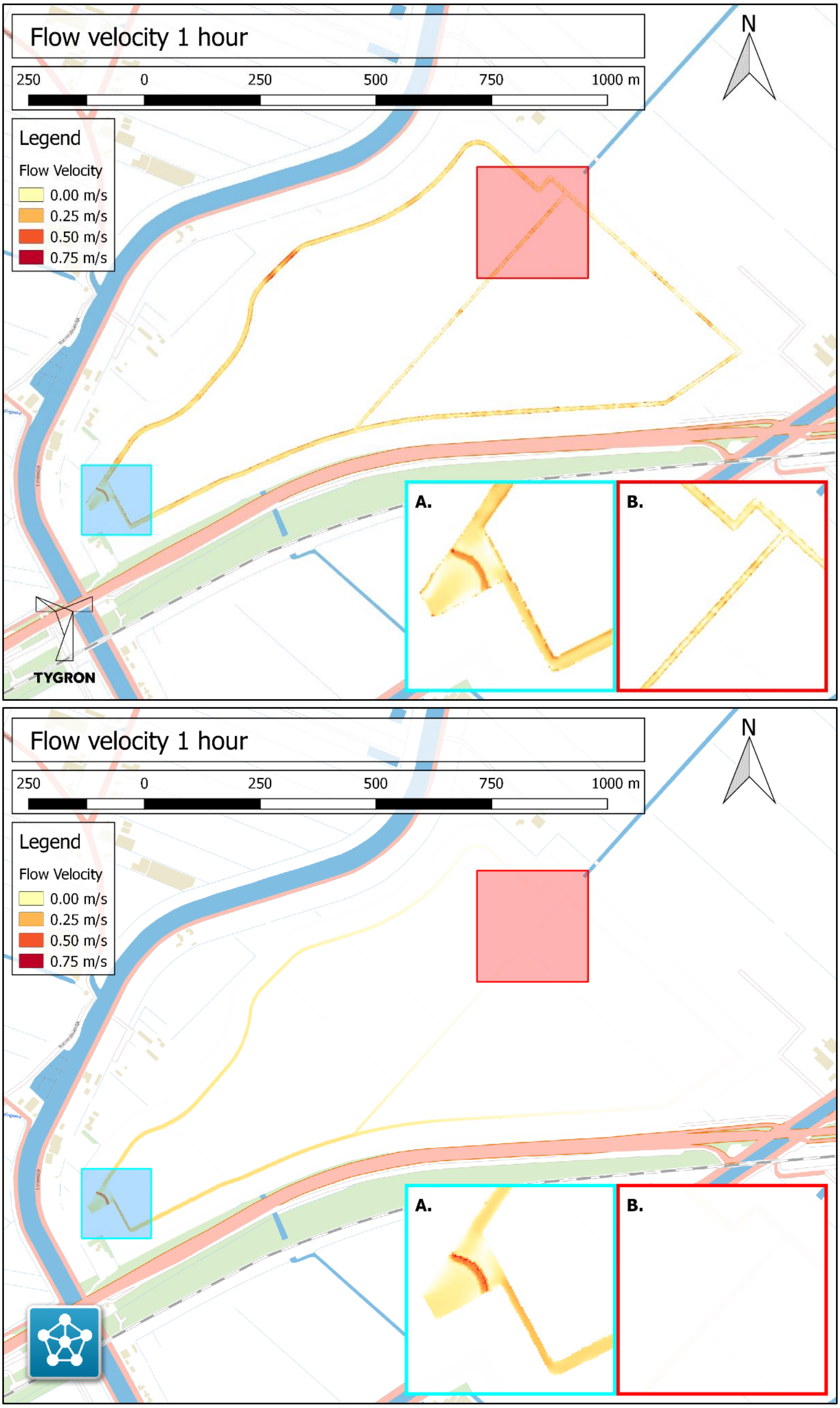


Figure A.4: Flow velocity at 1 hour for Tygron (top) and Delft3D (bottom).

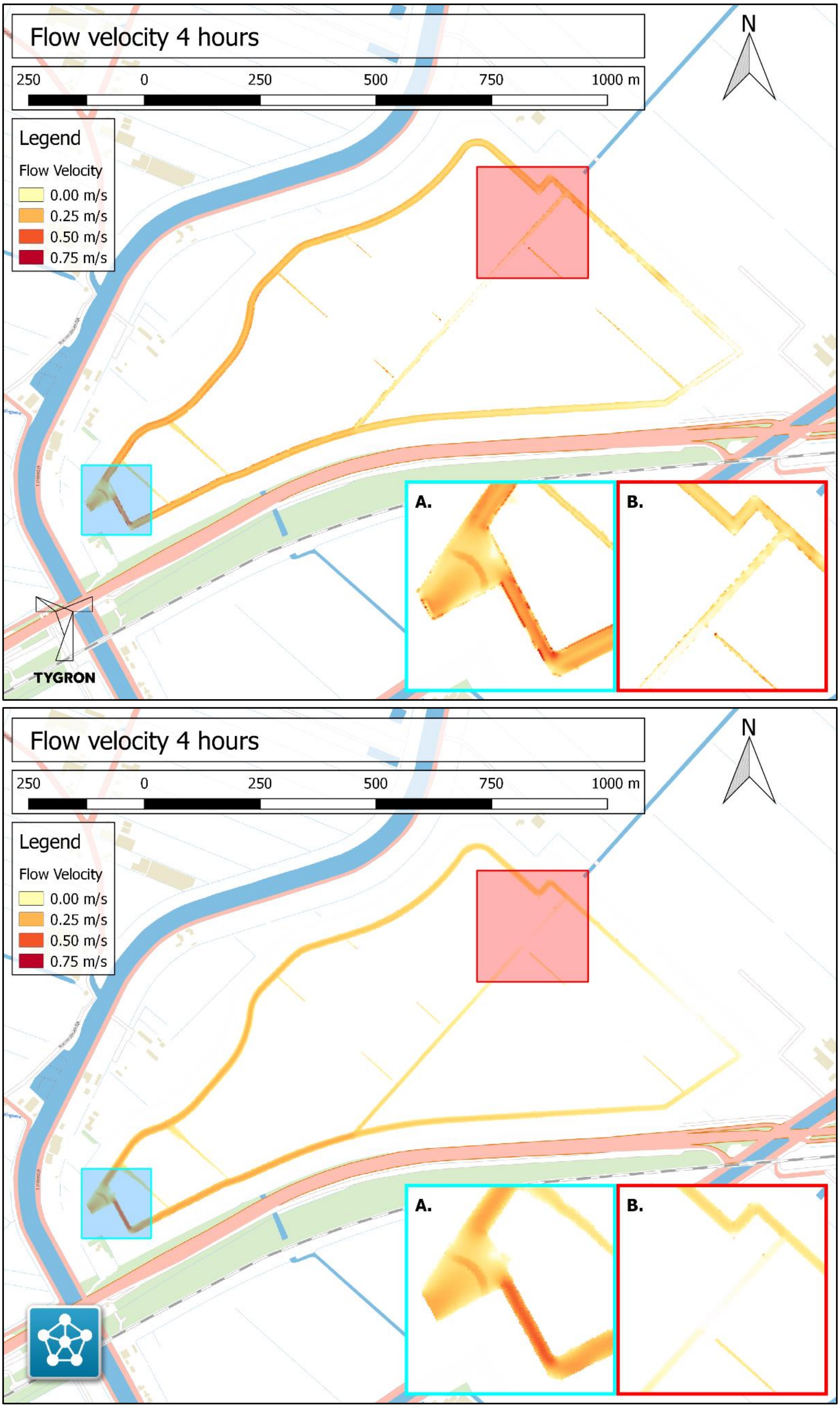
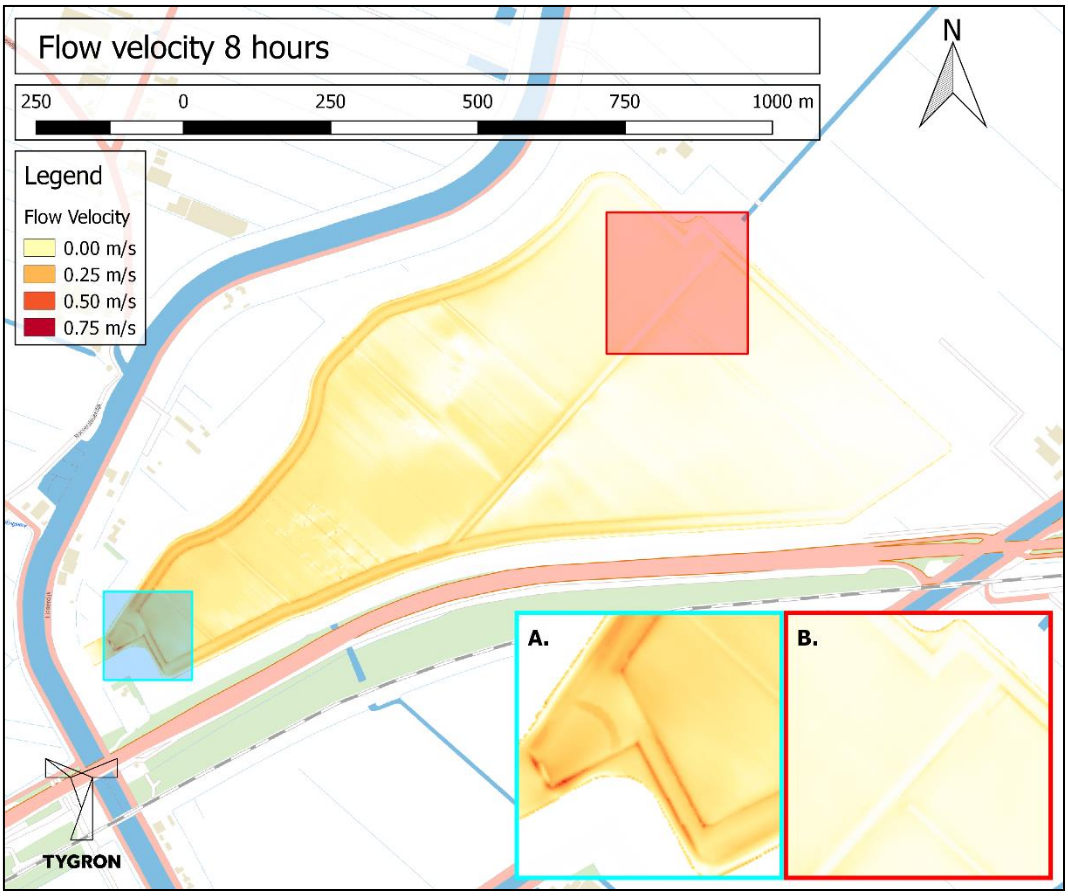


Figure A.5: Flow velocity at 4 hours for Tygron (top) and Delft3D (bottom).



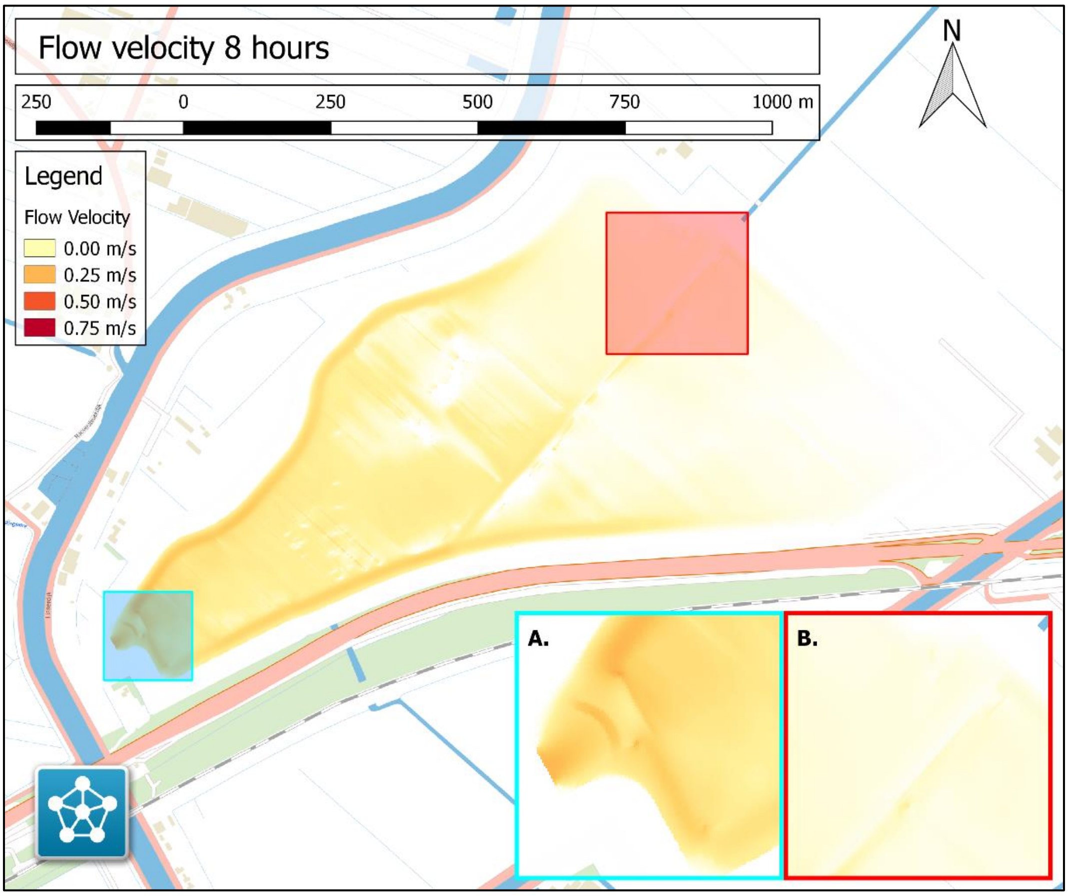


Figure A.6: Flow velocity at 8 hours for Tygron (top) and Delft3D (bottom).

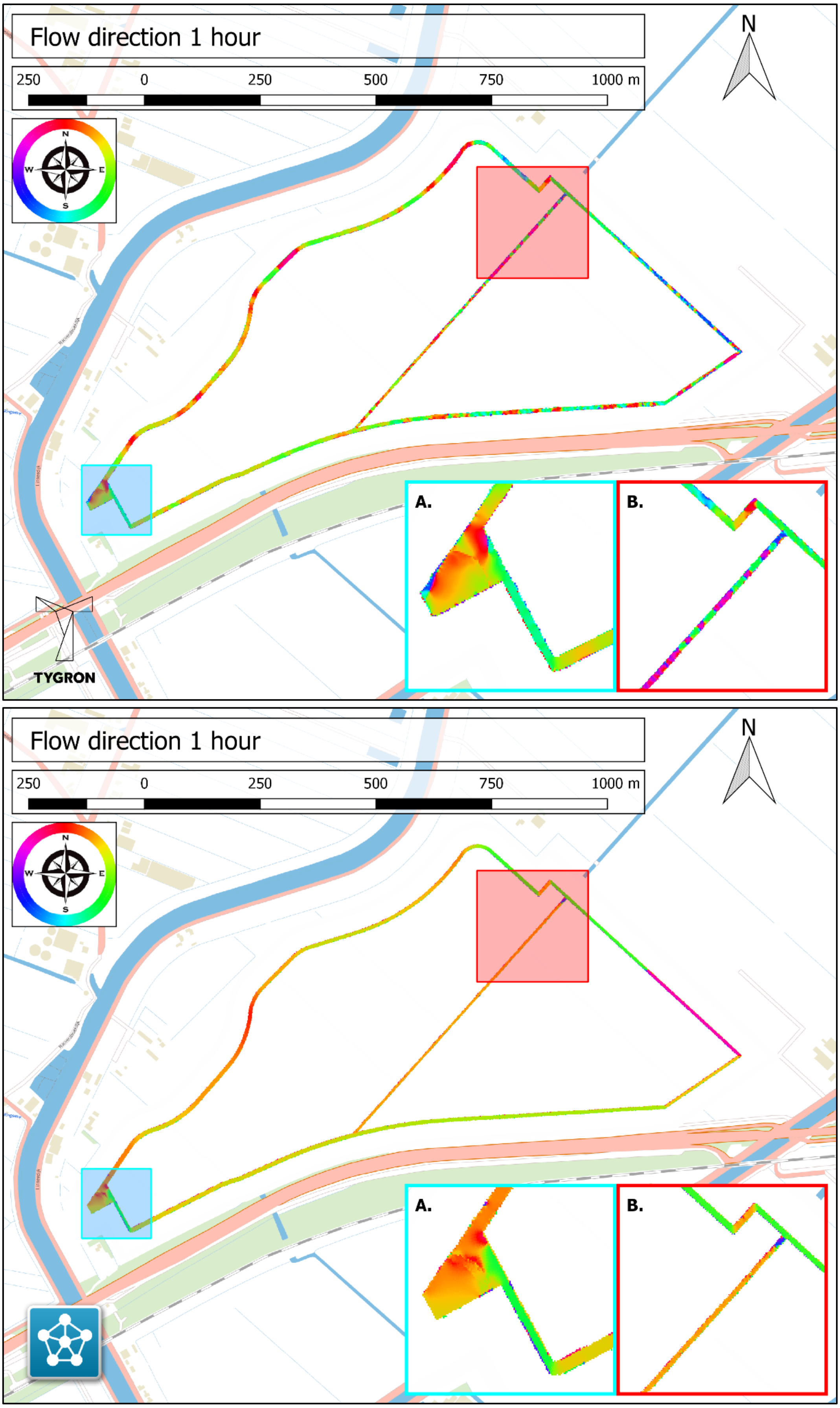
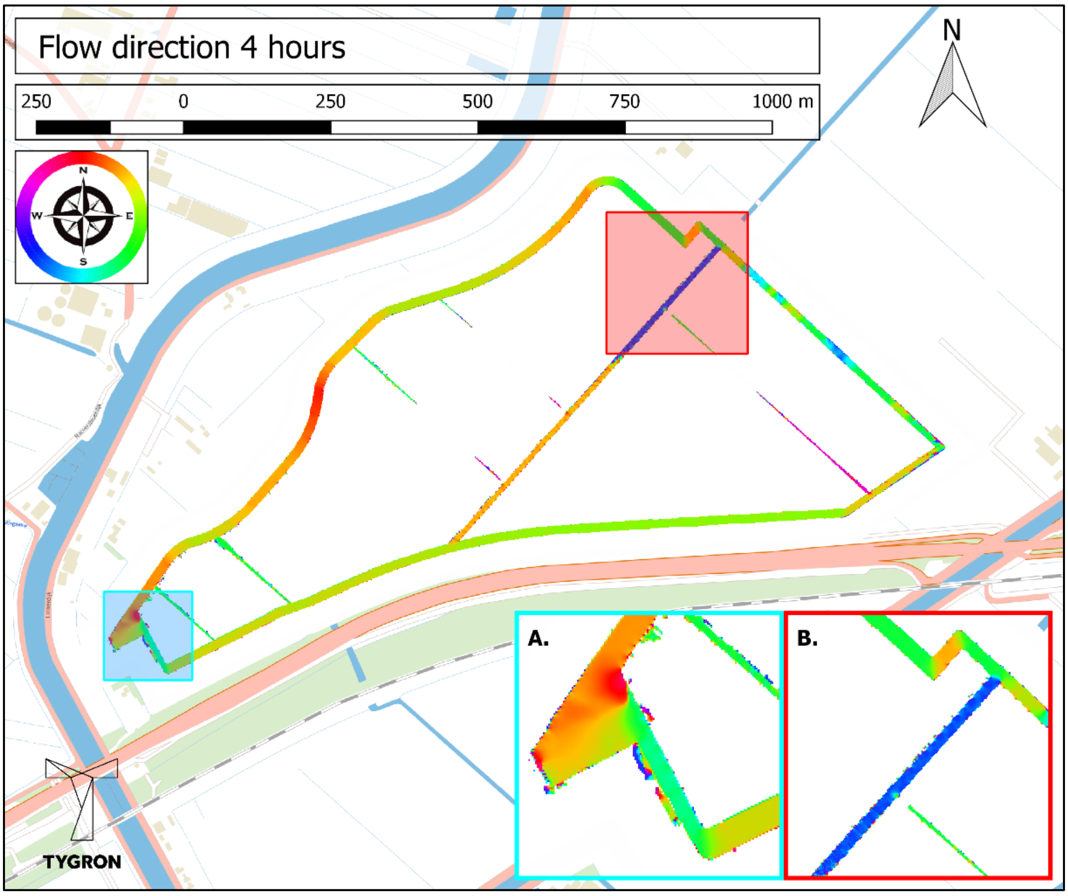


Figure A.7: Flow direction at 1 hour for Tygron (top) and Delft3D (bottom).



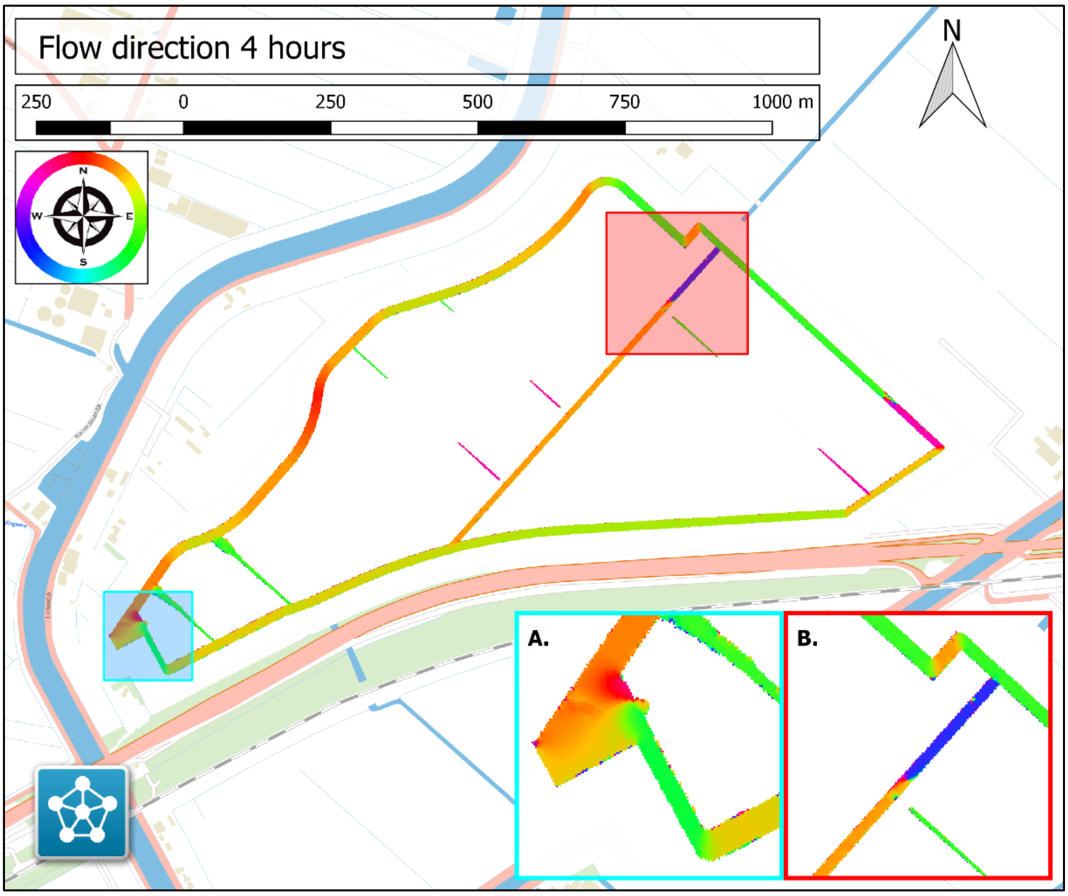


Figure A.8: Flow direction at 4 hours for Tygron (top) and Delft3D (bottom).

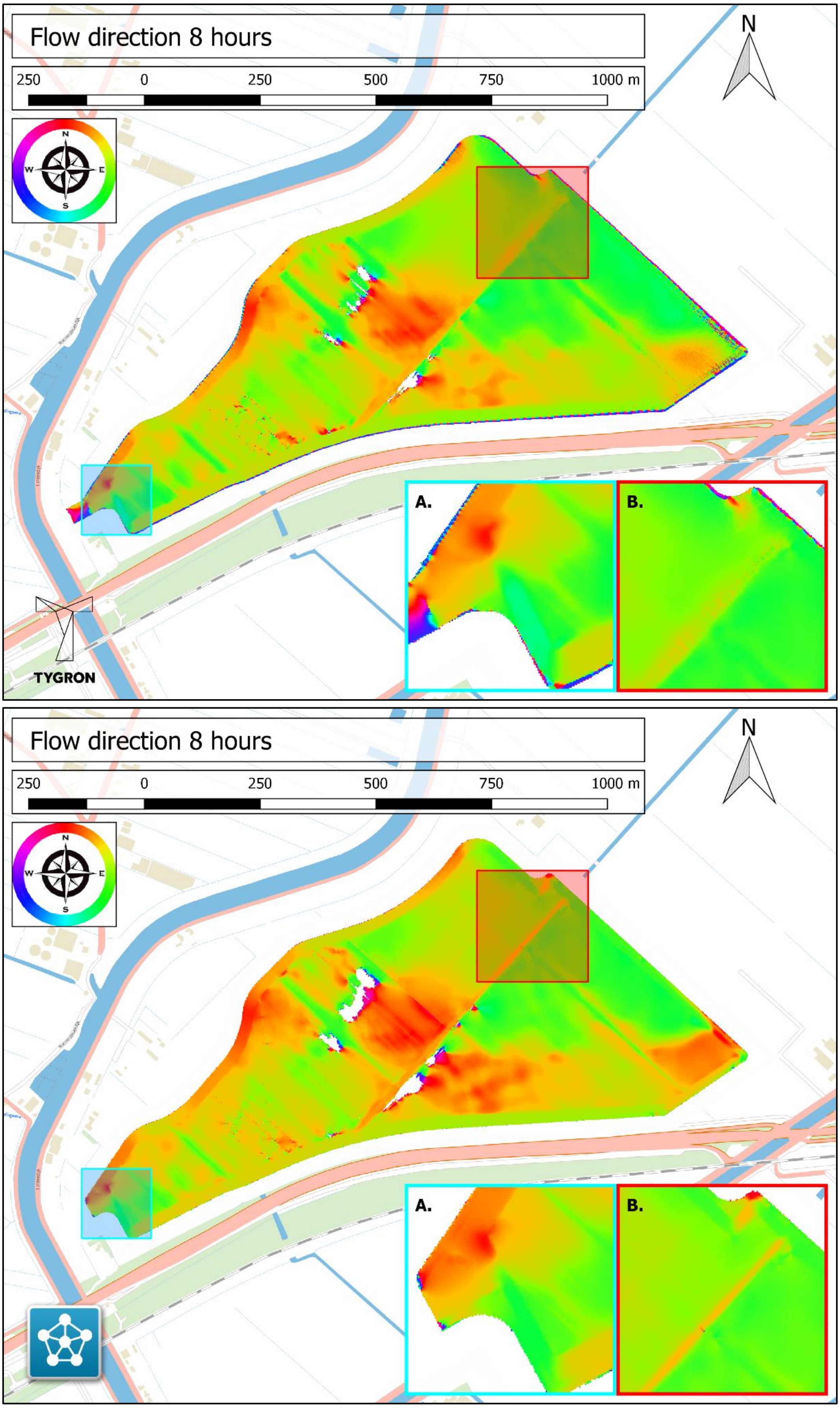


Figure A.9: Flow direction at 8 hours for Tygron (top) and Delft3D (bottom).

Appendix B – Tygron grid resolution comparison

The grid resolution in Tygron can be altered from 0,5 meter grid cells up to 200 meter grid cells. However, a relevant question to ask is what the effect of a smaller or larger grid resolution will be on the results of a simulation. The same model is run with three different grid resolutions; 0,5m, 1m and 2m grid cells. The results are given in the form of cross sections (see Figure 5.1 for the locations of the cross sections).

There seems to be a rather high difference in flow velocity at the cross sections. However, the differences do not seem to give an obvious pattern. In general it seems that the larger the grid cell, the lower the flow velocity, however several locations can be pointed out where this is not the case.

What is also visible in the cross sections, is that the peaks in flow velocity towards the edge of a channel, do not occur or occur less with a larger grid cell size. The patterns shown by the results from a larger grid cell size are closer to what they should be.

The water depth shows minor differences between simulations with different grid cell sizes, as is shown in Figure B.7. It seems that the flow velocity does not affect the water levels.

It can be concluded that on a simulation of this size, the grid resolution has a rather large impact on flow velocities. However, similar to the earlier drawn conclusions, the difference in flow velocity has a minor effect on the water depths in the simulation.

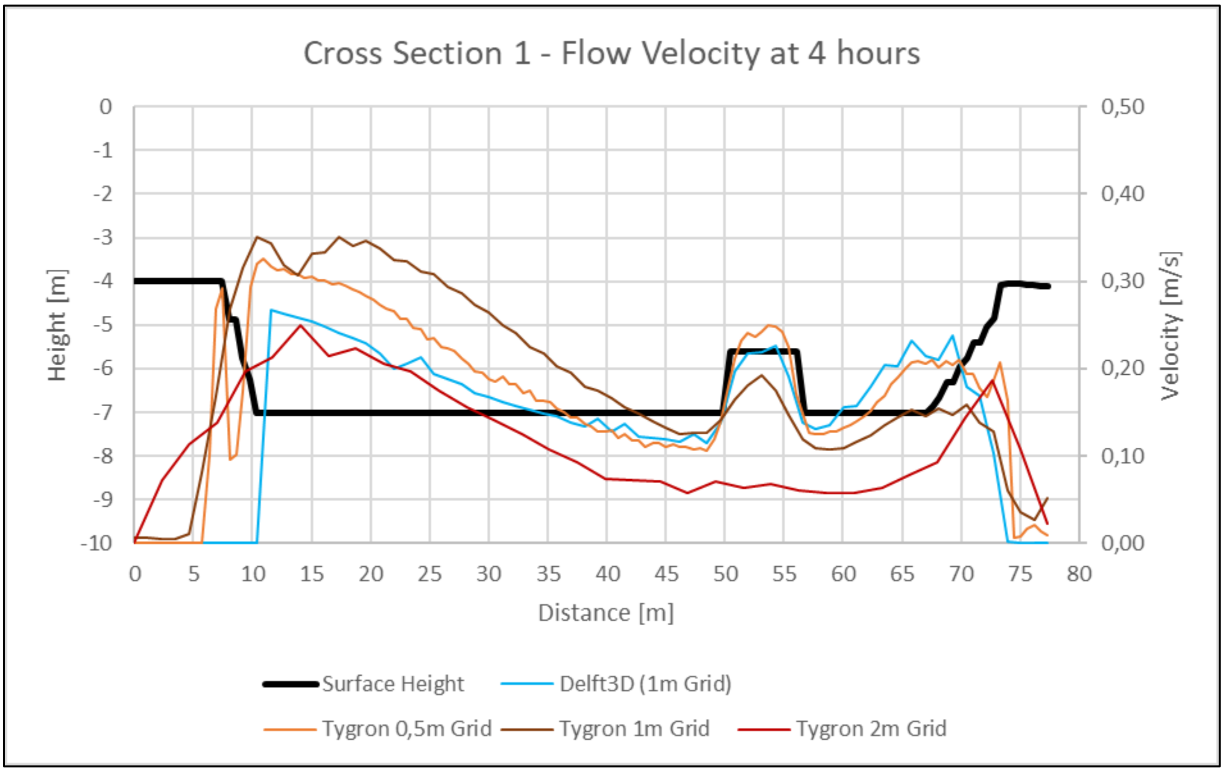


Figure B.1: Difference in flow velocity with different sized grids in Tygron.

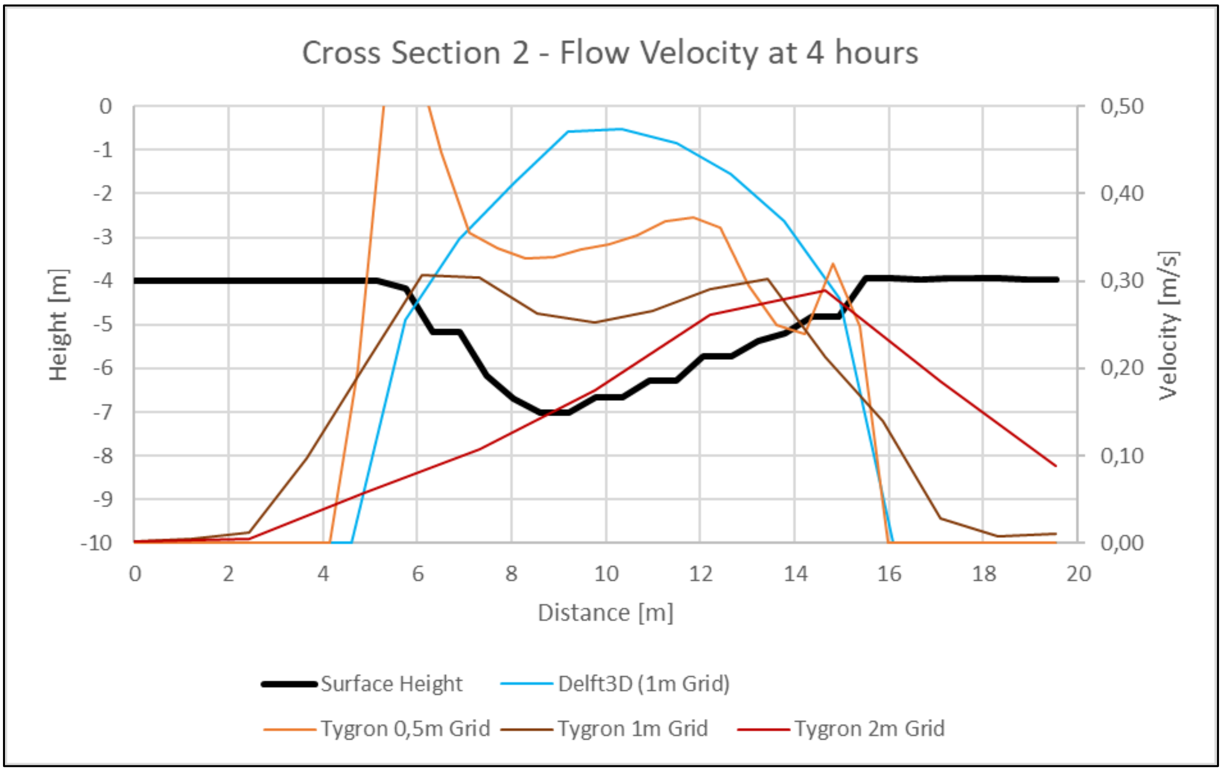


Figure B.2: Difference in flow velocity with different sized grids in Tygron.

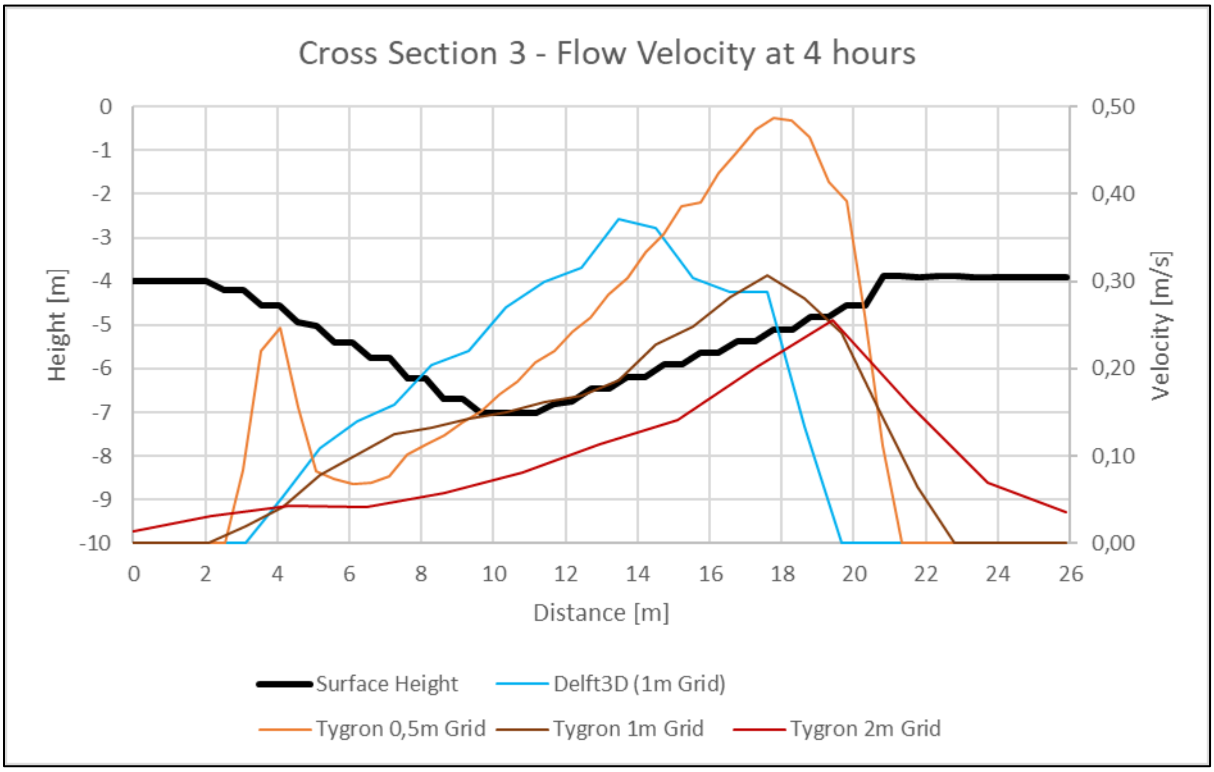


Figure B.3: Difference in flow velocity with different sized grids in Tygron.

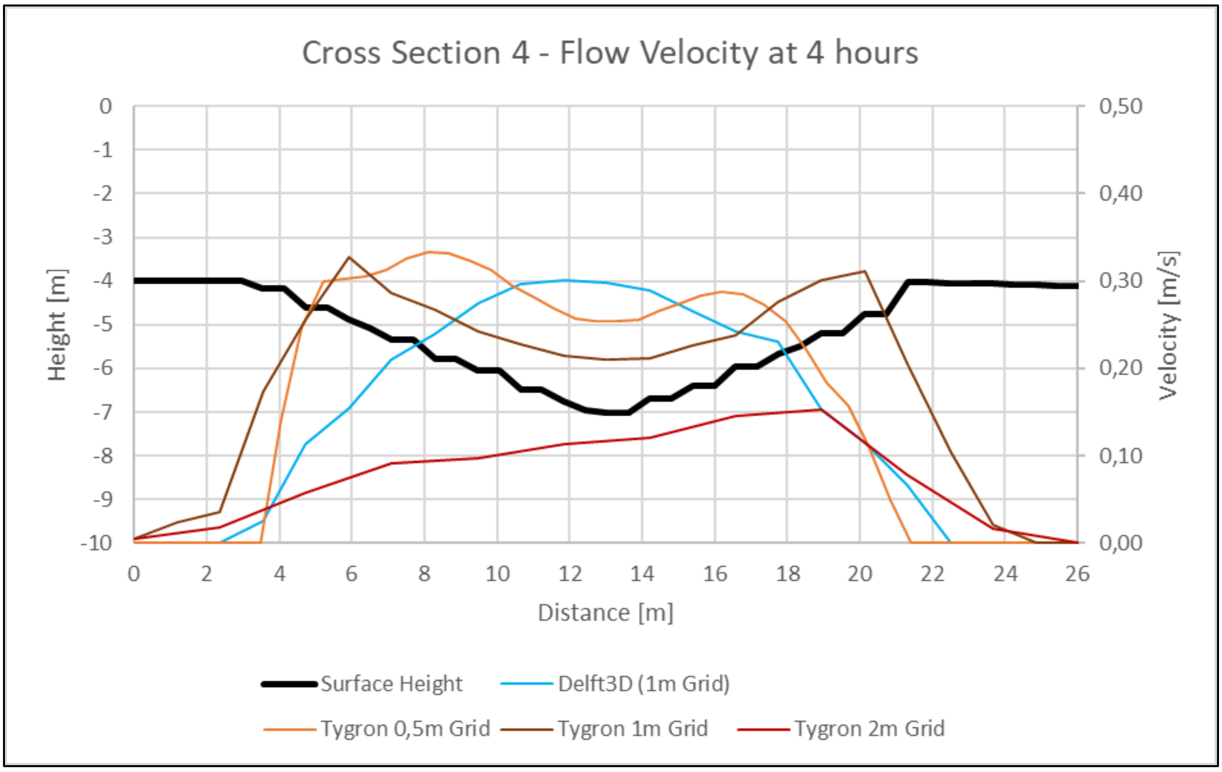


Figure B.4: Difference in flow velocity with different sized grids in Tygron.

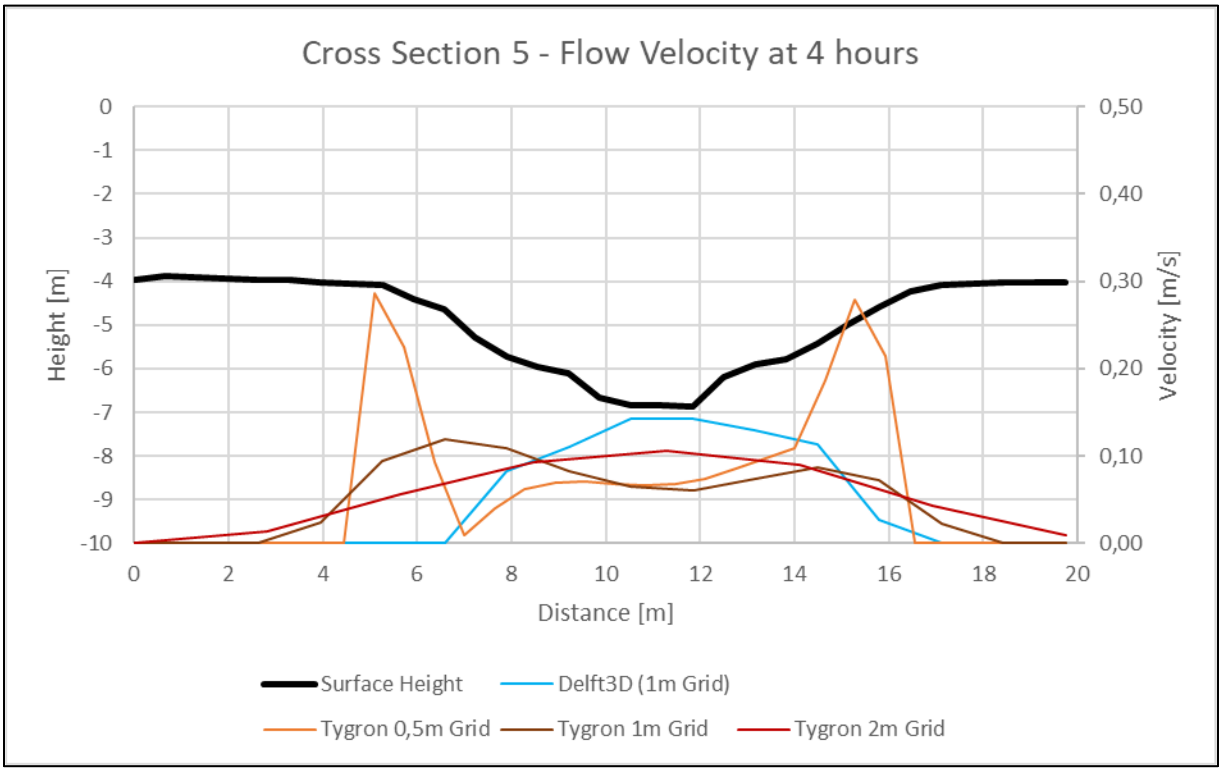


Figure B.5: Difference in flow velocity with different sized grids in Tygron.

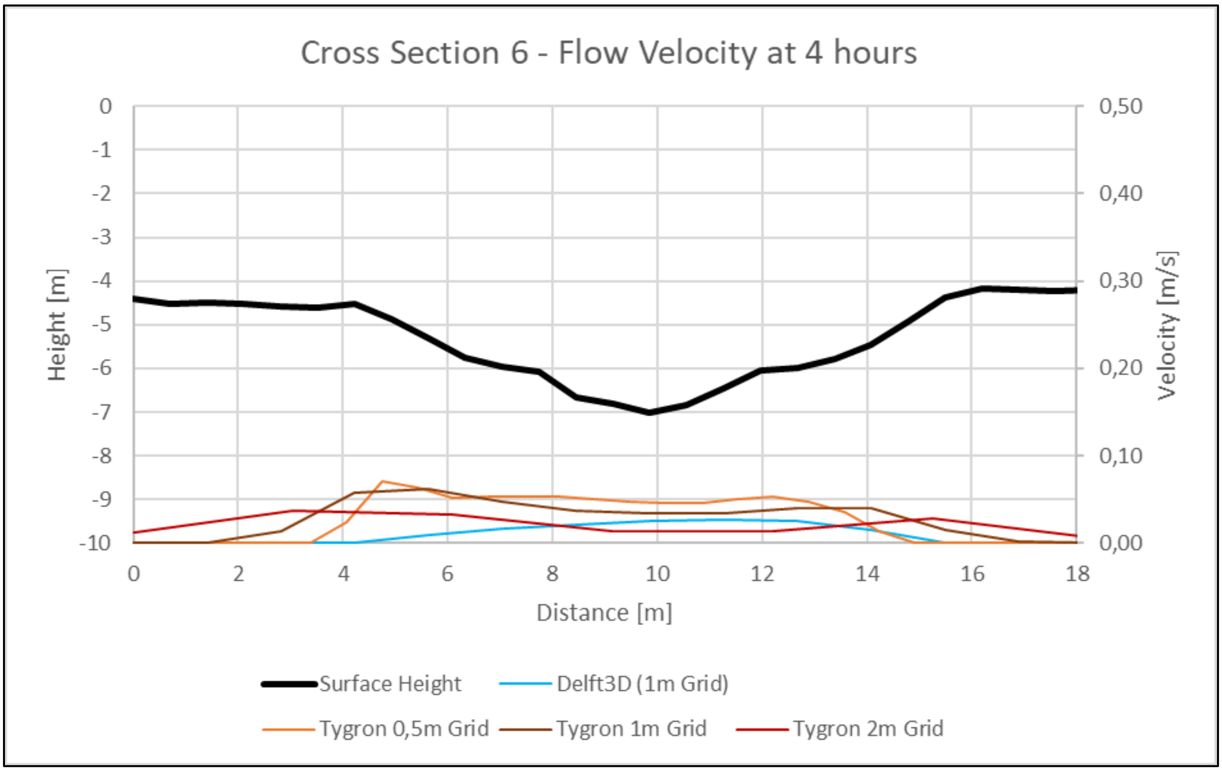


Figure B.6: Difference in flow velocity with different sized grids in Tygron.

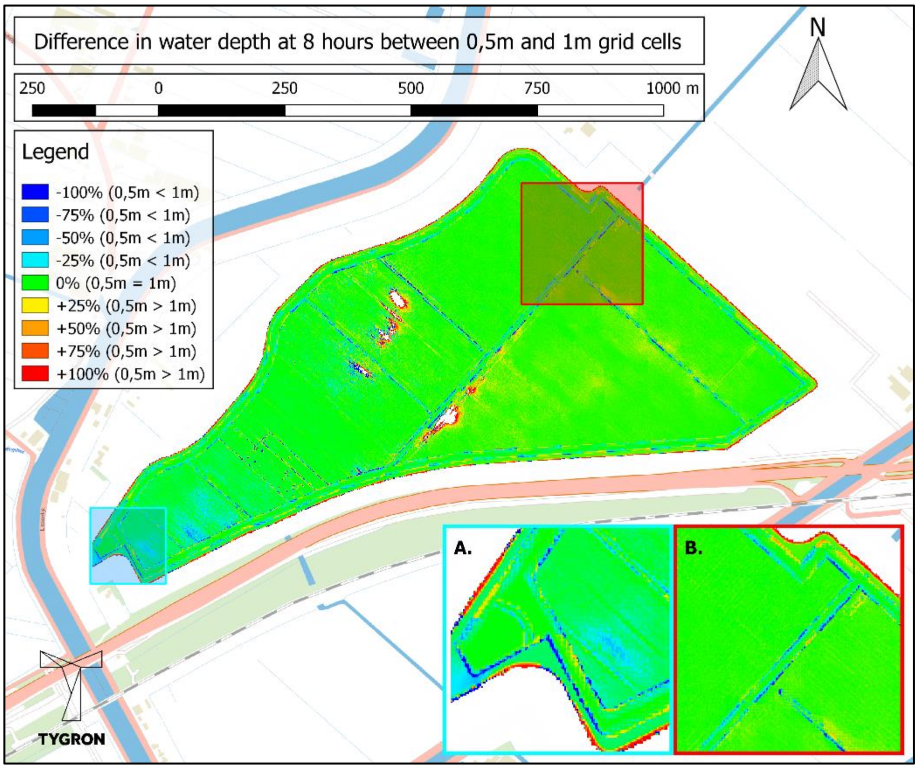


Figure B.7: Difference in water depth at 8 hours between 0,5m grid cells and 1m grid cells in percentages.

Appendix C – Delft3D computation time

There is a substantial difference in computation time between Tygron and Delft3D. The reason for this is the external supercomputer that Tygron has that does the computations through the cloud. An interesting question is the following. If the model in Delft3D is simplified to the point where its computation time is comparable with the computation time in Tygron, are the results still reliable? For this, the grid cell size in Delft3D is increased to square grid cells of 5 by 5 meter, with a timestep of 0,6 seconds. The computation time for this model was roughly half an hour, whereas Tygron takes about twenty minutes to compute the same system with square grid cells of 0,5 meter and an adaptive timestep around 0,15 seconds. The results are given in Figure C.1 to Figure C.6.

As is visible from the results, the simulation does give a very rough estimation of the area, but shows some differences on some particular places or phases in the simulation. For example in the smaller ditches. Due to the larger grid cells, these ditches are not registered as ditches, which is why flow through these ditches is not simulated. Also, due to the rougher discretization of the surface height to the grid, the narrow ditch in the south-west is simulated to be even narrower, which increases the flow velocity through this ditch. Towards the end of the simulation, differences in water level also become apparent. The simulation with the larger grid cells shows a larger area that is still unaffected by the flood, while the finer grid shows that these areas are already inundated.

To conclude on this, it is possible to reduce the computation time by Delft3D to that of Tygron, but it does involve a sacrifice on accuracy, of which the magnitude depends on the size of the case area and the size of its channels.

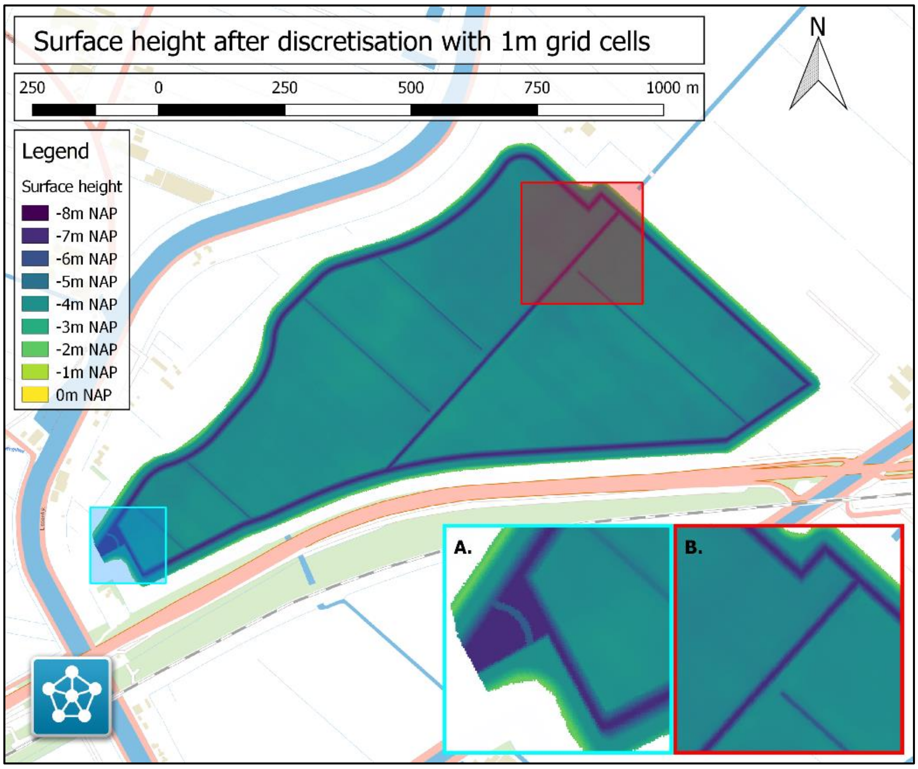


Figure C.1: Surface height after discretization with 1 meter grid cells.

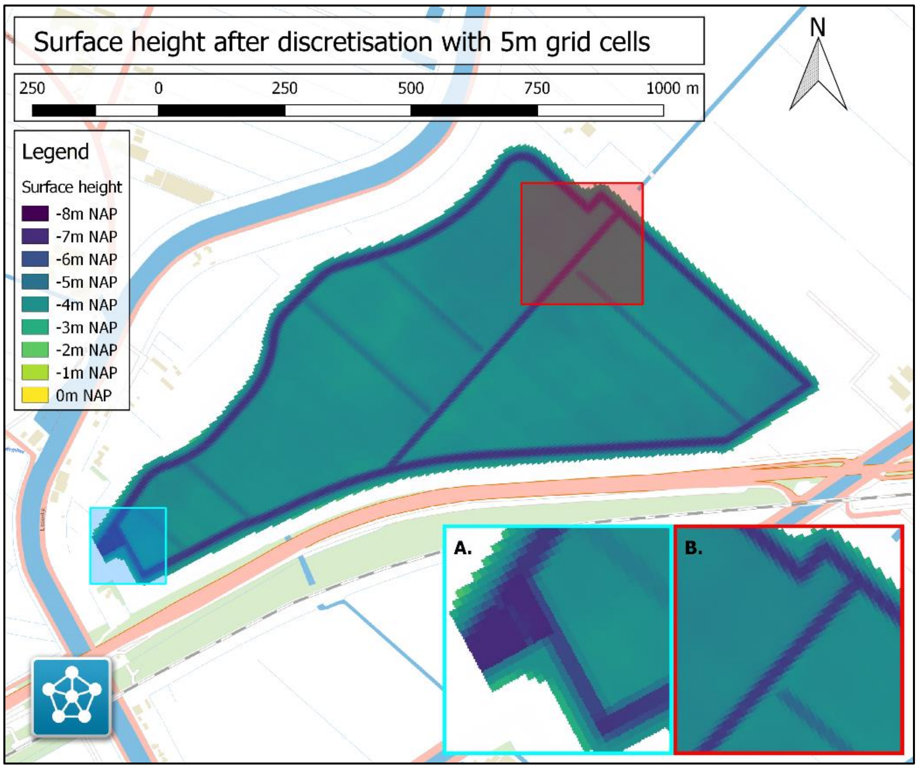


Figure C.2: Surface height after discretization with 5 meter grid cells.

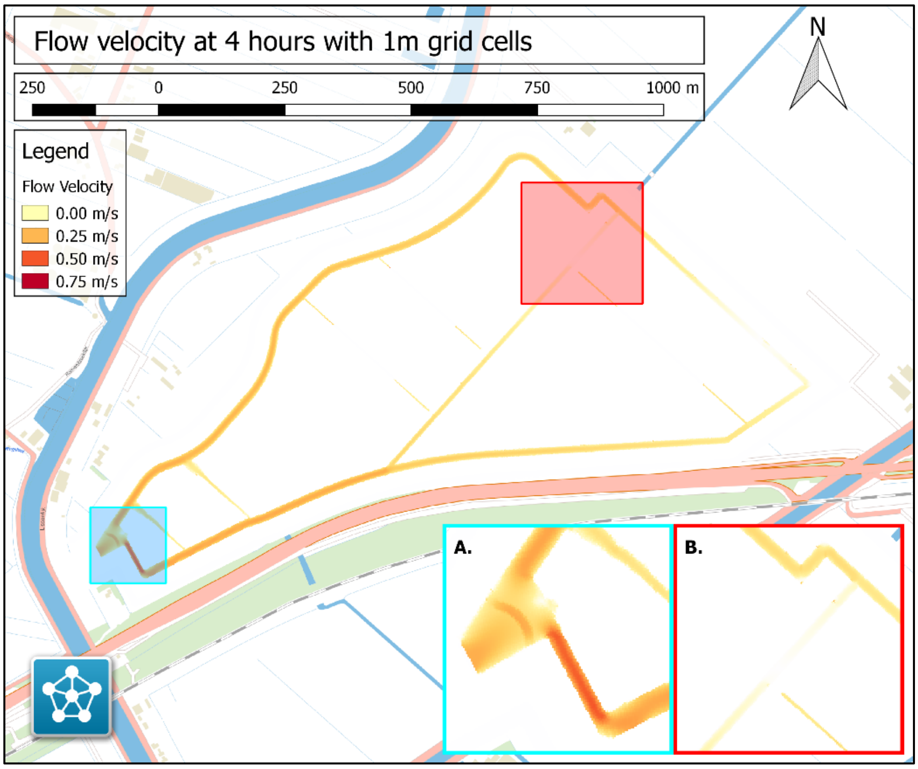


Figure C.3: Flow velocity at 4 hours with 1 meter grid cells.

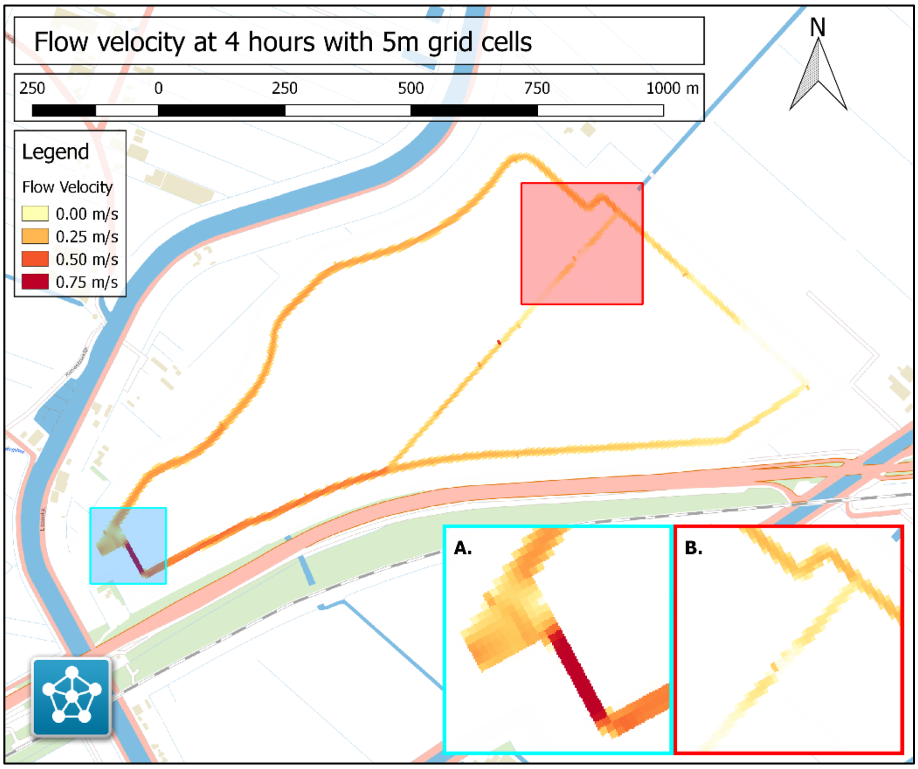


Figure C.4: Flow velocity at 4 hours with 5 meter grid cells.

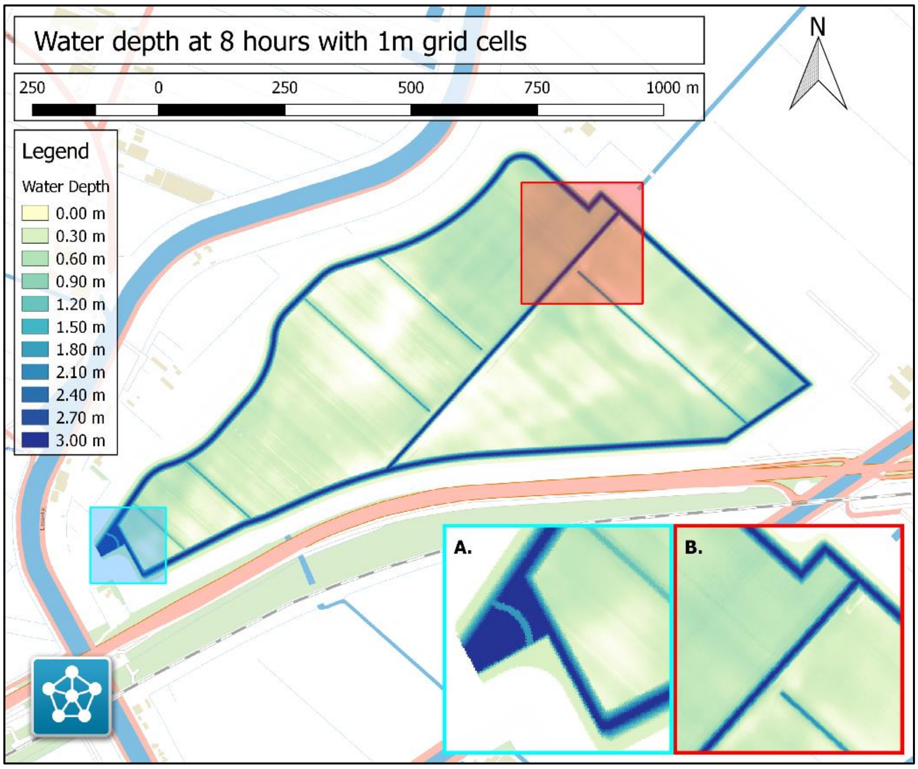


Figure C.5: Water depth at 8 hours with 1 meter grid cells.

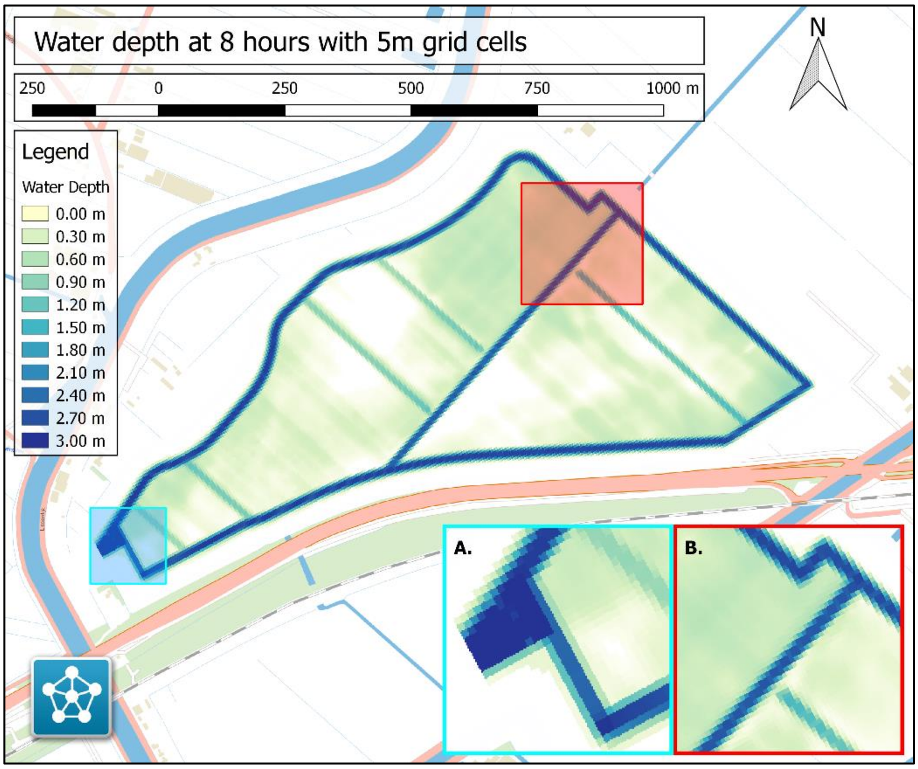


Figure C.6: Water depth at 8 hours with 5 meter grid cells.