Dutch Delta Systems

D-FAST Morphological Impact

User Manual

D-FAST
Morphological Impact

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D-FAST Morphological Impact, User Manual

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1 Introduction

This manual describes D-FAST Morphological Impact version 3 which provides a rapid, first estimate of the bed level changes to be anticipated in the main channel due to the implementation of local river adjustments outside the main channel (so-called interventions). The program is a successor to the WAQMORF and D-FAST Morphological Impact version 2 programs that implemented the rule of thumb developed in the context of Rijkswaterstaat programme Stroomlijn by Sieben (2010). This new version follows the same conceptual approach, but uses a fixed set of flow conditions independent of the intervention instead of three intervention-dependent flow conditions. It assumes a seasonal discharge variation that can be represented by means of series of flow conditions. Bed level changes outside the immediate vicinity of influence of the intervention are ignored in this analysis. The bed level changes are indicative for the effects over a sufficiently long cycle of high and low flow seasons.

The typical analysis cycle consists of the following steps:

1 Use D-FAST Morphological Impact or check chapter 5 to determine the hydrodynamic simulations that will provide the necessary input for the morphological impact analysis.
2 For the conditions obtained in step 1, simulations will be run using D-Flow FM for both the reference situation and the scenario with only the intervention to be evaluated implemented. All simulations need to be carried out using the same base mesh.
3 Using the simulation results of step 2, D-FAST Morphological Impact determines an estimate of the

   ◇ year-averaged bed level change [m] without dredging,
   ◇ maximum bed level change [m] without dredging, and
   ◇ minimum bed level change [m] without dredging

   once the (dynamic) equilibrium has been reached.

The methodology provides an indication of magnitude and location of the bed level changes, but can't always replace a complete morphodynamic simulation. The purpose of the rule of thumb is to provide a simple and consistent first estimate to avoid unnecessary morphodynamic simulations or to identify critical aspects in the design of the intervention early on and to underpin the need for more extensive analysis.

The appropriate use of the results – the estimated bed level changes – for the Dutch rivers is described in the "rivierkundig beoordelingskader". An evaluation of the rule of thumb (Paarlberg, 2009) states the following

◇ Based on a comparison of the tool and Delft3D results for 2 case studies it's concluded that the rule of thumb can provide a reliable and robust indication of the bed level changes in the main channel. However, the rule of thumb should only be applied in those cases for which it is intended and the user should be aware of the assumptions and restrictions of the method and understand the effect that those have on the computed bed level changes.
◇ If the estimated bed level changes are critical for navigation and/or safety, or if the intervention is outside the applicability domain of the rule of thumb, then the tool is not appropriate. In such cases further research is needed by means of a 1D and/or 2D morphodynamic model in consultation with the river manager. See chapter 3 on more guidance.
◇ The tool is most suited for the estimation of the morphological impact on the main channel by river-widening interventions which

   1 influence the main channel currents in a limited reach and
   2 withdraw only a limited amount of water from the main channel.

   The user should take care to analyze the results in case of interventions that deviate from these conditions and to verify how the assumptions and limitations of the methodology influence the results.

- ◇ The tool can be applied for different types of river-widening interventions. It is critical that the flow-carrying capacity of the intervention is well represented by the three discharge levels.
- ◇ The rule of thumb can probably also be applied for river reaches with (more) strongly graded sediments.

Finally, we reproduce below the introductory section of the text included in every report written by the tool:

```
D-FAST Morphological Impact implements an algorithm to estimate the local
morphological effects of a local intervention (i.e. an adjustment to the
river). The conceptual framework was originally introduced in
    "RWS-WD memo WAQUA vuistregel (Sieben, 2010)"
but it has been extended and improved over the years. Check the user manual
for the details of the currently implemented algorithm.

It is based on an estimation of the equilibrium bed level changes in the
main channel that would occur eventually when river maintenance would not
be adjusted.

The effect is expressed as:

    year-averaged bed level change [m] without dredging
    maximum bed level change [m] without dredging
    minimum bed level change [m] without dredging

By means of these estimates bottlenecks can be identified. The results are
not suitable for direct estimation of the impact on the maintenance of the
navigation channel!

The combination of the total equilibrium sedimentation volume and the
yearly sediment load of the river determines the period over which the
equilibrium can be reached.

This is version ....
```

2 Getting started

2.1 Introduction

This chapter gives an overview of how D-FAST Morphological Impact can be used. The program can run in two modes:

1 *batch mode*: in this mode the program runs the analysis without user interaction for a configuration file of which the name as command line argument,
2 *gui mode*: in this mode the user specifies the configuration via a graphical user interface from which the analysis can either be started directly or the configuration can be saved for batch mode execution at a later time.

The program runs by default in the gui mode; other run modes can be selected via the command line argument.

short	long	description
`-h`	`--help`	show help text and exit
	`--mode`	run mode `batch` or `gui` (default: `gui`
	`--rivers`	name of river configuration file (by default the `Dutch_rivers_v2.ini` included in the distribution is used)
	`--config`	name of analysis configuration file

By default the program runs for the Dutch Rhine and Meuse river branches, but a different river configuration can be provided by means of the `--rivers` command line switch; this option is supported by all run modes. For details on the format of the river configuration file, see the appropriate section in the appendix. The following list indicates the names of the output files:

- `report.txt` Text file with summary report of the analysis
- `dfastmi_results.nc` UGRID netCDF file containing variables for average yearly change, maximum change, and minimum change (when the analysis runs using D-Flow FM input)

The following sections describe the different execution modes.

2.2 Running in batch mode

The batch mode runs an analysis using D-Flow FM results without user interaction, old WAQUA files are no longer supported. The program should be started with the run mode set to `batch` and a configuration file specified on the command line as follows

```
> dfastmi --mode batch --config myfile.cfg
```

The content of the configuration file is described in section A.3; it can be generated using either a text editor or D-FAST Morphological Impact running in gui mode.

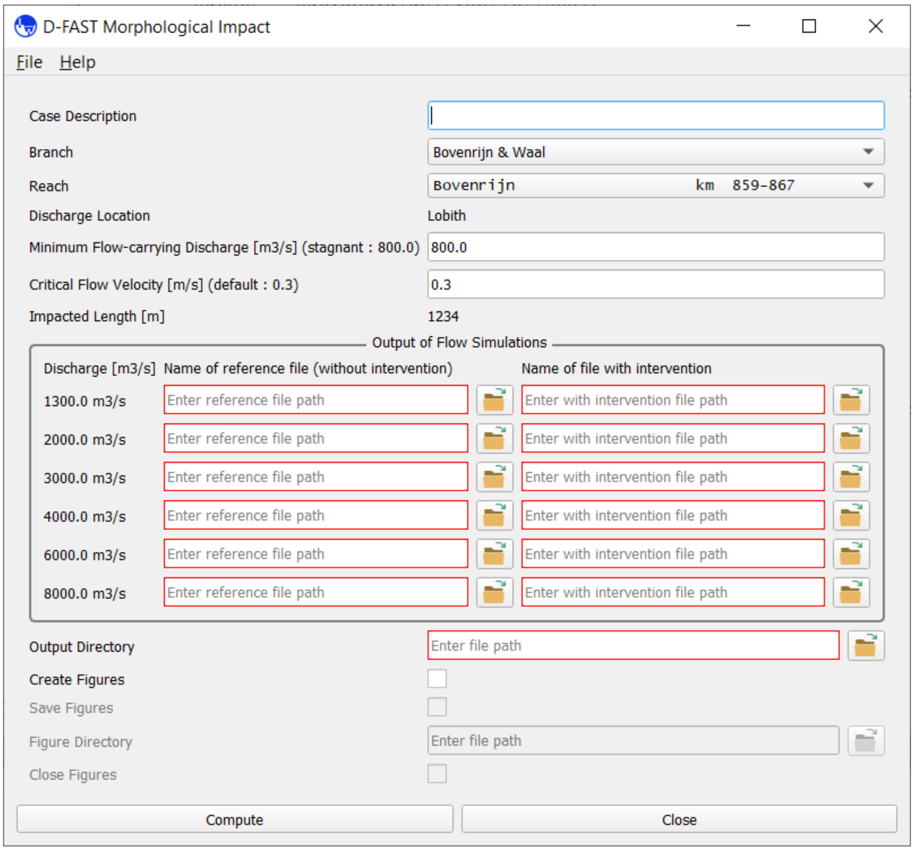

***Figure 2.1:** Example of the main dialog*

2.3 Running in gui mode

This is the default mode for the program, so no command line argument needed. The gui works only with the newer D-Flow FM result files. You may specify a configuration file to load upon start. For example

```
> dfastmi --config myfile.cfg
```

runs the program and loads the myfile.cfg configuration file into the graphical user interface.

The following text describes the functionality of the graphical user interface from top to bottom. The `File` menu provides access to options to load a configuration file and to save the current selection in the gui to a configuration file. The `Help` menu provides access to the user manual and the D-FAST Morphological Impact about box with version and license information.

As a user, you start by selecting the branch and reach of the study. Changing this selection will affect all fields below overwriting any previously entered values. You have to specify the minimum flow-carrying discharge; this is the discharge [$m^3\,s^{-1}$] above which the intervention influences the main channel flow. Together with the branch and reach selection, this determines the impacted length [m]; this is distance over which the bed level change can develop in one year. This length [m] is dynamically updated with each change you make.

The critical flow velocity [$m\,s^{-1}$] is the flow velocity magnitude above which bed level changes may occur. This value is used to avoid computing equilibrium bed level change values in areas where the (reference) flow velocity is too small. Tooltips appear when you hover over the *edit* field with your mouse pointer. See chapter 3 and chapter 5 for more guidance on the values to be used.

Subsequently, you are presented with a list of flow conditions for which you need to provide data files representing the reference situation and the situation with the intervention implemented. The names of the files need to be specified in the edit fields below.

Finally, we find at the bottom of the dialog some options for the output of the D-FAST Morphological Impact run, and a button to run the analysis in the folder from which the program was started, and a button to end the program.

2.4 Running from Python source code

It's recommended to run D-FAST Morphological Impact as binary, but you may also run it directly from the Python source code. The source code can be downloaded from https://github.com/Deltares/D-FAST_Morphological_Impact. When using the tool for projects, please carefully check that you use the appropriate source code version. A Python Poetry[1] environment has been configured to relatively easily install all libraries necessary for running the tool. See the D-FAST Morphological Impact Technical Reference Manual for details. Follow the steps in the online Developer user starter guide to set up the run environment using `poetry install`. In that case the program can be started from the command prompt as

```
poetry run python -m dfastmi ...options...
```

or from within a running Python environment as

```
import dfastmi.cmd
dfastmi.cmd.run()
```

where optionally the commandrunmode (default `GUI`), `configfile` (default `dfastmi.cfg`) and `rivers_file` (default `Dutch_rivers_v2.ini`) can be specified as arguments.

2.5 Figures

The analysis can generate one figure[2], see e.g. Figure 2.2. These figures are created using the Python `matplotlib` toolbox. Here, we will give a brief summary of the interactive options that these figures offer. The buttons in the toolbar from left to right serve the following purpose:

- **house**: reset the figure to the original view
- **left arrow**: reset the figure to the previous view
- **right arrow**: reset the figure to the next view (only when you have gone to a previous view)
- **cross arrows**: pan the zoom area (while pressing the left mouse button) and zoom in/out by moving up/down (while pressing the right mouse button)
- **looking glass**: zoom in/out by drawing a zoom box. Zoom in by drawing a box while pressing the left mouse button, and zoom out by drawing a box while pressing the right mouse button.
- **sliders**: change some white space settings (border margins).
- **graph**: change the title, min/max and scaling of axis, and the colormap used.

[1] https://python-poetry.org/

[2] More figures are foreseen for future versions.

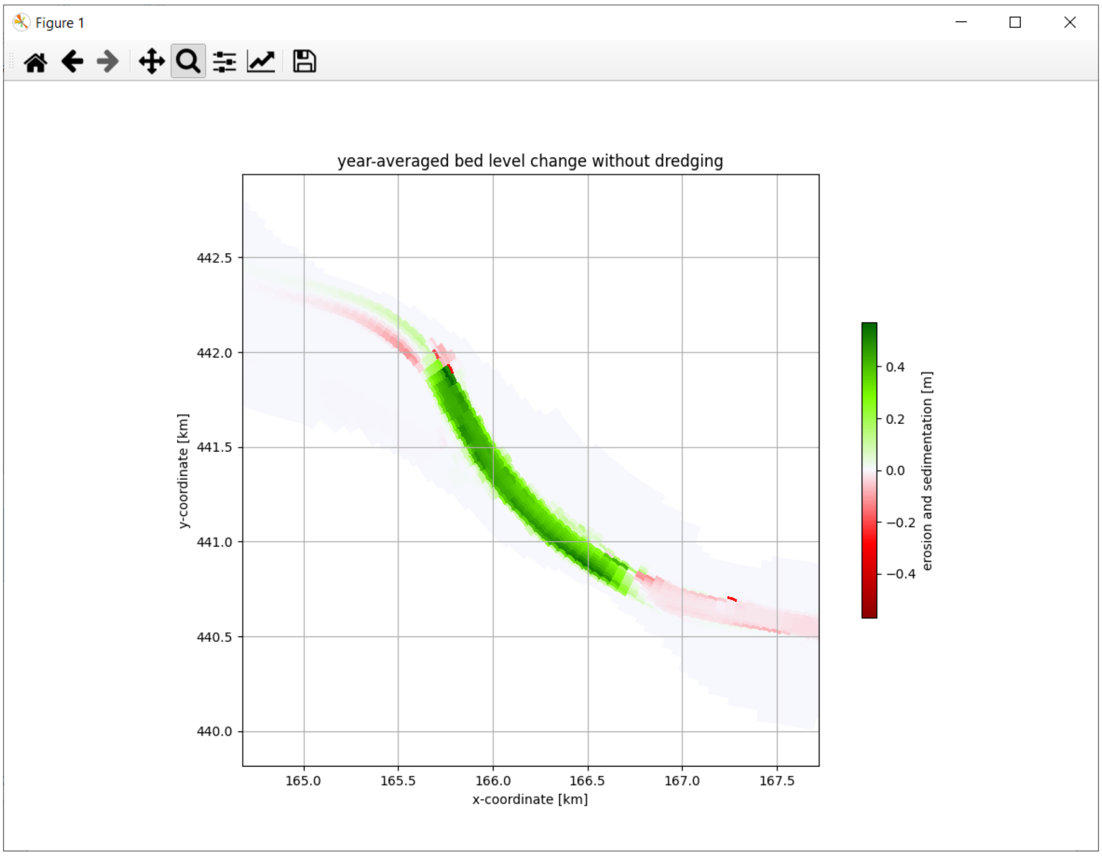

Figure 2.2: *Example of a figure created by D-FAST Morphological Impact.*

◇ **floppy**: export the figure to a number of different raster and vector image file formats.

3 User Guidance

D-FAST Morphological Impact is a rapid assessment tool that provides feedback regarding the morphological impact of river interventions on the main channel. The tool provides first estimates based on a couple of hydrodynamic simulations. When critical conditions are identified, this can support the call for more demanding morphological simulations. The conceptual framework is described in chapter 4. This chapter starts with an overview of applications for which D-FAST MI is or is not suitable. This is followed by a discussion of various assumptions and limitations of the D-FAST MI approach. The steps of the analysis are subsequently described in chapter 5.

3.1 (Un)suitable applications

Situations in which D-FAST MI is commonly applied are river widening interventions outside the main channel, such as

- side channels
- flood plain lowering
- adjustment of secondary levees
- widening of the bank region
- adjustment of the river groynes

The tool can be used to identify potential morphological impact (both size and location) in an early stage, such as during the design phase. Furthermore, the tool can be used to determine whether more advanced evaluation methods are required to determine whether the impact is acceptable. D-FAST MI should not be used

- if a more advanced impact assessment method is required, typically, in case of
  - critical conditions for shipping or river safety and/or
  - critical conditions identified by an initial D-FAST MI assessment and/or
  - in the final assessment of the planning phase and/or
  - if there are more strict requirements concerning quantification of the sedimentation in the context of the causation principle
- to estimate bed level changes due to discharge extractions (e.g. rerouting flow between the river branches would cause changes over large distances)
- to estimate bed level changes outside the main channel
- to estimate bed level changes due to interventions that cannot be represented well in the D-Flow FM schematizations
- to estimate bank erosion. D-FAST Bank Erosion should be considered instead.
- to estimate the impact of interventions in the main channel, such as
  - to quantify the total dredging volumes
  - to study the impact of different dredging strategies
- to estimate bed level changes due to changes in sediment supply and/or main channel bed levels
- to identify areas subject to erosion

3.2 Assumptions and limitations

The conceptual framework described in chapter 4 is based on a number of assumptions. Therefore, D-FAST MI has some limitations regarding the application.

1 It's assumed that the intervention (and the subsequent morphological development) does not significantly influence the water levels. The impact of large interventions that influence the backwater curve, may thus not be estimated accurately by D-FAST MI.
2 Interventions should be properly resolved on the D-Flow FM mesh. The discharges used by D-FAST MI should give a balanced representation of the influence of the intervention on the flow patterns. Hence, D-FAST MI is not suitable for interventions that have been designed to only have a noticeable effect for flow conditions not included in the analysis. An example of such a case is an intervention that is only active above the highest discharge level. A conservative estimate of the possible impact of such a case can be obtained by evaluating a similar intervention for which the maximum impact on the flow field has been shifted to the highest discharge level.
3 D-FAST Morphological Impact is not yet suited for tidally influenced areas. See section 4.4.
4 The river system is subdivided into branches and reaches. The characteristics, such as the characteristic bed celerity and normal channel width, may vary per branch or even reach. Interventions located across reaches, should be evaluated against the settings of the dominant reach, i.e. the reach in which the dominant effect is to be expected (typically the reach in which the largest part of the intervention is located). If an intervention is located close to, or even across branches, an additional verification should be done to determine whether D-FAST MI can be applied, and if so, how it should be applied.
5 The morphological impact of an intervention will only accumulate over the period during which the intervention is active. The original WAQMORF algorithm selected discharges based on the specific characteristics of the intervention being evaluated, and as such it was not suited for evaluating multiple interventions at once. The new algorithm uses a fixed set of discharges, which makes it more generic, but the reported impacted length L_s, i.e. the distance over which the morphological changes can develop over the period of one year, still depends on the specified minimum flow-carrying discharge Q_{thr}, i.e. the discharge above which the intervention will be influencing the flow. Consider the following two interventions:

   ◇ One intervention that is active only at high flow ($Q_{\text{thr}1}$ is large). Let us assume that this intervention has a significant impact on the flow patterns in the main channel at those flow conditions and hence a significant long-term morphological impact, i.e. a large year-averaged equilibrium bed level change $\bar{\Delta z}_{b1}$. This intervention is associated with a small impacted length, $L_{s1} \ll L_{s2}$, since its minimum flow-carrying discharge is exceeded only a small part of the year. Hence, when this intervention is evaluated by itself, the *first-year* impact (estimated as the equilibrium effect accumulated over the impacted length) would be modest.
   ◇ One intervention that is almost always active ($Q_{\text{thr}2} = 0$). Let us assume that this intervention has very little to no morphological impact by itself, i.e. $\bar{\Delta z}_{b2} \ll \bar{\Delta z}_{b1}$. Since this intervention is active under all flow conditions, the impacted length L_{s2} is basically equal to the distance over which any bed disturbance can travel in a year. However, the *first-year* impact of just this intervention would also be modest since $\bar{\Delta z}_{b2}$ is small.

   However, when the two interventions are evaluated *together*, the impacted length will be based on the smaller minimum flow-carrying discharge $Q_{\text{thr}2}$ of intervention 2 (and hence L_s will be large), while the year-averaged equilibrium bed level change of the two interventions together will be similar to that of the first intervention, $\bar{\Delta z}_{b1}$. The estimated first-year effect, obtained by integrating $\bar{\Delta z}_{b1}$ over L_{s2}, will be significantly bigger than each of the measures individually. We conclude that it's wise to only evaluate interventions together if they have similar threshold discharges. If the threshold discharges differ significantly, then the estimate for the first-year effect will be on the conservative side.

6 When combining multiple interventions, or when making a single intervention longer, you will reach the point at which the effect of an intervention on the flow can no longer be seen as one stretch where water leaves the main channel, and one where it flows back to it (or the other way around). There will be multiple of these stretches due to the sequence of interventions, or due to the alongstream variation of the left and right floodplain width. As a result, the morphological impact will not be represented by a single sedimentation (or erosion) area, but a series of them. Earlier versions, therefore, suggested to restrict the use of this tool to interventions shorter than 4 km, but this restriction can be relaxed by not only taking into account the most upstream area in the estimation of the first-year sedimentation volume, but all separate areas. See section 4.5. However, it's still preferred to evaluate interventions less than the length of one flood plain section.

7 D-FAST Morphological Impact doesn't use any information about the bed composition. It doesn't get information about non-erodible layers, nor about natural variability in the erodibility of the bed material. As such, it is more difficult for D-FAST MI to predict scour accurately than sedimentation. The primary purpose of D-FAST MI is the estimation of sedimentation that may cause problems for navigation. As such, it is better suited for evaluating interventions that increase the flow area than interventions that decrease the flow area.

8 D-FAST Morphological Impact conceptual model is based on a change in the discharge in the main channel. Such a change may be caused by changes in the floodplain, or changes in the main channel. When the intervention affects the floodplain, its impact on the main channel is easy to interpret since both simulations with and without the intervention use the same bed levels for that area. However, when the intervention affects the main channel, for instance by deepening, the resulting impact (sedimentation to get back to the original bed level) must be interpreted as relative to the bed levels of the simulation *with* the intervention implemented. Furthermore, it should be noted that Equation (4.5) is evaluated using the water depth h obtained from the reference simulation. If the intervention includes a significant change to the bed level in the main channel, this approximation may no longer be valid. Therefore, D-FAST MI is not recommended for such interventions.

9 D-FAST Morphological Impact does not take into account the dynamic feedback that morphological change may have on the hydrodynamics. This general limitation is related to the following three statements.

10 D-FAST Morphological Impact assumes that a new equilibrium can be reached by adjusting the bed level locally such that the flow velocity at that point returns to the original value. This is the result of the 1D conceptual approach in which the flow cannot redistribute laterally. Consequently, D-FAST MI is better at estimating the one-dimensional, width-averaged impact than the two-dimensional, lateral variability of the impact. The lateral variability may force further variability up- and downstream that will not be identified by D-FAST MI.

11 D-FAST Morphological Impact focuses on the long-term equilibrium effect and the rate of change. It does not estimate in any way the dynamic effect of the intervention: the erosion wave downstream of a sedimentation area caused by an increase in flow area, or the sedimentation wave downstream of an erosion area. These dynamic effects will be of the same order as the first-year sedimentation or erosion, but of opposite sign. They will propagate downstream unless they are compensated by dredging or suppletion once.

12 D-FAST Morphological Impact does not take into account bank erosion or bank failure due to erosion; neither related to the dynamic effect mentioned in the previous bullet, nor related to the long-term change to the bed levels. Consider using D-FAST Bank Erosion, or expert judgment.

4 Conceptual framework

This chapter describes the conceptual framework of the method used by D-FAST Morphological Impact. It all starts with the design of a river intervention, i.e. a local river adjustment, to address some issue e.g. an adjustment to increase the flow capacity. In order to evaluate the intervention, it's important to also look at the morphological changes caused by the changing flow patterns. D-FAST Morphological Impact implements algorithms to provide an estimate of the long-term morphological effect inside the main channel, as well as the degree to which this adjustment may occur in the first year. The next couple of sections provide context and theory to underpin the implemented algorithms. Section 3.2 provides an overview of the assumptions and limitations of this tool.

4.1 Characteristics of bed level changes due to river interventions

A river intervention, i.e. a local river adjustment (typically a flow capacity enlarging adjustment) outside the main channel, may result in changes in the flow pattern within the main channel. The bed levels within the main channel will react to such changes depending on the magnitude, duration and length scale of these flow pattern changes in the main channel.

Hence, the core focus of the rule-of-thumb is to determine and characterize the changes in the flow pattern within the main channel. Here, we define the main channel as the part of the river between the groyne heads.

At the upstream end of the floodplain adjustment part of the main channel discharge will leave the main channel, which will flow through the enlarged floodplain, secondary channel or bank area, and return to the main channel at the downstream end of the project area. The resulting changes in the main channel flow pattern cause sedimentation in the main channel at the upstream "offtake" of the new outflow and erosion at the downstream "confluence" when the flow enters the main channel again. See Figure 4.1. Because the river discharge varies, the pattern will also vary during the year. As a result a part of the main channel bed level adjustment is stationary and a part of the adjustment is transitional and it will migrate downstream. A reduction in the water depth may thus not only be observed locally where the flow diverges into the flood plain, but also downstream thereof.

The bed level change due to river enlargement can largely be characterized as follows

- ◇ The magnitude of the bed level change varies over the seasons; the maximum change is observed at the end of the flood season and the adjustment reaches a minimum at the end of the low flow period.
- ◇ Local evaluation of the bed level changes is insufficient because of partial downstream migration of the bed level changes.

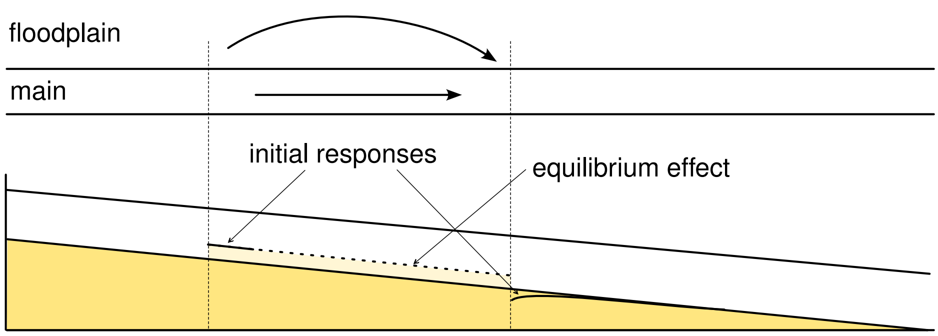

Figure 4.1: *Equilibrium and initial response under steady discharge*

◇ The maximum impact is observed on that side of the river which is closest to the adjustment.

Because part of the bed level changes migrate downstream, the morphological impact on projects located downstream may be increased. After all, the maximum bed level change of one single river enlarging intervention is reached at the end of the flood period and it's the result of that flood period. However, when a series of interventions along the river are combined (for instance, lowering of the groynes along a reach) the downstream bed level changes may be increased by accumulation of downstream migrating bed waves, such that the accumulated bed level change may be significantly larger. In other words, river interventions extending over longer reaches may result in a larger morphodynamic response than comparable but more isolated interventions.

The aforementioned observations result in the following premises. The rule-of-thumb described in the following sections

◇ will only be valid for the estimation of the impact of local interventions with a length of at most one flood plain,
◇ should take into account seasonal variations, and
◇ needs to be estimate the spatial pattern of the bed level change.

4.2 Characterization of the changes in the main channel flow pattern

When an intervention in the floodplains does not include something like a permanently active secondary channel, the flow pattern in the main channel will only be affected during flood conditions. If on the other hand, such a secondary channel (or other intervention active under medium to low flow conditions such as groyne adjustments) is included in the design then the flow pattern will also be influenced during transitional or even low flow conditions. It's therefore critical to determine the effect of the intervention on the main channel flow pattern at different discharge levels.

Secondary channels may have a major impact on the morphodynamics of the main channel. The magnitude of the discharge through the secondary channel varies as function of the river discharge. Because the hydraulic conditions of the secondary channel can change over time (e.g. due to vegetation, siltation, or erosion) the discharge through a secondary channel is typically controlled by some hydraulic structure. The typical characteristics of a weir (Dutch: overlaat, drempel) and orifice (Dutch: onderlaat, duiker) are shown in Figure 4.2.

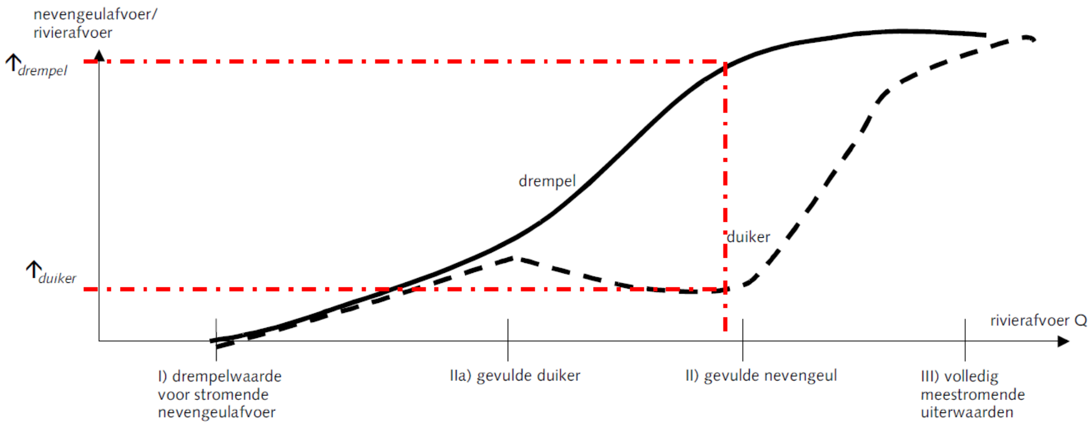

Figure 4.2: *Schematic of the controlled discharge through a secondary channel.*

The discharge through a secondary channel is characterized by a number of special conditions as illustrated by Figure 4.2:

1 the beginning of flow through the secondary channel
2 the bankfull secondary channel
3 the fully developed flow in the secondary channel and surrounding floodplain.

When the discharge through the secondary channel is controlled by an orifice, the fully flooded condition may add an additional characteristic discharge. In order to characterize the flow patterns during flood it's necessary to distinguish the condition in which the flood plains just start to carry flows, and the condition of fully developed flow in the flood plains. D-FAST Morphological Impact version 2 and before (in WAQMORF) used an algorithm to determine which three flow conditions would best represent the effect of the intervention under various conditions. However, as these conditions varied depending on the thresholds specified by the user, the tool could give different results depending on the user. In D-FAST Morphological Impact version 3, a new method has been implemented that removes most input parameters; only the threshold discharge at which the intervention starts affecting the flow velocities in the main channel, besides the general location characteristics of the branch and reach in which the intervention is located.

4.3 Equilibrium bed level change: the discharge dominated case

D-FAST Morphological Impact is based on a highly simplified model of river morphodynamics. The derivation of the algorithm starts by assuming a quasi-stationary flow pattern and an outflow of discharge and sediment from the main channel while the local water level is independent of the hydraulic and morphological changes in the main channel (a *rigid-lid* approximation). Note that the outflow of sediment is assumed to be a consequence of the outflow of discharge only; the conceptual framework does not allow for selective removal of only sediments.

water $$\frac{\partial q_{\text{mc}}}{\partial s} = -q_{\text{out}} \tag{4.1}$$

sediment $$\frac{\partial z_b}{\partial t} + \frac{\partial s_{\text{mc}}}{\partial s} = -s_{\text{out}} \tag{4.2}$$

in which

q_{mc}	main channel discharge per unit width [m^2 s^{-1}]
q_{out}	discharge per channel unit width *to* the flood plain per unit river length [m^2 s^{-1} m^{-1}]
s	stream-wise coordinate [m]
z_b	bed level change due to intervention [m]
s_{mc}	main channel sediment transport per unit width [m^2 s^{-1}]
s_{out}	sediment transport per channel unit width *to* the flood plan per unit river length [m^2 s^{-1} m^{-1}]

The response of the main channel is represented here by a bed level change Δz_b [m] (raise or lowering) which is small relative to the local water depth. The sediment transport capacity per unit width of the main channel, s_{mc}, is approximated by $s_{\text{mc}} = m\,(q_{\text{mc}}/h)^b$ with h the water depth [m] in the main channel, m a calibration factor [m^{2-b} s^{b-1}] and a dimensionless sediment transport exponent b, which is 5 for Engelund and Hansen (1967). Based on these equations, one can derive that the bed level development during such a period of constant discharge is given by the following relaxation

$$\Delta z_b = \Delta z_b(0) + [\Delta z_{b,\text{eq}} - \Delta z_b(0)](1 - e^{-t/T_m}) \tag{4.3}$$

where the morphological time scale T_m is given by

$$T_m = \frac{L}{c} \approx \frac{hL}{bs_{\text{mc}}} \tag{4.4}$$

where c is the bed celerity [m s^{-1}] ($\approx bs_{\text{mc}}/h$), and the equilibrium bed level change $\Delta z_{b,\text{eq}}$ (for one steady flow forcing) equals the product of the water depth and the relative change in the main channel velocity u [m/s]

$$\Delta z_{b,\text{eq}} \approx -h\left(\frac{\Delta u}{u}\right) \tag{4.5}$$

The easiest way to understand this equation is to realize that it states that the velocity change caused by the intervention will be compensated by a bed level change such that the velocity, and hence the sediment transport capacity, returns to the original value. Note that we have assumed that the effect on the water level is negligible, hence the water depth change Δh equals the bed level change $\Delta z_{b,\text{eq}}$.

$$\Delta h u + h\Delta u \approx 0. \tag{4.6}$$

In reality the discharge isn't constant throughout the year. Instead, the year is assumed to be represented by a hydrograph series of constant discharges. The bed level development during a single period of the hydrograph is given by Equation (4.3), such that at the end of period i (lasting T_i days) the morphological effect of the intervention is given by

$$\Delta z_{b,i+1}(0) = \Delta z_{b,i}(0)\sigma_i + \Delta z_{b,i,\text{eq}}(1-\sigma_i) \text{ with } \sigma_i = e^{-T_i/T_{m,i}} \tag{4.7}$$

Let N be the number of periods of constant flow occurring in the order from $i = 1$ to $i = N$ in the hydrograph; each period i may have a different duration T_i. Note that the same discharge may occur multiple times during the hydrograph and there may be multiple peaks and lows in the hydrograph. The initial bed level change $\Delta z_{b,i}(0)$ of a period i equals the final bed level change $\Delta z_{b,i-1}(T_{i-1})$ of the preceding period $i-1$. This gives a set of N equations with N unknowns $\Delta z_{b,i}(0)$ for the dynamic long-term equilibrium if we assume that the final bed level of the last period $\Delta z_{b,N}(T_N)$ or $\Delta z_{b,N+1}(0)$ equals the initial bed level of the first period $\Delta z_{b,1}(0)$.

$$\Delta z_{b,i+1}(0) = \Delta z_{b,i}(0)\sigma_i + \Delta z_{b,i,\text{eq}}(1-\sigma_i) \text{ for } i \text{ equals 1 to } N \tag{4.8}$$

This set of equations can be solved for $\Delta z_{b,i}(0)$ giving

$$\Delta z_{b,i}(0) = \frac{1}{\xi}\sum_{j=0}^{N-1} \Delta z_{b,i+j,\text{eq}}(1-\sigma_{i+j}) \prod_{k=j+1}^{N-1} \sigma_{i+k} \tag{4.9}$$

where $\xi = 1 - \prod_{i=1}^{N} \sigma_i$ and all indices $m > N$ are equivalent to $m - N$ for reasons of periodicity. If the impact of the intervention increases as the discharge increases, the maximum bed level change is likely reached at the end of the period with the highest discharge. However, this isn't true for all hydrographs and for all interventions. Similarly, the minimum bed level change is frequently reached at the end of the period with the lowest discharge, but this may also depend on the details of the hydrograph used (which may for instance include multiple low flow periods of different duration). For this reason, the minimum and maximum values are determined independently for every individual grid cell as the minimum and maximum over all N fields of $\Delta z_{b,i}(0)$. The year-averaged bed level change $\bar{\Delta z_b}$ at long-term dynamic equilibrium can be computed as

$$\bar{\Delta z_b} = \frac{\sum \Delta z_{b,i,\text{eq}} T_i}{\sum T_i} + \frac{\sum (\Delta z_{b,i,\text{eq}} - \Delta z_{b,i}(0)) T_{m,i}(\sigma_i - 1)}{\sum T_i} \tag{4.10}$$

More details are given in Jagers and Giri (2022).

4.4 Equilibrium bed level change: extending to tides

The concept of the “hydrograph” consisting of N periods of constant forcing. The forcing could besides the discharge that was discussed above, also include the downstream water level (storm surge and tidal conditions). Although the current D-FAST Morphological Impact version includes code preparations for such extensions; the application domain is, for the time being, limited to the river reaches where such effect can be ignored.

4.5 Estimate for dredging volumes

An order-of-magnitude estimate of the dredging (or dumping) volume $V_{\text{dredge,1yr}}$ that will required to keep the bed levels at the initial[1] level can be obtained by accumulating the year-averaged equilibrium bed level change $\bar{\Delta z_b}$ (see Equation (4.10)) over the impacted length L_s. In a 1D setting with x indicating the alongstream coordinate [m], we can write that down as

$$V_{\text{dredge,1yr}} = \int_{x_0}^{x_0+L_s} \bar{\Delta z_b}(x) dx \tag{4.11}$$

where x_0 marks the upstream border of the impacted reach. The impacted length L_s is defined as the distance over which a bed level disturbance can travel during the part of the year that the flow conditions are different due to the intervention being evaluated, i.e.

$$L_s = \sum_{i \text{ where } Q_i > Q_{\text{thr}}} c_i T_i' \tag{4.12}$$

where i loops over the conditions for which the discharge Q_i is larger than minimum flow-carrying discharge Q_{thr}. The rivers configuration file specifies for each flow condition i the period T_i and celerity c_i. These values are thus given and should not be changed. The effective morphological period T_i' is equal to the period T_i except for the first flow condition for which the discharge Q_i is larger than minimum flow-carrying discharge Q_{thr}. For that condition the period is adjusted based on the discharge exceedance curve (given by `QFit` in the Rivers configuration file). The minimum flow-carrying discharge Q_{thr} is thus the only parameter given by the user that affects the impacted length. The sediment transport during the remainder of the year may adjust the shape and location of the deposit, but the total volume remains the same.

It is foreseen that this estimate may be computed automatically in a future release of D-FAST MI, but this is currently left as a manual step for the user. In case the intervention triggers multiple separate sedimentation (or erosion) areas, the volumes should be accumulated for each area individually, i.e. not only the most upstream area should be considered, and subsequently the total volume can be accumulated over all areas.

[1] If the bed levels in the main channel differ between the reference simulation and the simulation with the intervention, the level meant here is the bed level as included in the simulation *with* the intervention.

5 Steps in the analysis

To apply D-FAST Morphological Impact one should carry out the following six steps.

1 Characterize the intervention to be evaluated using D-FAST MI. Verify that it is appropriate to use D-FAST MI instrument; see chapter 3. Determine the branch and reach on which it is located; use the D-FAST MI GUI for this[1]. The default <Dutch_rivers_v3.ini> rivers configuration file supports the evaluation of interventions in the following reaches:

- ◇ Bovenrijn (Rkm 859-867)
- ◇ Waal (Rkm 868-951)
- ◇ Pannerdensch-Kanaal (Rkm 868-879)
- ◇ Nederrijn (Rkm 880-922)
- ◇ Lek (Rkm 923-989)
- ◇ IJssel (Rkm 880-1000)
- ◇ Merwede (Rkm 951-980)
- ◇ Meuse (Rkm 16-227)

Determine the threshold discharge Q_{thr} (at Lobith/Borgharen) at which the intervention (indirectly) starts to influence the flow pattern in the main channel. The threshold discharge is critical for determining the fraction of the year that the intervention influences the flow, and hence the duration over which the bed level difference (compared to the reference situation) can develop. As a result, this value is critical for determining the total volume of sedimentation (or erosion) that can be expected after one year. Therefore, it is important to clearly specify how this threshold value has been determined.

2 Determine, given the branch/reach on which the intervention is location, which D-Flow FM simulations should be carried out[2]. The D-FAST MI GUI will provide you that list after selecting the appropriate branch/reach. For the Dutch rivers these values are given by the following table

river	location	flow conditions
Rhine branches	Lobith	steady state 1300, 2000, 3000, 4000, 6000, 8000 $m^3\,s^{-1}$
Meuse	Borgharen	*details to be confirmed*

These flow conditions have been pre-configured for the latest D-Flow FM schematizations of these rivers[3]. It is not necessary to run simulations for conditions at which the intervention doesn't influence the flow patterns (i.e. discharges associated with stagnant conditions due to closure of barriers, and discharges below the intervention specific Q_{thr}). At this stage, D-FAST MI already reports the impacted length ('aanzandingslengte'), which is the distance over which a bed level change can built up during the period that the discharge of the river is above the threshold discharge. D-FAST MI is not suitable for interventions that only (start to) have a noticeable effect at (or above) the highest discharge.

3 Perform for each condition the hydrodynamic simulations for both the reference situation and the situation with intervention. Verify that

- ◇ the D-Flow FM results are stable
- ◇ the intervention is properly represented on the mesh used (check a.o. proper alignment of groynes and levees, channel shape and bed roughness)

[1] The reaches are specified in the GUI both by a descriptive name and by an approximate indication of the river chainage. Follow item 4 of section 3.2 if an intervention is located across or near a branch/reach boundary.

[2] Note that in WAQMORF and D-FAST MI version 2, the discharges depended on the characteristics of the intervention. That is no longer the case. The flow conditions are now fixed per river branch/reach. Only the threshold discharge is relevant as this is the lowest discharge at which the intervention has any effect, and hence discharges below that value can be skipped.

[3] The rationale behind the selection of these flow conditions and the associated bed celerity values is given in Appendix C.

- ◇ all simulations use the same base mesh (changes in dry areas may result in slight differences in the mesh effectively used)
- ◇ there is a visible difference in the velocities in the main channel between the simulations with and without intervention

See section 5.1 for recommendations regarding steady-state results.

4 Run D-FAST Morphological Impact to compute for each grid point in the main channel, the following three variables

- ◇ year-averaged bed level change [m] without dredging
- ◇ maximum bed level change [m] without dredging
- ◇ minimum bed level change [m] without dredging

once the (dynamic) equilibrium is reached. The year-averaged value is the main value for further analysis. The minimum and maximum values indicate the variability of the bed level during an average year; this may provide critical insight for the stability of structures, such as groynes. Note these values represent the morphological impact of the static intervention as defined in the D-Flow FM schematisation when a (dynamic) equilibrium bed level is finally reached and maintenance dredging/dumping volumes are not adjusted to compensate. Depending on the size of the impact and the morphological activity of the system, the new equilibrium may be reached quickly or very slowly over many years or decades.

5 The computational results are provided in <dfastmi_results.nc> in the specified output folder and can be used to visualize the characteristic bed level changes in a graph and/or on a map. Use patches with clearly defined colour scales for the overview. Clip small bed level changes, e.g. less than 5 mm. Create zoomed plots as appropriate with more detailed information, such as numeric values and isolines. Add relevant information such as river chainage, navigation lane, and groynes/normal lines.

6 Estimate the yearly amount of dredging needed to counteract any sedimentation. The first-year sedimentation volume is an estimate for the yearly amount of dredging needed to counteract any sedimentation as indicated in section 4.5. Since, if that volume is dredged after the first year, the river bed will be effectively reset to the initial condition, and the cycle will repeat. For this estimate the user needs to accumulate the equilibrium bed level change (sedimentation) over the distance indicated by the impacted length starting from the upstream side of the impacted area. If there are disjunct sedimentation areas, the accumulation should be carried out for each of the areas individually. If areas are shorter than the impacted length, then the total equilibrium impact can be reached within one year.

5.1 How to get steady-state results?

The dynamic solver of D-Flow FM is used to obtain steady-state results by providing a constant forcing over a suitably long simulation period. However, even with a constant forcing some fluctuations may remain in the computed flow fields, e.g. due to natural formation and shedding of eddies, and sensitivity of numerical formulations related to for instance drying-flooding. Therefore, it is preferred to use, for steady-state conditions, the mean flow conditions over a certain period to suppress any instabilities and fluctuations in the instantaneous flow conditions. These results can be obtained by using the Fourier option of D-Flow FM. For this purpose, a standardized Fourier input file <fourier_last_s.fou> is included that contains the following configuration:

```
* This Fourier file is prepared for computing statistics for river modelling
* For stationary computations
*
* In the MDU file the following keywords are advised:
* FouUpdateStep = 2   # Fourier-timestep equal to HIS-output-timestep
* HisInterval = 300.  # Every 5 minutes HIS-output
```

```
*
* The following parameters will be output:
* - wl: last water level(from average over last 25 steps = 2 hours)
* - uc: velocity magnitude (from average over last 25 steps = 2 hours)
* - ux: velocity in x-direction (from average over last 25 steps = 2 hours)
* - uy: velocity in y-direction (from average over last 25 steps = 2 hours)
* - q1: discharge through flow links (from average over last 25 steps = 2 hours)
*
*
*var  tstart  tstop  tsteps  knfac  v0plu  layno  param
 wl     -1      -1     25      1.     0.           last
 uc     -1      -1     25      1.     0.     1     last
 ux     -1      -1     25      1.     0.     1     last
 uy     -1      -1     25      1.     0.     1     last
 q1     -1      -1     25      1.     0.     1     last
```

6 Examples

This chapter describes some examples of the D-FAST MI analysis. The first two examples are taken from Giri and Jagers (2022). That report tested a pilot implementation of D-FAST MI version 3 and used a number of slightly different hydrographs; the examples presented here use the final configuration as included in the D-FAST MI distribution. The input files of the examples are included in the <examples> folder of the D-FAST MI distribution.

6.1 Example 1: secondary channel along the Nederrijn

The input files of this case are included in the distribution under <examples/01 - Palmerswaard>.

For this first example, we compare the results of D-FAST Morphological Impact with the results of a morphological simulation using Delft3D-FLOW. For consistency the D-FAST Morphological Impact analysis was performed using the hydrodynamic results of Delft3D-FLOW[1].

For this analysis, the Nederrijn grid of the DVR model has been used. The intervention concerns a secondary channel planned in the Palmerswaard which is located at Rkm 910-912 in the reach upstream of the Amerongen barrier at Rkm 922. The reference model is based on the Baseline schematization ‘rijn-beno18_5-v1’. Since the DVR model was too coarse to represent the actual secondary channel, a combination of flow extraction (at Rkm 910.5) and insertion (at Rkm 912) was used to represent the side channel.

Since the intervention is located on the Rhine branches, the new D-FAST Morphological Impact method requires the input of simulation results for 6 steady discharges: 1300, 2000, 3000, 4000, 6000, and 8000 $m^3 s^{-1}$ at Lobith. However, since the intervention is located in the backwater curve of the Amerongen barrier which is closed at discharges below 1500 $m^3 s^{-1}$ causing largely stagnant flow conditions, the lowest discharge isn’t relevant for this case. Hence, D-FAST MI asks for the results of 10 simulations (5 discharges with and without intervention), see Figure 6.2. After specifying all input files, the dialog will look like Figure 6.3 and if you save the configuration, the file will look as follows:

```
[General]
  Version           = 3.0
  CaseDescription   = Example 1: Palmerswaard
  Branch            = Pannerdensch Kanaal & Nederrijn-Lek
  Reach             = Nederrijn stuwpand Amerongen km  892-922
  Qthreshold        = 1500.0
```

[1] Since D-FAST Morphological Impact expects D-Flow FM results in netCDF UGRID format, the results were converted to the appropriate file format by means of `sim2ugrid`, see Appendix B.

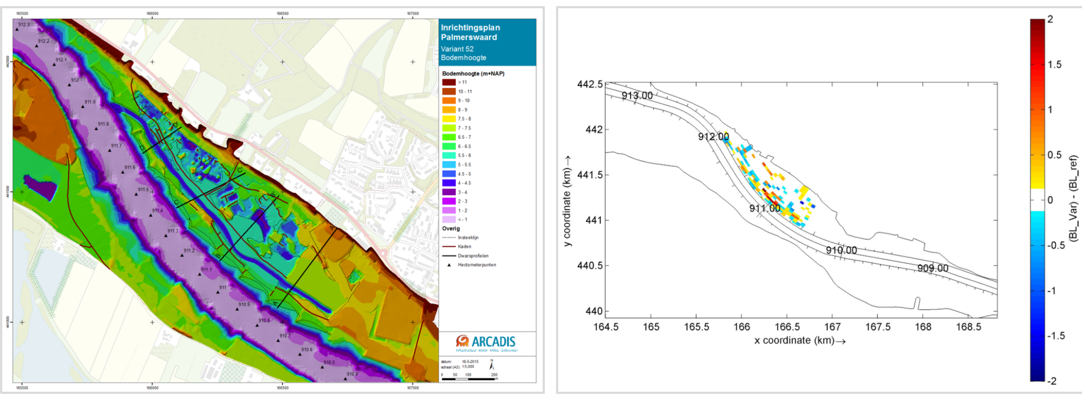

Figure 6.1: *Side channel design (left) and initial representation on the grid (right).*

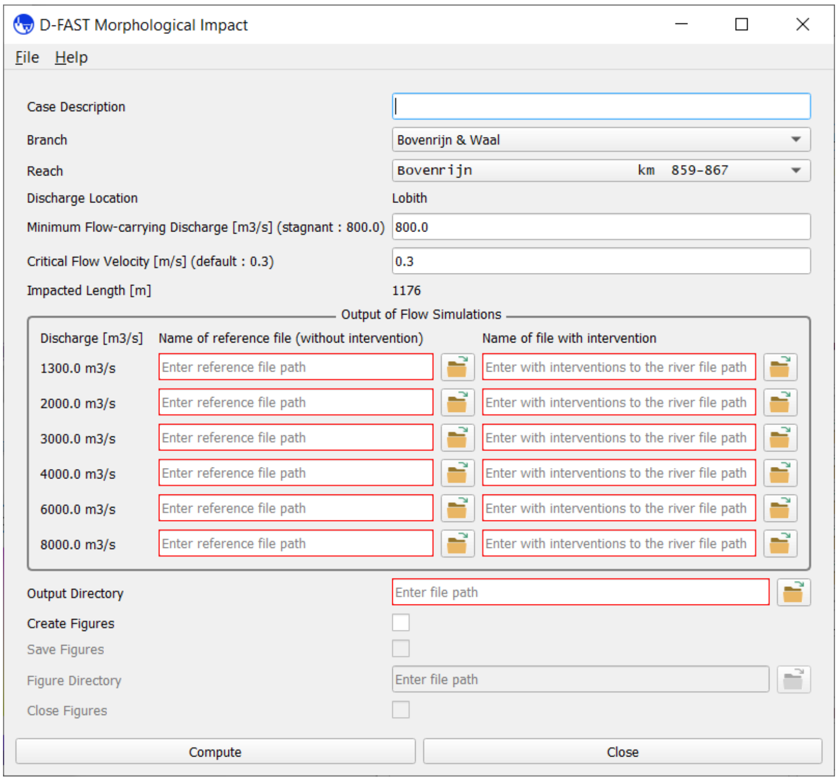

Figure 6.2: *Initial D-FAST MI screen after selecting the appropriate branch and reach.*

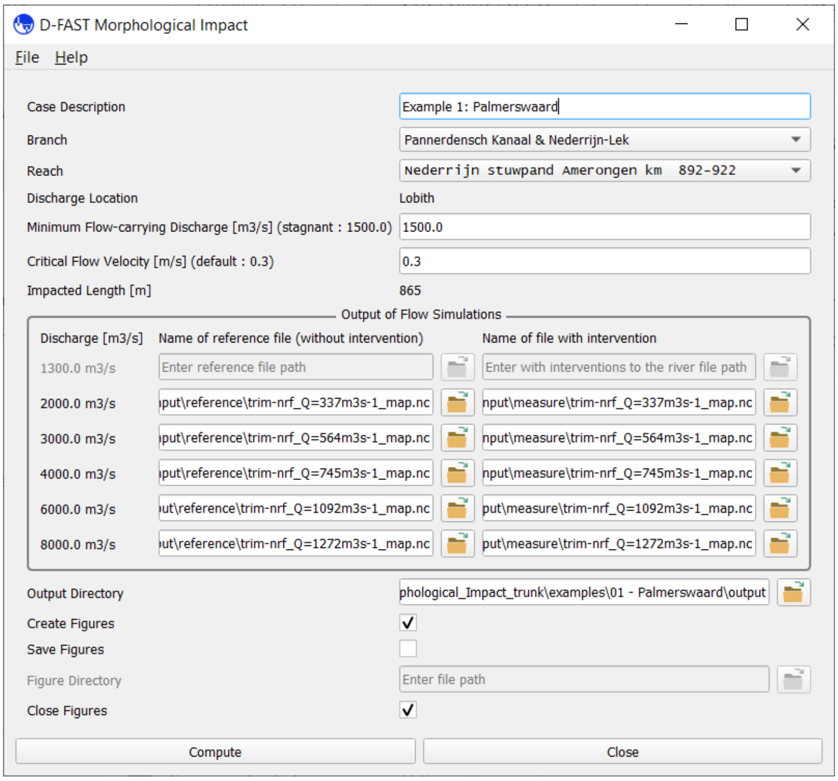

Figure 6.3: *D-FAST MI screen after specifying all files.*

```
  Ucrit            = 0.3
  OutputDir        = output
  Plotting         = True
  SavePlots        = False
  FigureDir        =
  ClosePlots       = True
  RiverKM          =

[C2]
  Discharge        = 2000.0
  Reference        = input\reference\trim-nrf_Q=337m3s-1_map.nc
  WithIntervention = input\measure\trim-nrf_Q=337m3s-1_map.nc

[C3]
  Discharge        = 3000.0
  Reference        = input\reference\trim-nrf_Q=564m3s-1_map.nc
  WithIntervention = input\measure\trim-nrf_Q=564m3s-1_map.nc

[C4]
  Discharge        = 4000.0
  Reference        = input\reference\trim-nrf_Q=745m3s-1_map.nc
  WithIntervention = input\measure\trim-nrf_Q=745m3s-1_map.nc

[C5]
  Discharge        = 6000.0
  Reference        = input\reference\trim-nrf_Q=1092m3s-1_map.nc
  WithIntervention = input\measure\trim-nrf_Q=1092m3s-1_map.nc

[C6]
  Discharge        = 8000.0
  Reference        = input\reference\trim-nrf_Q=1272m3s-1_map.nc
  WithIntervention = input\measure\trim-nrf_Q=1272m3s-1_map.nc
```

The D-FAST MI analysis is performed when you click on the *Compute* button. The program will show a message that the analysis has successfully ended, and that a report.txt file has been written to the output folder. Furthermore, since we have selected the "Create Figures" option, it will create a rudimentary overview picture of the change in the year-averaged equilibrium bed level that the result of the intervention. The initial view will cover the whole model area as shown in Figure 6.4. You can zoom in on the area of interest as shown in Figure 6.5. See section 2.5 for navigating these figures. The content of the report file is shown below:

```
D-FAST Morphological Impact implements an algorithm to estimate the local
morphological effects of a local intervention (i.e. an adjustment to the
river). The conceptual framework was originally introduced in
    "RWS-WD memo WAQUA vuistregel (Sieben, 2010)"
but it has been extended and improved over the years. Check the user manual
for the details of the currently implemented algorithm.

It is based on an estimation of the equilibrium bed level changes in the
main channel that would occur eventually when river maintenance would not
be adjusted.

The effect is expressed as:

    year-averaged bed level change [m] without dredging
    maximum bed level change [m] without dredging
    minimum bed level change [m] without dredging

By means of these estimates bottlenecks can be identified. The results are
not suitable for direct estimation of the impact on the maintenance of the
navigation channel!

The combination of the total equilibrium sedimentation volume and the
yearly sediment load of the river determines the period over which the
equilibrium can be reached.

This is version 3.0.0.


In order to use D-FAST Morphological Impact you need to run reference and
scenario simulations on the same computational mesh.
```

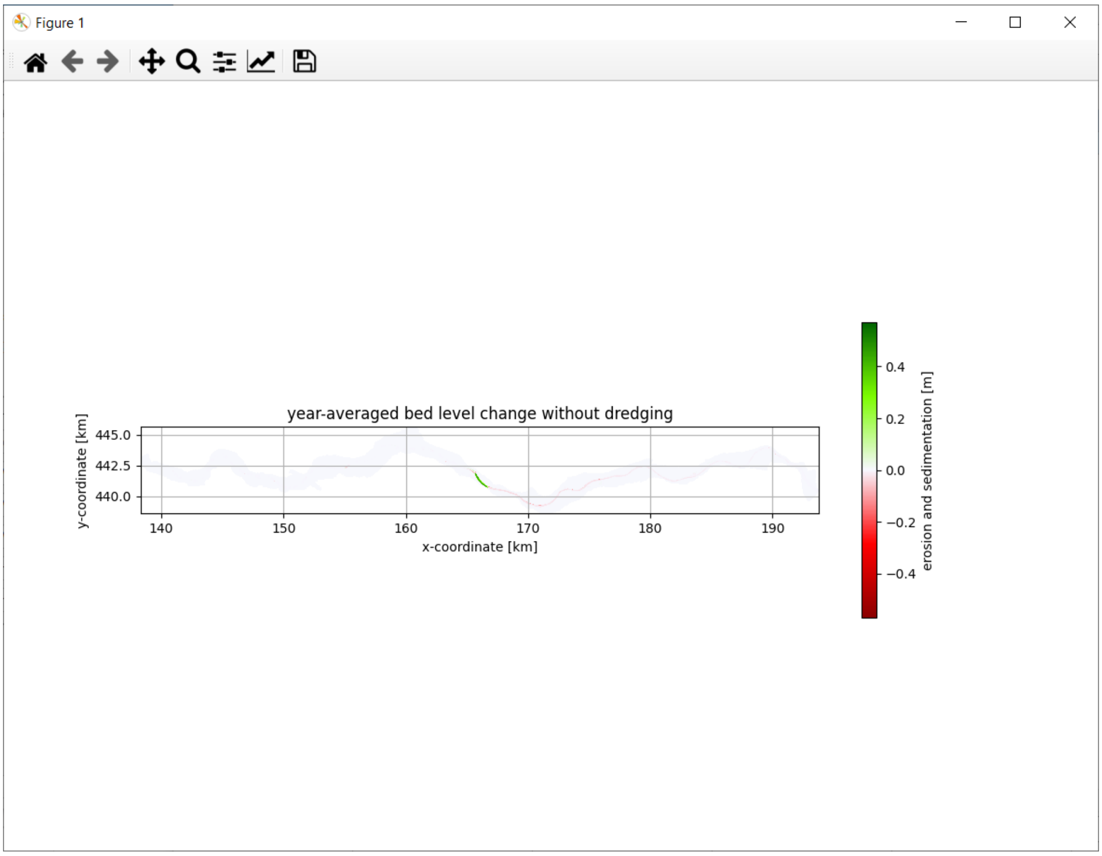

Figure 6.4: *Initial view of the analysis results.*

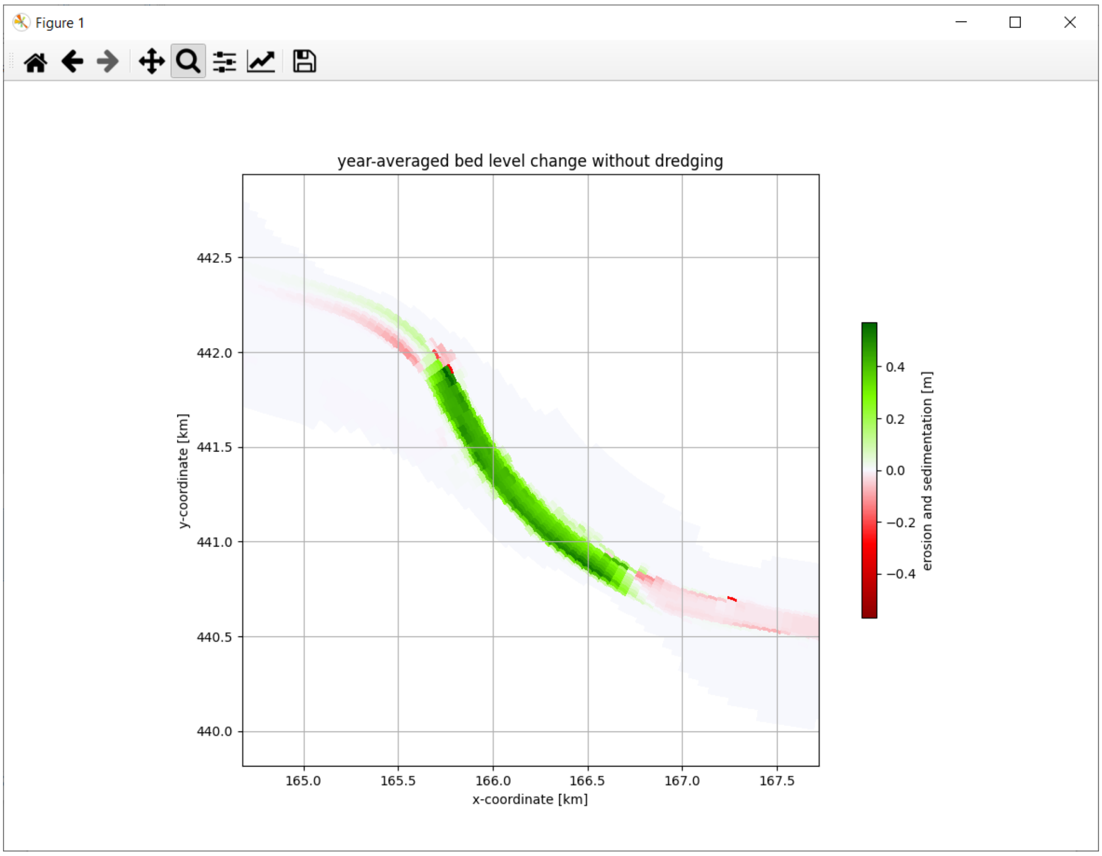

Figure 6.5: *Zoomed view of the analysis results.*

```
================================================================================

Configuration settings used for computation:

Case description                    : Example 1: Palmerswaard
Branch                              : Pannerdensch Kanaal & Nederrijn-Lek
Reach                               : Nederrijn stuwpand Amerongen km  892-922
Discharge location                  : Lobith
Minimum flow-carrying discharge     : 1500.0 m3/s
Impacted length                     : 865 m

Critical flow velocity              : 0.3 m/s

Condition               | Reference file (without intervention)   | File with intervention
 1300.0 m3/s            | ---                                     | ---
 2000.0 m3/s            | trim-nrf_Q=337m3s-1_map.nc              | trim-nrf_Q=337m3s-1_map.nc
 3000.0 m3/s            | trim-nrf_Q=564m3s-1_map.nc              | trim-nrf_Q=564m3s-1_map.nc
 4000.0 m3/s            | trim-nrf_Q=745m3s-1_map.nc              | trim-nrf_Q=745m3s-1_map.nc
 6000.0 m3/s            | trim-nrf_Q=1092m3s-1_map.nc             | trim-nrf_Q=1092m3s-1_map.nc
 8000.0 m3/s            | trim-nrf_Q=1272m3s-1_map.nc             | trim-nrf_Q=1272m3s-1_map.nc

================================================================================

The result of this program is one netCDF file named:

    dfastmi_results.nc

containing three variables containing the characteristic bed level changes:

    avgdzb: year-averaged change [m] without dredging
    maxdzb: maximum change [m] after flood without dredging
    mindzb: minimum change [m] after low flow without dredging

If the bed level changes are removed on a yearly basis, the impacted river reach
is estimated at 865 m from the upstream edge of the impacted reach.

The program has ended !!!
```

Figure 6.6 shows the results side by side of a reference morphology simulation using Delft3D 4 (for details, see Giri and Jagers (2022)) and the D-FAST MI version 3 analysis. The overall D-FAST MI results compare well with the long term (12 yr) Delft3D simulation although the asymmetry downstream of the main sedimentation patch differs.

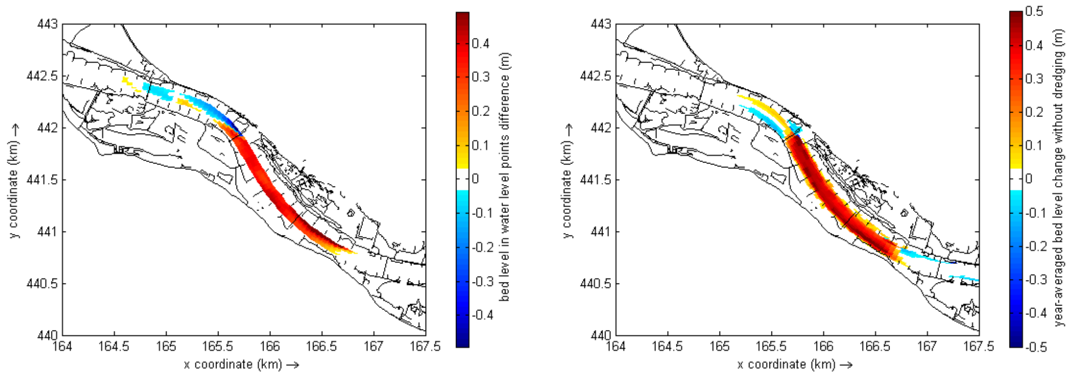

Figure 6.6: *Long-term morphological impact as obtained from a 12 year morphological simulation (left) and as obtained from D-FAST MI version 3 (right). Visualized using QUICKPLOT.*

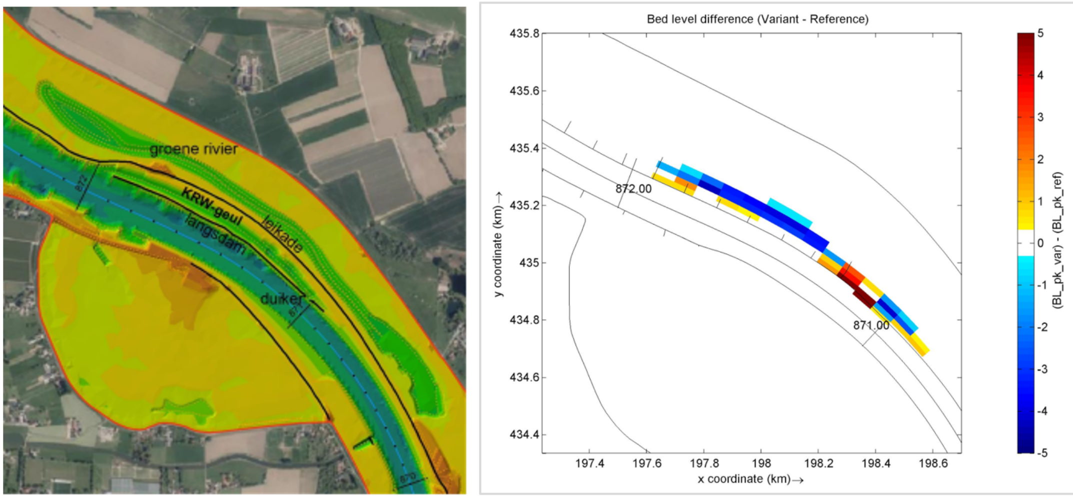

Figure 6.7: *Side channel design (left) and initial representation on the grid (right).*

6.2 Example 2: secondary channel along the Pannerdensch Kanaal

The input files of this case are included in the distribution under <examples/02 - Pannerdensch Kanaal>.

For this second example, we follow the same approach as example 1: we compare the results of D-FAST Morphological Impact with the results of a morphological simulation using Delft3D-FLOW. The model was based on the DVR model, but the domain was reduced to focus mainly on the Pannerdensch Kanaal (Bom and Van Leeuwen, 2020). Because of the two bifurcations upstream and downstream, it still included parts of all the branches (Bovenrijn, Pannerdensch Kanaal, Waal, Nederrijn and IJssel). Only results for the Pannerdensch Kanaal will be presented here.

The intervention concerns a secondary channel 'green river' implemented along the right bank at Rkm 871-872 just downstream of Pannerden. The reference model is based on the Baseline schematization 'rijn-beno18_5-v1'. Again, a combination of flow extraction and insertion was used to represent the side channel because the secondary channel wasn't represented accurately on the grid.

Since the intervention is located on the Rhine branches, the new D-FAST Morphological Impact method requires the input of simulation results for 6 steady discharges: 1300, 2000, 3000, 4000, 6000, and 8000 $m^3 s^{-1}$ at Lobith. Contrary to example 1, the lowest discharge is relevant for this case. Hence, D-FAST MI asks for the results of 12 simulations (6 discharges with and without intervention). After specifying all input files, the dialog will look like Figure 6.8 and if you save the configuration, the file will look as follows:

```
[General]
  Version            = 3.0
  CaseDescription    = Example 2: Pannerdensch Kanaal
  Branch             = Pannerdensch Kanaal & Nederrijn-Lek
  Reach              = Pannerdensch Kanaal          km  868-879
  Qthreshold         = 800.0
  Ucrit              = 0.3
  OutputDir          = output
  Plotting           = True
  SavePlots          = False
  FigureDir          =
  ClosePlots         = True
  RiverKM            =
```

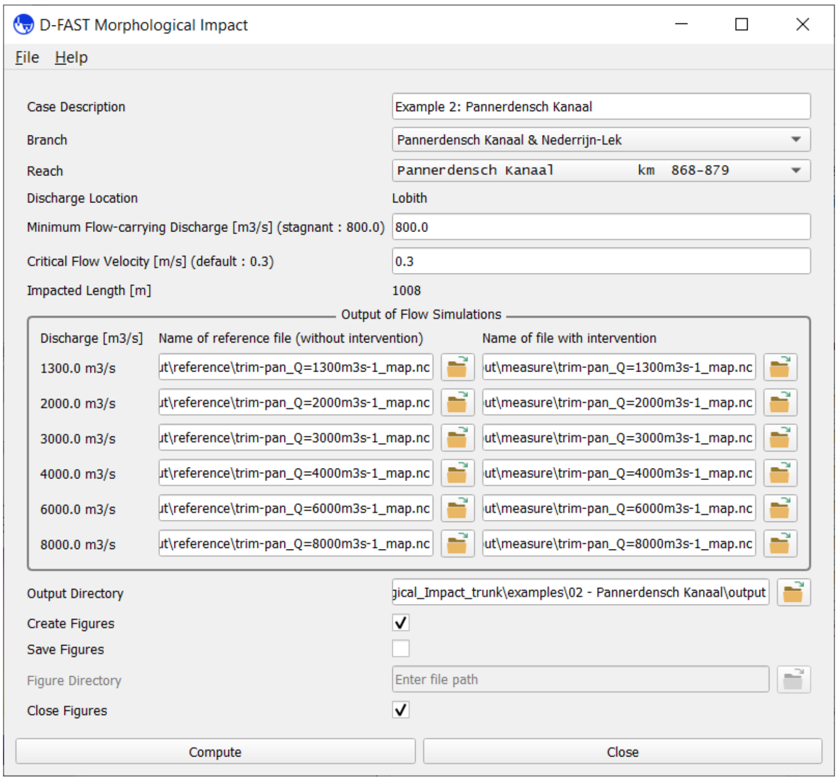

Figure 6.8: *D-FAST MI screen after specifying all files.*

```
[C1]
  Discharge        = 1300.0
  Reference        = input\reference\trim-pan_Q=1300m3s-1_map.nc
  WithIntervention = input\measure\trim-pan_Q=1300m3s-1_map.nc

[C2]
  Discharge        = 2000.0
  Reference        = input\reference\trim-pan_Q=2000m3s-1_map.nc
  WithIntervention = input\measure\trim-pan_Q=2000m3s-1_map.nc

[C3]
  Discharge        = 3000.0
  Reference        = input\reference\trim-pan_Q=3000m3s-1_map.nc
  WithIntervention = input\measure\trim-pan_Q=3000m3s-1_map.nc

[C4]
  Discharge        = 4000.0
  Reference        = input\reference\trim-pan_Q=4000m3s-1_map.nc
  WithIntervention = input\measure\trim-pan_Q=4000m3s-1_map.nc

[C5]
  Discharge        = 6000.0
  Reference        = input\reference\trim-pan_Q=6000m3s-1_map.nc
  WithIntervention = input\measure\trim-pan_Q=6000m3s-1_map.nc

[C6]
  Discharge        = 8000.0
  Reference        = input\reference\trim-pan_Q=8000m3s-1_map.nc
  WithIntervention = input\measure\trim-pan_Q=8000m3s-1_map.nc
```

The D-FAST MI analysis is performed when you click on the *Compute* button. The program will show a message that the analysis has successfully ended, and that a report.txt file has been written to the output folder. Furthermore, since we have selected the "Create Figures" option, it will create a rudimentary overview picture of the change in the year-averaged equilibrium bed level that the result of the intervention. A zoomed-in version of that figure is shown in Figure 6.9. See section 2.5 for navigating these figures. The content of the report file is

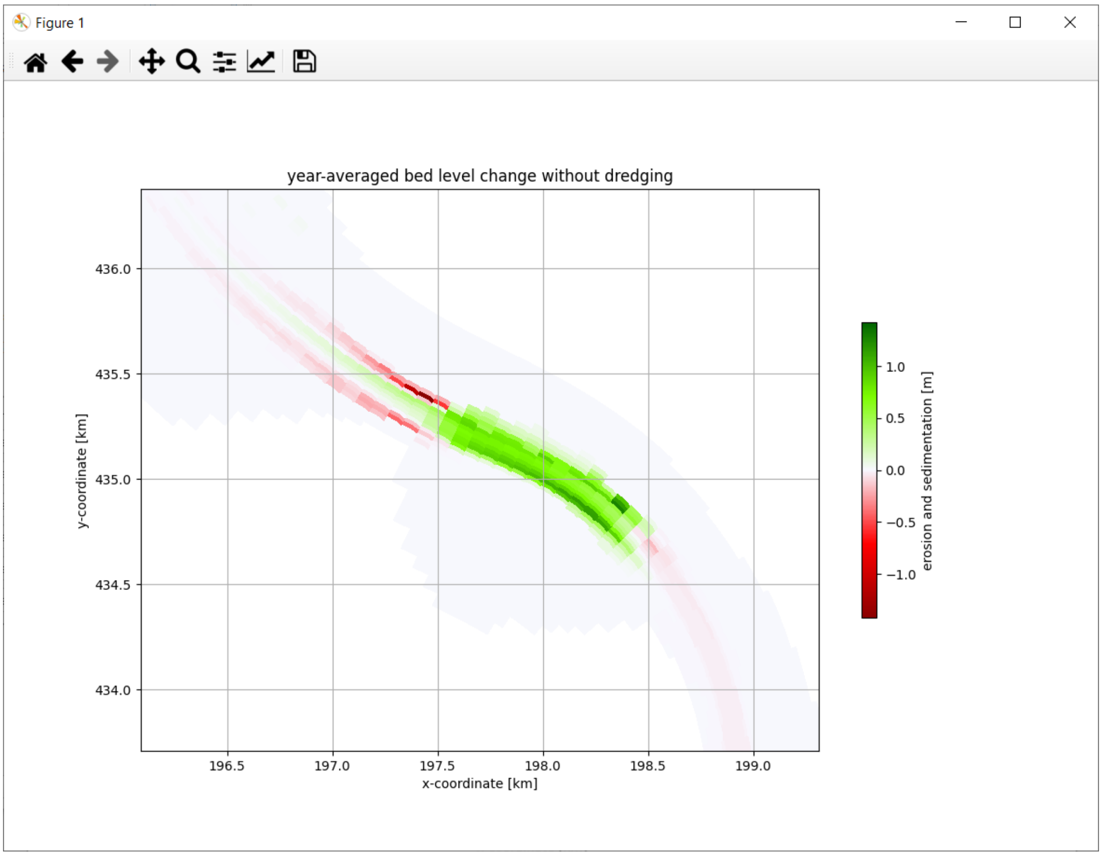

Figure 6.9: *Zoomed view of the analysis results.*

shown below:

```
D-FAST Morphological Impact implements an algorithm to estimate the local
morphological effects of a local intervention (i.e. an adjustment to the
river). The conceptual framework was originally introduced in
    "RWS-WD memo WAQUA vuistregel (Sieben, 2010)"
but it has been extended and improved over the years. Check the user manual
for the details of the currently implemented algorithm.

It is based on an estimation of the equilibrium bed level changes in the
main channel that would occur eventually when river maintenance would not
be adjusted.

The effect is expressed as:

    year-averaged bed level change [m] without dredging
    maximum bed level change [m] without dredging
    minimum bed level change [m] without dredging

By means of these estimates bottlenecks can be identified. The results are
not suitable for direct estimation of the impact on the maintenance of the
navigation channel!

The combination of the total equilibrium sedimentation volume and the
yearly sediment load of the river determines the period over which the
equilibrium can be reached.

This is version 3.0.0.


In order to use D-FAST Morphological Impact you need to run reference and
scenario simulations on the same computational mesh.


================================================================================
```

```
Configuration settings used for computation:

Case description                    : Example 2: Pannerdensch Kanaal
Branch                              : Pannerdensch Kanaal & Nederrijn-Lek
Reach                               : Pannerdensch Kanaal          km  868-879
Discharge location                  : Lobith
Minimum flow-carrying discharge     : 800.0 m3/s
Impacted length                     : 1008 m

Critical flow velocity              : 0.3 m/s

Condition                | Reference file (without intervention)  | File with intervention
 1300.0 m3/s             | trim-pan_Q=1300m3s-1_map.nc            | trim-pan_Q=1300m3s-1_map.nc
 2000.0 m3/s             | trim-pan_Q=2000m3s-1_map.nc            | trim-pan_Q=2000m3s-1_map.nc
 3000.0 m3/s             | trim-pan_Q=3000m3s-1_map.nc            | trim-pan_Q=3000m3s-1_map.nc
 4000.0 m3/s             | trim-pan_Q=4000m3s-1_map.nc            | trim-pan_Q=4000m3s-1_map.nc
 6000.0 m3/s             | trim-pan_Q=6000m3s-1_map.nc            | trim-pan_Q=6000m3s-1_map.nc
 8000.0 m3/s             | trim-pan_Q=8000m3s-1_map.nc            | trim-pan_Q=8000m3s-1_map.nc

================================================================================

The result of this program is one netCDF file named:

    dfastmi_results.nc

containing three variables containing the characteristic bed level changes:

    avgdzb: year-averaged change [m] without dredging
    maxdzb: maximum change [m] after flood without dredging
    mindzb: minimum change [m] after low flow without dredging

If the bed level changes are removed on a yearly basis, the impacted river reach
is estimated at 1008 m from the upstream edge of the impacted reach.

The program has ended !!!
```

Figure 6.10 shows the results side by side of a reference morphology simulation using Delft3D 4 (for details, see Giri and Jagers (2022)) and the D-FAST MI version 3 analysis. The overall D-FAST MI results compare well with the long term (15 yr) Delft3D simulation although D-FAST MI suggests sedimentation in the centre of the channel downstream of the main sedimentation area whereas the morphological simulation doesn't show that behaviour.

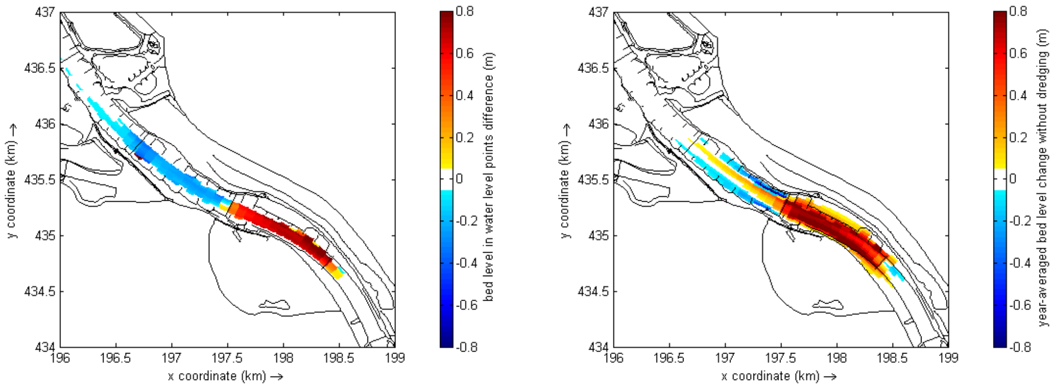

Figure 6.10: *Long-term morphological impact as obtained from a 12 year morphological simulation (left) and as obtained from D-FAST MI version 3 (right). Visualized using QUICKPLOT.*

References

Bom, S. and B. van Leeuwen, 2020. *Rivierkundig Onderzoek Krib- en Oeververlaging Pannerdensch Kanaal: Op basis van Definitief Ontwerp (DO).* Tech. Rep. 1996/U20111/F/BvL, Svašek Hydraulics, The Netherlands. In Dutch.

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Paarlberg, A., 2009. *Verificatie WAQmorf: Vergelijking resultaten WAQmorf en Delft2D en advies gebruik vuistregel*. Tech. Rep. PR1720.10, HKV Lijn in water. In Dutch.

Sieben, A., 2010. *Methodiek inschatting morfologische effecten in het zomerbed door lokale rivieringrepen*. Memo, Waterdienst, Rijkswaterstaat, The Netherlands. In Dutch.

A File formats

The software distinguishes 6 files:

- ◇ The *rivers configuration file* defines the branches and reaches, and all parameter settings specific for the overall system, per branch or per reach.
- ◇ The *dialog text file* defines all strings to be used in the interaction with the users (GUI, report, or error messages).
- ◇ The *analysis configuration file* defines the settings that are relevant for a specific execution of the algorithm, i.e. for a specific branch, reach and intervention.
- ◇ The *simulation result files* define the spatial variations in the velocities and water depths as needed by the algorithm.
- ◇ The *report file* contains a logging of the settings and lumped results for the analysis.
- ◇ The *spatial output file* contains the estimate of the spatial variation in the sedimentation and erosion patterns that will result from the intervention (minimum, mean and maximum).

Each file type is addressed separately in the following subsections.

A.1 Rivers configuration file

The rivers configuration file follows the common ini-file format. The file must contain a `[General]` block with a keyword `Version` to indicate the version number of the file. The version number should be `3.0`.[1]

Besides the `[General]` block version 3.0 files should only contain data blocks identifying the river branches (in Dutch: takken). The names of those blocks will be used as branch names. For instance, a block [My branch] will be processed as a branch called "My branch". The order of the branches in the gui will correspond to the order of the blocks in the file. The branch block defines the reaches (in Dutch: stukken) to be distinguished as well as the branch or reach specific parameter settings. The `[General]` block may contain default values for the various parameters. Further details follow below.

Table A.1: *Description of rivers configuration version 3*

Block	Keyword	Description
`General`	`Version`	Version number. Should be `3.0`.
`General`	`checksum`	Checksum of the rivers configuration file. Used to verify that the rivers configuration file wasn't accidentally modified.
BranchName<i>	`QLocation`	Location at which discharges for branch <i> are defined.
BranchName<i>	`Reach<j>`	Name of reach <j> within branch <i>.
`*`	`NWidth`	Normal width [m] of main channel.
`*`	`QStagnant`	Discharge [m^3/s] below which main channel flow can be assumed stagnant.
`*`	`UCrit`	Critical (minimum) velocity [m/s] for sediment transport.

(continued on next page)

[1] Initially this file version was named `2.0` but to avoid confusion with the fact that this file format is only supported by D-FAST Morphological Impact version 3.0, the version number has been increased. Files with version `2.0` are still accepted, but not recommended.

(continued from previous page)

Block	Keyword	Description
*	HydroQ	Series of discharges [$m^3\,s^{-1}$] representing each stage of the "hydrograph".
*	Tide	Flag to indicate whether the stages of the "hydrograph" are represented by discharge only (False) or by a combination of discharge and tide (True).
*	TideBC	Series of other tidal conditions representing the stages of the "hydrograph". Only used in case `Tide` equals True.
*	AutoTime	Flag to indicate whether the duration of each discharge period should automatically be derived from the exceedance curve given by `QFit`. The default value is False.
*	HydroT	Series of values specifying the duration of each stage of the "hydrograph". The unit used for specifying the durations is arbitrary: the sum of all durations is assumed to be equivalent to 1 year. The length of the series should be equal to the length of the series of discharges specified for `HydroQ`. Only used in case `AutoTime` equals False.
*	QFit	Two discharges [$m^3\,s^{-1}$] used for representing the exceedance curve in case `AutoTime` equals True.
*	CelerForm	Flag to indicate the method used for determining the bed celerity. The options are 1 (series of discharge, bed celerity pairs) and 2 (power-law relation between celerity and discharge). The default value is 2.
*	PropQ	Strictly-monotonous increasing list of discharges [$m^3\,s^{-1}$] for which the bed celerity is given. Only used in case `CelerForm` equals 1.
*	PropC	List of bed celerities [$km\,yr^{-1}$] one value for each discharge specified by `PropQ`. The length of the lists given by `PropQ` and `PropC` should be equal. Only used in case `CelerForm` equals 1.
*	CelerQ	Two values representing the multiplication scalar and exponent of the power-law relation of the bed celerity [$km\,yr^{-1}$] as function of the discharge [$m^3\,s^{-1}$]. Only used in case `CelerForm` equals 2.

All keywords listed for block * may occur either in the `[General]` block or in one of the branch specific blocks where they may optionally be concatenated with the reach number <j>. Those keywords may thus occur in three flavours:

1 Plain keyword in block `[General]`: global default value valid for all branches
2 Plain keyword in branch specific block: default value for that branch (overrules any global default)
3 Keyword followed by reach number <j> in branch specific block: value valid for that specific reach (on that branch).

Example

The following excerpt of the default `Dutch_rivers.ini` configuration file shows the `[General]` as well as the first part of the `[Bovenrijn & Waal]` block for the first branch. It includes a global value of 0.3 for `UCrit` and 100 for `QMin`. The other parameters are specified at branch level and mostly uniform for the whole branch. Only `NWidth` and `PRLow` vary depending on the reach selected.

```
[General]
    Version    = 3.0
    UCrit      = 0.3
    CelerForm  = 1
    checksum   = 2377805458

[Bovenrijn & Waal]
    QLocation  = Lobith
    HydroQ     = 1300 2000 3000 4000 6000 8000
    AutoTime   = True
    QStagnant  = 800
    QFit       = 800  1280

    Reach1     = Bovenrijn                    km  859-867
    NWidth1    = 340
    PropQ1     = 3500  3501
    PropC1     = 0.89  3.65

    Reach2     = Boven-Waal                   km  868-886
    NWidth2    = 260
    PropQ2     = 3500  3501
    PropC2     = 0.81  3.65

    ... continued ...
```

A.2 Dialog text file

The dialog text file uses the block labels enclosed by square brackets of the common ini-file format, but the lines in between the blocks are treated verbatim and don't list keyword/value pairs. Every print statement in the program is associated with a short descriptive identifier. These identifiers show up in the dialog text file as the block labels. The text that follows the block label will be used at that location in the program. The order of the blocks in the file is not important. Please note that every line is used as is, so don't add indentations or blank lines unless you want those to show up during the program execution. Most blocks may contain any number of lines, but some blocks may only contain a single line in particular block that start with `gui_` or `filename_`. Some data blocks may contain one or more named placeholders, e.g. `version`, used for inserting values by means of the Python `format()` method.

Example

The following excerpt of the default `messages.NL.cfg` dialog text file shows the string definition for 5 identifiers, namely " (the identifier for an empty line), 'header', 'confirm', 'confirm_or' and 'confirm_or_restart'. The header string contains one placeholder, namely `version` for the the version number.

```
[]

[reduce_output]
The option 'reduce_output' is active.

[header]
```

```
D-FAST Morphological Impact implements an algorithm to estimate the local
morphological effects of a local intervention (i.e. an adjustment to the
river). The conceptual framework was originally introduced in
    "RWS-WD memo WAQUA vuistregel (Sieben, 2010)"
but it has been extended and improved over the years. Check the user manual
for the details of the currently implemented algorithm.

It is based on an estimation of the equilibrium bed level changes in the
main channel that would occur eventually when river maintenance would not
be adjusted.

The effect is expressed as:

    year-averaged bed level change [m] without dredging
    maximum bed level change [m] without dredging
    minimum bed level change [m] without dredging

By means of these estimates bottlenecks can be identified. The results are
not suitable for direct estimation of the impact on the maintenance of the
navigation channel!

The combination of the total equilibrium sedimentation volume and the
yearly sediment load of the river determines the period over which the
equilibrium can be reached.

This is version {version}.

[confirm]
Confirm using "y" ...

[confirm_or]
Confirm using "y", or reply "n" ...

... continued ...
```

A.3 Analysis configuration file

The analysis configuration file follows the common ini-file format. The file must contain a `[General]` block with a keyword `Version` to indicate the version number of the file. The version number should be `3.0`.[2]

Version 3.0 files must contain in the `[General]` block also the keywords `Branch` and `Reach` to identify the branch (in Dutch: tak) and reach (in Dutch: stuk) in which the intervention is located. The specified names may be shortened, but they should uniquely identify the branch and reach amongst the names of the other branches and reaches. The same block may also contain `QThreshold` and `UCrit` values representative for this particular intervention if they differ from those typical for the selected reach. Furthermore, this block may contain `FigureDir` and `OutputDir` specifying where the figures and other output files should be written. The `RiverKM` keyword to specify the chainage along the reach of interest is needed for estimating the initial year dredging volumes. Last but not least, the user needs to specify the names of the D-Flow FM map- or fourier-files containing the results of the simulations without intervention (reference) and with intervention for the selected flow conditions. These names must be specified in a continuous sequences of numbered blocks named `C1`, `C2`, etc. The order of the blocks is not important: the relevant blocks are identified by means of the `Discharge` and optionally `TideBC` specified per block. There should be a match for every stage of the configured “hydrograph” for the selected branch/reach. The file names may be specified using relative or absolute paths.

[2] Initially this file version was named `2.0` but to avoid confusion with the fact that this file format is only supported by D-FAST Morphological Impact version 3.0, the version number has been increased. Files with version `2.0` are still accepted, but not recommended.

Block	Keyword	Description
General	Version	Version number. Should be 3.0.
General	CaseDescription	Description of the analysis.
General	Branch	Name of the selected branch.
General	Reach	Name of the selected reach.
General	QThreshold	Minimum discharge [$m^3\,s^{-1}$] at which intervention becomes active.
General	UCrit	Critical (minimum) velocity [$m\,s^{-1}$] for sediment transport.
General	RiverKM	Name of file with river chainage [km] and corresponding xy-coordinates.
General	FigureDir	Directory for storing figures (default relative to work dir: figure).
General	OutputDir	Directory for storing output files.
C<i>	Discharge	Discharge [m^3/s] of condition <i>.
C<i>	TideBC	Tidal boundary of condition <i>.
C<i>	Reference	Name of D-Flow FM map- or fourier-file to be used for reference condition <i>.
C<i>	WithIntervention	Name of D-Flow FM map- or fourier-file that includes the intervention <i>.

Example

This example shows a complete analysis configuration file for an intervention in the first branch/reach of the default Dutch_rivers.cfg configuration. It reports the default settings. Only the Version, Branch, Reach, Reference and WithIntervention keywords are required for the full analysis.

```
[General]
  Version          = 3.0
  CaseDescription  =
  Branch           = Bovenrijn & Waal
  Reach            = Boven-Waal                     km  868-886
  Qthreshold       = 1000.0
  Ucrit            = 0.3
  OutputDir        =
  Plotting         = False
  SavePlots        = False
  FigureDir        =
  ClosePlots       = False
  RiverKM          =

[C1]
  Discharge        = 1300.0
  Reference        = Case42/Q1/Reference/DFM_OUTPUT_Q1/Q1_map.nc
  WithIntervention = Case42/Q1/Updated/DFM_OUTPUT_Q1/Q1_map.nc

[C2]
  Discharge        = 2000.0
  Reference        = Case42/Q2/Reference/DFM_OUTPUT_Q2/Q2_map.nc
  WithIntervention = Case42/Q2/Updated/DFM_OUTPUT_Q2/Q2_map.nc

[C3]
  Discharge        = 3000.0
```

```
Reference        = Case42/Q3/Reference/DFM_OUTPUT_Q3/Q3_map.nc
WithIntervention = Case42/Q3/Updated/DFM_OUTPUT_Q3/Q3_map.nc

  ... continued ...
```

A.4 Simulation result files

D-FAST Morphological Impact expects all data in UGRID netCDF file similar to the map-file output of D-Flow FM. D-FAST Morphological Impact reads the results directly no conversion is necessary. These files may contain multiple time steps; the final time steps will be used for the analysis. The mesh geometry is transferred from one of the simulation files to the D-FAST Morphological Impact spatial output "results" file.

A.5 Report file

D-FAST Morphological Impact will write a report of the analysis. This report file is a simple text file consistent with the earlier reports written by WAQMORF. The length and content of the report vary depending on the availability of the simulation result files and the language selected.

A.6 Spatial output file

D-FAST Morphological Impact generates one UGRID netCDF file containing the spatial results of the analysis. The mesh information is copied from the first D-Flow FM map- or fourier-file read, and the three data fields (erosion and sedimentation patterns for mean, minimum, and maximum impact) follow standardized conventions for data stored at cell centres (`face`-values) on an unstructured mesh. As a result the data may be visualized using a number of visualization tools such as QUICKPLOT and QGIS.

B Interoperability

D-FAST Morphological Impact reads data from 2D UGRID/CF netCDF files such as written by D-Flow FM. Other software may also write their netCDF result following the general CF (Climate & Forecasting) and UGRID conventions. In the following sections we discuss to which degree D-FAST MI depends on D-Flow FM specific choices, and how to convert the output of other models to the format supported by D-FAST MI.

B.1 File format assumptions

Simulation files (both with and without interventions to the river) should contain *one* 2D UGRID mesh variable. These variables must be identifiable by means of the attributes `cf_role = mesh_topology` and `topology_dimension = 2`. The `face_node_connectivity` attribute of this variable must point to the face-node connectivity of the 2D mesh. The `node_coordinates` attribute must point to the x,y coordinates of the nodes; currently. For geospatial operations (research functionality) D-FAST MI assumes that the coordinates are projected coordinates in metres.

The file must contain one or more time steps for the following quantities:

◇ depth-averaged flow velocity vector defined on the faces of the mesh, identifiable by means of the CF standard names `sea_water_x_velocity` and `sea_water_y_velocity`, and attributes `mesh` pointing to the mesh variable and `location = face`.
◇ water depth defined on the faces of the mesh, identifiable by means of the CF standard name `sea_floor_depth_below_sea_surface`, and attributes `mesh` pointing to the mesh variable and `location = face`.

B.2 File conversion

The formal working order is to base the D-FAST Morphological Impact analysis on the results of D-Flow FM simulations. However, sometimes it may be useful to use results obtained from other hydrodynamic models, such as Delft3D-FLOW or WAQUA (SIMONA). This pathway has in particular been used to validate the D-FAST MI analysis using Delft3D flow results against Delft3D morphological simulations using the same model configuration. For this purpose, a tool `sim2ugrid` has been made that converts Delft3D-FLOW (trim-files) or WAQUA results (SDS-files) to 2D UGRID/CF netCDF files accepted by D-FAST MI. This tool has been implemented in MATLAB and is distributed as binary alongside Delft3D-QUICKPLOT. It is a command-line tool that accepts one or more simulation result files (trim or SDS) and one argument that indicates the number of time steps (of flow velocity and water depth) to transfer to the netCDF file. The name of the netCDF file is based on the name of the first result file specified; if that file already exists, it will be overwritten without asking for confirmation. The default setting is to transfer only the last time step. This can be extended to the last N time steps by specifying the N on the command-line. If you want to transfer *all* time steps, you can specify a colon `:`.

```
Usage:
   SIM2UGRID <inputFile> {<inputFile>} {N}
   Transfers the data from the input files to a new netCDF file with the name
   <basename>_map.nc where <basename>.<ext> is the name of the first input file.
   The data of the last N time steps is transferred (N=1 by default).
```

Note that the tool is a bit slow to start as it needs to load the MATLAB runtime environment and doesn't use a splash screen like QUICKPLOT does. A typical listing of the screen output of the `sim2ugrid` reads as follows:

```
[Your folder]> sim2ugrid.exe trim-nrf.dat
--------------------------------------------------------------------------------
SIM2UGRID conversion tool.
Version 2.70.8271afff4 (64bit) (10-Sep-2023 13:13:09)
Repository https://git.deltares.nl/oss/delft3d.git
Source hash 8271afff46535b79e80a4f77adbdcc071fbcb671
--------------------------------------------------------------------------------
Opening trim-nrf.dat ...
Processing the time-independent data ...
Warning: No Chezy information found. Converted file not suitable for D-FAST Bank Erosion.
> In sim2ugrid (line 101)
Warning: Bed levels defined at faces. Converted file not suitable for D-FAST Bank Erosion.
> In sim2ugrid (line 109)
Checking available time steps ...
Creating trim-nrf_map.nc ...
Writing time-independent data ...
Transferring data for time step 5 ...
Data transfer completed successfully.
```

The warnings are only relevant for D-FAST Bank Erosion and shouldn't affect D-FAST Morphological Impact.

C Background information

The following pages reproduce a memo by Arjan Sieben on the choice of the representative flow conditions and bed celerities for the Rhine branches and the Meuse river.

Bepaling standaardset afvoeren DFAST-MI, d.d. 26-03-2024, Arjan Sieben, RWS-WVL

1 Aanleiding

Deze memo beschrijft kort hoe te komen tot een vaste set afvoeren voor het gebruik van DFAST-mi.

DFAST-mi is een hulpmiddel bij het bepalen van morfologische effecten. Het wordt ingezet voor een snelle schatting van effecten en volstaat als gebruik van DMOR-berekeningen niet nodig zijn. Het kan voorkomen dat een project zowel DFAST-mi als DMOR gebruikt. Om dat zo consistent mogelijk te kunnen doen is voor beiden het gebruik van vergelijkbare hydraulische simulaties efficiënt. Met andere woorden, in het ideale geval gebruiken DMOR en DFAST dezelfde afvoersituaties als basis voor analyse van morfologische effecten. Dat is op het moment van schrijven echter nog niet mogelijk; de DMOR modellen voor de Rijntakken zijn in ontwikkeling, een passende afvoerreeks is daarvan nog niet beschikbaar.

2 Welke afvoersituaties zijn nodig?

Met DFAST-MI is het mogelijk om de effectbepaling op een vaste, vooraf gespecificeerde set afvoersituaties te baseren. Bovendien kan deze set (via frequentie en volgorde van de afvoersituaties) toegepast worden in de vorm van scenario's met bijvoorbeeld overwegend "natte" , "droge" en "gemiddelde" jaren. Maar dit laatste is niet geverifieerd (en niet operationeel?).

Voor bepaling van morfologische effecten zijn de afvoersituaties nodig die de impact van ingrepen op de stroming weergeven

i) in alle afvoerregimes van de Rijn of Maas met mobiel bodemsediment
ii) op een schaal die past bij de ingreep

Het eerste is een systeemeigenschap en dat leidt tot onderscheid in karakteristieke regimes. Het tweede volgt uit de aard en maatvoering van de ingrepen die worden verwacht en leidt tot het *aantal afvoersituaties waarmee elk karakteristiek regime wordt beschreven*.

Om alle eventuele ingrepen te ondervangen die voor toekomstige toepassing denkbaar zijn, is een groot aantal afvoersituaties nodig en dat betekent in veel gevallen onnodig rekenwerk. Om dat te voorkomen is een pragmatische afweging nodig. Een voorbeeld daarvoor zijn de Delft3D morfologie modellen voor de Rijntakken, die een vaste afvoerreeks gebruiken. Deze reeks is weergegeven in Tabel 1 met een aanvulling voor de Maas ter indicatie.

Boven-Rijnafvoer [m^3/s] Delft3D	Kans van onderschrijden 1990-2020	Boven-Maas afvoer [m^3/s]
1203	0.113	38
1635	0.349	83
2250	0.674	225
3053	0.853	467
3824	0.921	663
4717	0.964	884
6151	0.9876	1236
8592	0.9985	2224

Tabel 1 Afvoeren Delft3D model Rijntakken met equivalente reeks voor de Maas.

3 Onderscheid in afvoerregimes

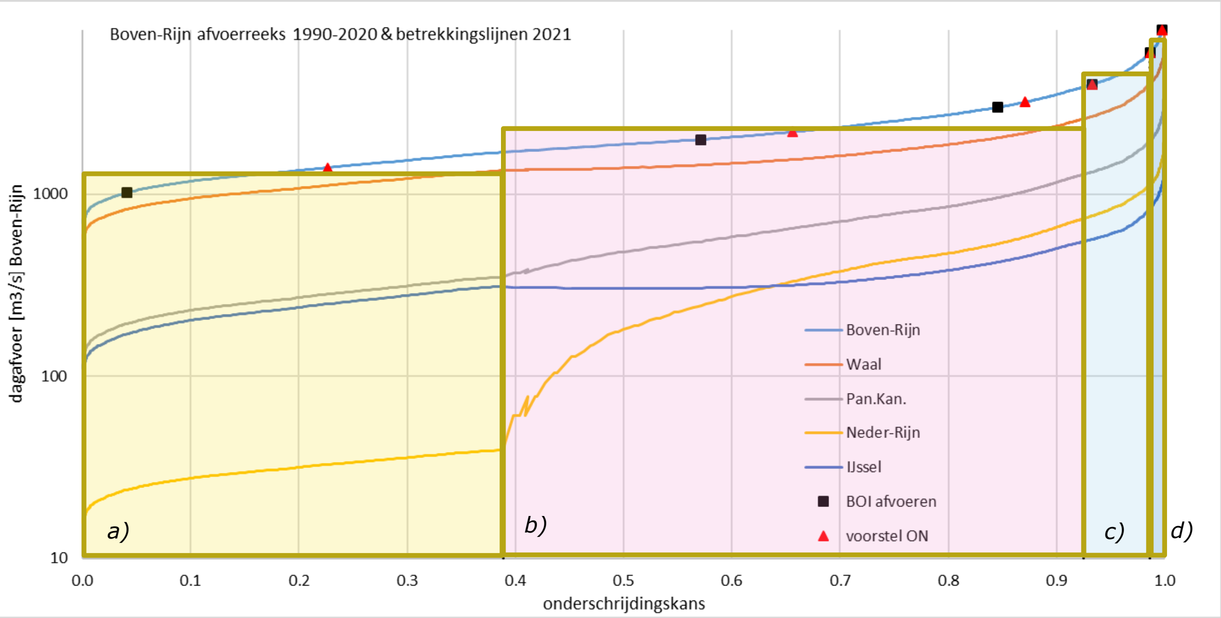
Een eerste stap voor het bepalen van de afvoersituaties is het onderscheid in regimes. In de Maas en Rijntakken worden met toenemende rivierafvoer drie afvoerregimes onderkend; 1) stuwen vrijwel gesloten (afgezien lekdebiet etc); 2) overgang van gestuwd naar vrij-afstromend en 3) vrij-afstromend zonder invloed van stuwen. De invloed daarvan varieert uiteraard per traject. Behalve de stuwen is er de invloed van de normalisatie op het stroombeeld. Dat levert met toenemende rivierafvoer grofweg drie stroombeeld-situaties i) alleen zomerbed-vullend; ii) met ontwikkelende uiterwaardstroming en iii) met ontwikkelde uiterwaardstroming.

Omdat stuwen vooral gericht zijn op peilbeheer in het zomerbed, worden hier als vereenvoudiging gesteld dat beide regimes min of meer samenvallen in een vereenvoudigde indeling van Tabel 2. Omdat alle stuwen eigenlijk afzonderlijk worden bediend is deze generalisatie een sterke vereenvoudiging van de werkelijkheid.

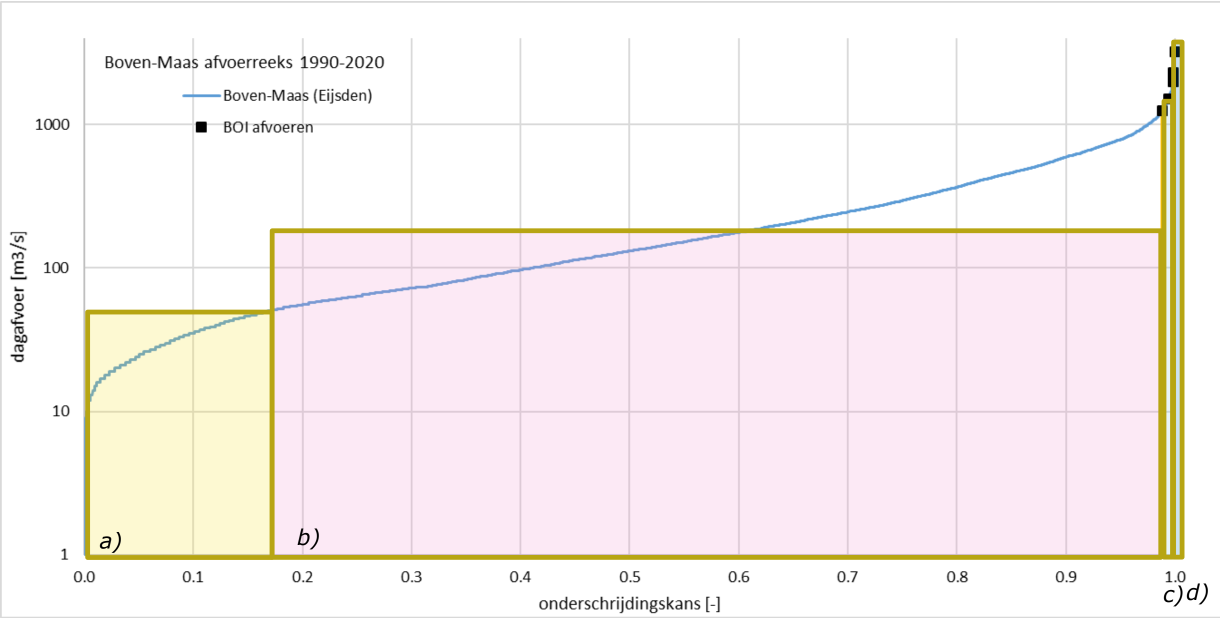
Regime	afvoer Boven-Maas [m³/s]	afvoer Boven-Rijn [m³/s]
a) alleen zomerbed gevuld, stuwen vrijwel gesloten	<50	<1700
b) alleen zomerbed gevuld, stuwen in overgang naar volledig open	50-1250	1700-3870
c) ontwikkelende uiterwaardstroming stuwen volledig geopend	1250-2300	3870-6000
d) ontwikkelde uiterwaardstroming stuwen volledig geopend	>2300	>6000

Tabel 2 Vereenvoudigde indeling afvoerregimes Rijn en Maas.

Er worden vier karakteristieke regimes onderscheiden. Een relatieve duur van elk regime kan voor de bijbehorende afvoerrange worden afgeleid uit een historische afvoerreeks zoals 1990-2020. Figuur 1 geeft de vier regimes voor Rijn en Maas weer, met behulp van de afvoeren uit 1990-2020. Dit illustreert dat de vier regimes in ongelijke mate optreden gedurende een jaar.



Figuur 1-a Karakteristieke afvoerregimes Rijntakken.



Figuur 1-b Karakteristieke afvoerregimes Maas.

DFAST-MI is een inschatting van de morfologische reactie op de invloed van een maatregel op stroomsnelheden in de hoofdgeul. In elk van de vier regimes kan sprake zijn van een invloed op de hydraulica. Dat betekent dat in elk van de vier regimes tenminste één afvoersituatie moet worden beschouwd, tenzij stroomsnelheden zo laag zijn (minder dan 0.3 m/s) dat nauwelijks sprake is van morfodynamiek.

4 Minimaal aantal karakteristieke afvoersituaties per regime

In deze sectie worden de afvoersituaties bepaald die relevant zijn voor effectbepaling, indien de hydraulische impact van de ingreep voor alle rivierafvoeren binnen een regime niet zou veranderen. Dat levert een minimum aantal afvoersituaties per regime op.

De grootte van de morfologische reactie is min of meer evenredig met de grootte en duur van de relatieve forcering (snelheidsverandering) en de waterdiepte die daarbij hoort. Daarom weegt de duur van een regime mee bij het bepalen van karakteristieke afvoer voor elk regime.

<u>Regime a) alleen zomerbed gevuld, stuwen vrijwel volledig gesloten</u>

In dit regime zijn de stuwen maximaal gesloten. Dat heeft een jaarlijkse kans van voorkomen van $f_{gestuwd}$. Als dit regime wordt gekarakteriseerd met een enkele afvoersituatie Q_1 met een duur $f_{gestuwd}$, dan past dit bij de afvoeroverschrijdingskromme als Q1 bepaald wordt uit $f(Q_1)=f_{gestuwd}/2$.
Hierin is $f(Q_1)$ de gemiddelde jaarlijkse kans voor het onderschrijden van afvoer Q_1.

Voor de periode 1990-2020 zijn de stuwen vrijwel gesloten bij afvoeren tot ca 1700 m^3/s in de Boven-Rijn en tot ca 50 m^3/s in de Boven-Maas. Uit de historische afvoerreeks 1990-2022 volgt $f_{gestuwd}$= 0.388 voor de Rijn en $f_{gestuwd}$= 0.172 voor de Maas. Representatieve waarden voor Q_1 met onderschrijdingskans $f_{gestuwd}/2$ zijn dan 1336 m^3/s voor de Rijn en 32 m^3/s voor de Maas.

<u>Regime b) alleen zomerbed gevuld, stuwen in de overgang naar volledig open</u>

In dit regime veranderen de stuwen van maximaal gesloten naar volledig open. De kans van voorkomen van volledig geopende stuwen is gedefinieerd als $f_{ongestuwd}$. De kans van voorkomen van de overgang tussen volledige gesloten en volledig geopende stuwen is dan 1- ($f_{gestuwd}$+$f_{ongestuwd}$). Omdat het een overgangsregime betreft met een veranderende afvoersituatie is weergave met één enkele afvoersituatie onvoldoende representatief. Iets passender is het gebruik van twee afvoersituaties:

Q_2 bepaald uit f(Q_2)= $f_{gestuwd}$+ [1-$f_{ongestuwd}$ - $f_{gestuwd}$]/4

Q_3 bepaald uit f(Q_3)= $f_{gestuwd}$+3[1-$f_{ongestuwd}$ - $f_{gestuwd}$]/4

Beiden met een relatieve duur [1-$f_{ongestuwd}$ - $f_{gestuwd}$]/2. Hierin is f(Q_2) de gemiddelde jaarlijkse kans voor het onderschrijden van afvoer Q_2 (en f(Q_3) de onderschrijdingskans van afvoer Q_3).

Met de afvoerreeks 1990-2020 is $f_{ongestuwd}$, de kans van voorkomen van volledig geopende stuwen $f_{ongestuwd}$= 0.075 voor de Rijn en $f_{ongestuwd}$= 0.012 voor de Maas. Daarmee is de jaarfractie van het overgangsregime 1-$f_{gestuwd}$-$f_{ongestuwd}$=0.537 voor de Rijn en 0.815 voor de Maas. De definities van de afvoersituaties leiden dan tot de waarden in Tabel 3.

	$f_{gestuwd}$	$f_{ongestuwd}$	$f(Q_2)$	$f(Q_3)$	duur	Q_2 [m^3/s]	Q_3 [m^3/s]
Boven-Rijn	0.388	0.075	0.522	0.791	0.269	1900	2700
Boven-Maas	0.172	0.012	0.376	0.784	0.408	90	340

Tabel 3 Minimum set afvoersituaties regime b.

Afvoerregime c ontwikkelende uiterwaardstroming, stuwen volledig geopend

In dit regime zijn stuwen volledig geopend, maar is de stroomvoering in de uiterwaarden nog niet volledig ontwikkeld. De relatieve duur van dit regime is bepaald met 1- $f_{volledige\ stroomvoering}$ –(1-$f_{ongestuwd}$). Hierin is $f_{volledige\ stroomvoering}$ de relatieve duur van een volledig ontwikkelde stroomvoering in de uiterwaard. De afvoersituatie Q_4 wordt dan bepaald uit $f(Q_4)$= (1-$f_{ongestuwd}$+ 1-$f_{volledige\ stroomvoering}$)/2

Dat wordt hier pragmatisch geschat met

Boven-Rijn $f_{volledige\ stroomvoering}$ = 1-f(6000 m^3/s) = 0.014

Boven-Maas $f_{volledige\ stroomvoering}$ = 1-f(2300 m^3/s) = 0.001

Ondanks dat ook dit een overgangsregime betreft waarin de uiterwaardstroming ontwikkeld, is de jaarlijkse duur ervan gemiddeld beperkt. Daarom wordt verondersteld dat een enkele afvoersituatie vooralsnog voldoende is om de jaarlijkse bijdrage van dit regime aan morfodynamiek te karakteriseren.

	$f_{ongestuwd}$	$f_{volledig\ stroomvoerend}$	$f(Q_4)$	duur	Q_4 [m^3/s]
Boven-Rijn	0.075	0.014	0.9556	0.061	4473
Boven-Maas	0.012	0.001	0.9934	0.011	1444

Tabel 4a Minimum set afvoersituaties regime c.

Afvoerregime d ontwikkelde uiterwaardstroming, stuwen volledig geopend

In dit regime is de stroomvoering in de uiterwaarden volledig ontwikkeld met een relatieve duur $f_{volledige\ stroomvoering}$. De afvoersituatie Q_5 wordt bepaald uit f(Q_5)= 1-$f_{volledige\ stroomvoering}$ /2

	$Q_{volledig\ stroomvoerend}$	$f_{volledig\ stroomvoerend}$	$f(Q_5)$	duur	Q_5 [m^3/s]
Boven-Maas	6000	0.014	0.993	0.014	6724
Boven-Rijn	2300	0.001	0.999	0.001	2623

Tabel 4b Minimum set afvoersituaties regime d.

De bepaling van representatieve afvoersituaties op basis van de afvoeroverschrijdingskromme kan worden samengevat met Tabel 5.

Regime	afvoersituatie (Boven-Rijn [m^3/s])	relatieve duur [-]
a) alleen zomerbed gevuld, stuwen vrijwel gesloten	1336	0.388
b) alleen zomerbed gevuld, stuwen in overgang naar volledig open	1900 2700	0.269 0.269

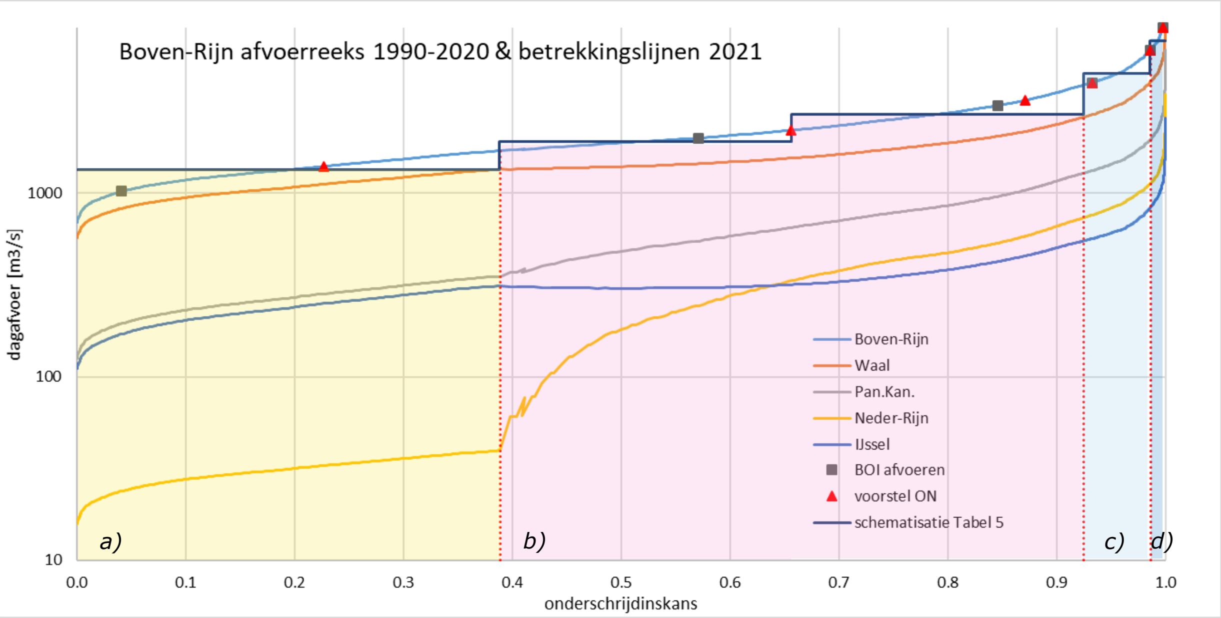
Regime	afvoersituatie (Boven-Rijn [m³/s])	relatieve duur [-]
c) ontwikkelende uiterwaardstroming stuwen volledig geopend	4473	0.061
d) ontwikkelde uiterwaardstroming stuwen volledig geopend	6724	0.014

Regime	afvoersituatie (Boven-Maas [m³/s])	relatieve duur [-]
a) alleen zomerbed gevuld, stuwen vrijwel gesloten	32	0.086
b) alleen zomerbed gevuld, stuwen in overgang naar volledig open	90 340	0.408 0.408
c) ontwikkelende uiterwaardstroming stuwen volledig geopend	1444	0.011
d) ontwikkelde uiterwaardstroming stuwen volledig geopend	2623	0.001

Tabel 5 Karakterizering regimes met minimum set afvoersituaties.

5 Vergelijking BOI afvoeren met minimaal benodigde set afvoersituaties
Het resultaat van Tabel 5 is weergegeven in Fig.2 voor de Rijn en Fig.3 voor de Maas.

In Fig.2 zijn behalve het verloop van karakteristieke afvoeren ook de set afvoeren die vanuit BOI beschikbaar is en het voorstel van RWS-ON weergegeven. Het grootste verschil tussen beide is de laagste afvoerwaarde. In Fig.2 is te zien dat de laagste waarde uit de BOI set te laag is om het eerste blok te karakteriseren. Nu is in gestuwde delen van de Nederrijn de morfodynamiek in a) en een groot deel van b) door de lage stroomsnelheden redelijk beperkt, daar zou een minder representatieve afvoersituatie wellicht minder hinderen. Maar dat geldt niet voor de andere takken, daar schiet de reeks die beschikbaar is uit BOI tekort. Voor hogere waarden is het onderscheid tussen de BOI reeks en het RWS ON voorstel minder groot en met beiden kunnen de blokken voldoende gekarakteriseerd worden. Met andere woorden, als de laagste waarde uit het ON voorstel aan de BOI afvoerreeks wordt toegevoegd, dan zijn alle blokken met die reeks voldoende te karakteriseren.

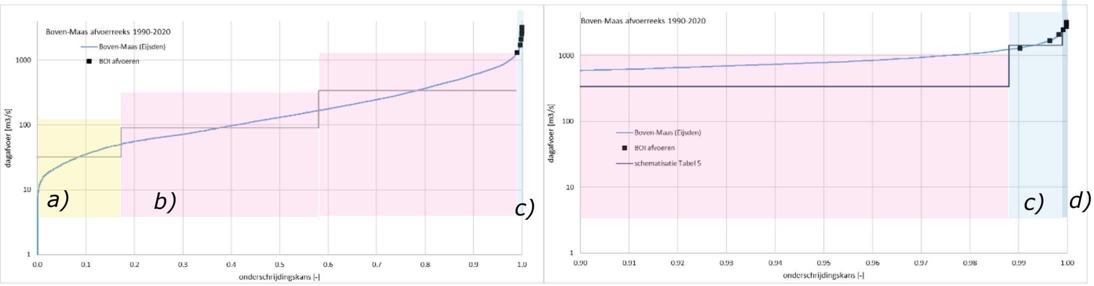


Figuur 2 Afvoerblokken per regime voor de Rijn.

In Fig.3 zijn de karakteristieke afvoerblokken weergegeven die de regimes voor de Maas karakteriseren. Behalve deze afvoerblokken zijn ook de uit BOI beschikbare afvoeren geplot. Deze

BOI afvoerwaarden komen alleen overeen met de blokken Q_4 en Q_5. Voor lagere afvoeren zijn in de BOI reeks geen waarden beschikbaar. Nu draagt stroming in de regimes met lagere afvoer niet vergelijkbaar bij aan de morfodynamiek; in de gestuwde trajecten van de Maas zelf blijven snelheden gedurende a) en b) beperkt en kan de meeste morfodynamiek ontwikkelen tijdens c en d. Hoewel grofweg vanaf 200 m^3/s sediment in beweging begint te komen zal ook in de grovere grindbodem van de ongestuwde delen van de Maas de meeste mobiliteit vooral goed ontwikkelen in de regimes c) en d).

Fig.3 laat zien dat voor het karakteriseren van de regimes c) en d) er meer dan genoeg afvoeren uit de BOI reeks beschikbaar zijn. Deze behoeven zelfs niet allen te worden gebruikt. Om met name het hogere deel van regime b), waarin een grotere delen van het bed mobiel kunnen zijn, te karakteriseren is ten opzichte van de BOI reeks een extra afvoer nodig in de orde van 750 m^3/s.



Figuur 3 Afvoerblokken per regime voor de Maas.

6 Conclusies DFAST MI

De Rijn en de Maas kennen vier afvoerregimes die voor de bepaling van morfologische effecten onderscheiden kunnen worden.

Rijntakken
Het karakteriseren van de vier afvoerregimes vergt voor de Rijntakken vijf afvoersituaties. Om de maatvoering van vooral ingrepen voor hogere afvoeren beter te ondervangen kan dit worden uitgebreid tot zes afvoerniveaus. Hoewel een aantal van acht optimaal lijkt vanuit consistentie met andere modellen, wordt dit aantal van zes afvoerniveaus als praktisch uitgangspunt gebruikt. Deze zes afvoerniveaus kunnen worden gebaseerd op de afvoerwaarden uit de BOI reeks, als deze worden aangevuld met een afvoer van circa 1400 m^3/s. Dat brengt de set op de afvoersituaties die horen bij 1400; 2000; 3000; 4000, 6000 en 8000 m^3/s (Boven-Rijnafvoer).

Maas
Voor de Maas zijn de hoogwaterregimes c en d, en het deel van b) met hogere afvoeren relevant voor de morfodynamiek. Dat komt overeen met drie afvoersituaties. Om de maatvoering van vooral ingrepen voor hogere afvoeren beter te ondervangen, en om de eventuele invloed van zeer extreme afvoeren mee te kunnen nemen, kan dit worden uitgebreid tot zes afvoerniveaus. Deze niveau's kunnen worden gebaseerd op de reeks afvoeren van de BOI reeks, als deze wordt aangevuld met een waarde van circa 750 m^3/s. Dat brengt de set op de afvoersituaties die horen bij 750; 1300; 1700; 2100; 2500 en 3200 m^3/s (Boven-Maasafvoer).

7) Afvoeren in DFAST-BE

DFAST-BE is een hulpmiddel om een inschatting te maken van het jaarlijks erosievolume van dynamische oevers en het uiteindelijk evenwichtsprofiel dat volgens de huidige stand van de kennis wordt verwacht. Afvoeren zijn in DFAST-BE relevant voor het definieren van de oeverlijn en voor het bepalen van de hydraulische belasting op de oever. Als voorbeeld daarvan wordt in de manual voor de Maas en Rijntakken gegeven:

Dicharge level nr.	Discharge (m^3/s)	1998-2002 (wet)	2004-2010 (dry)	2008-2011 (intermediate)
1	75	0.2932	0.1808	0.3110
2	150	0.1918	0.2466	0.2329
3	272	0.1918	0.2603	0.2055
4	400	0.0411	0.0548	0.0685
5	500	0.1507	0.1370	0.0959
6	750	0.0548	0.0712	0.0548
7	900	0.0329	0.0384	0.0164
8	1100	0.0164	0.0082	0.0055
9	1300	0.0137	0.0014	0.0021
10	1500	0.0041	0.0014	0.0021
11	1700	0.0041	0.0000	0.0021
12	1900	0.0041	0.0000	0.0021
13	2300	0.0014	0.0000	0.0014

Table 3.1: Probabilities of a discharge level for different scenarios (De Vries, 2012)

Dicharge level nr.	Discharge (m^3/s)	average	16% undershot (wet)	50% undershot (intermediate)	84% undershot (dry)
1	1020	0.062	0.000	0.022	0.135
2	1203	0.160	0.066	0.193	0.245
3	1635	0.115	0.101	0.121	0.151
4	2250	0.200	0.154	0.238	0.189
5	3053	0.253	0.326	0.258	0.170
6	3824	0.116	0.179	0.086	0.063
7	4717	0.058	0.094	0.046	0.042
8	6151	0.027	0.061	0.026	0.006
9	8592	0.010	0.020	0.010	0.000

Table 3.2: Probabilities of discharge level in the Boven-Rijn (1989-2016) for different scenarios

Definitie oeverlijn

In DFAST-BE worden in het numeriek riviermodel de oeverlijn gedefinieerd met de roostercellen met een land-waterovergang (diepte=0 m) bij een referentie waterstand. Deze referentie-waterstand hoort bij een referentie-afvoer. Het betreft een situatie waarbij de land-waterovergang bijvoorbeeld op een jaargemiddelde ligt, de jaargemiddelde afvoerwaarde lijkt daarvoor een goede pragmatische keuze.

De hoogte en ligging van deze oeverlijn is vooral bepalend voor het evenwichtsprofiel dat met DFAST-BE wordt voorspeld.

Hydraulische belasting

Er worden voor het voorspellen van erosie in DFAST-BE twee typen belasting beschouwd;

i) erosie door schuifspanningen van golven op de oever als gevolg van passerende schepen

ii) erosie door schuifspanningen door rivierstroming over en langs de oever

Ad i) Erosie door golven

Het invloedgebied van scheepsgolven is in DFAST-BE gedefinieerd als de zone tussen een halve karakteristieke golfhoogte boven de hoogte van de oeverlijn en tweemaal de karakteristieke golfhoogte onder de hoogte van de oeverlijn. De frequentie van voorkomen van waterstanden in dit invloedgebied bepaalt de duur van optreden van oevererosie door scheepsgolven.

Omdat de oever is gedefinieerd als de land-water overgang bij referentie-waterstand, is in DFAST-BE oevererosie door scheepvaartgolven dus beperkt tot situaties met waterstanden tot een halve karakteristieke golfhoogte daarboven en tweemaal de karakteristieke golfhoogte daaronder. Ook de karakteristieke golfhoogte zelf varieert met de waterdiepte (hoe dieper, des te kleiner) en is daarmee plaats- en afvoerafhankelijk. Deze belasting wordt in DFAST-BE minstens met de situatie met referentie-afvoer meegenomen, maar om de frequentie daarvan goed af te bakenen zijn afvoeren in een bandbreedte rondom deze referentieafvoer nodig.

Ad ii) Erosie door stroming
De grootte van het tweede type oever erosie varieert met de grootte (kwadratisch) en duur (lineair) van de stroomsnelheid ter plekke van de oever. Dit betekent dat vooral afvoeren boven de referentie-afvoer nodig zijn om de grootte en duur van stroomsnelheden ter plekke van de oever te kunnen beschouwen. Ook deze belasting is plaats- en afvoerafhankelijk.

8) Voorstel afvoerniveau's DFAST-BE

In de DFAST-BE handleiding wordt geadviseerd om met voldoende afvoerniveau's te starten die de hele hydrograaf discretizeren, zie de voorbeelden in de manual van achtereenvolgens 13 afvoeren voor de Maas en 9 voor de Rijntakken.

Tot deze afvoerniveau's behoort een afvoerwaarde met een land-water lijn die de oeverlijn karakteriseert. In afgelopen jaren was dat de eerste afvoerwaarde die in de reeks werd aangeboden (zie de twee voorbeelden uit de DFAST-BE manual hieronder). Omdat het een goede weergave van de meest frequente golfbelastingen betreft, ligt een 50% waarde voor de hand als referentie afvoer. Voor een (willekeurige) reeks 1990-2020 van Boven-Rijn afvoeren is dit 1877 m^3/s en voor de Boven-Maas 131 m^3/s. Dat kan worden afgerond naar achtereenvolgens 2000 m^3/s en 130 m^3/s.

Voorgesteld wordt voor de set voor de Rijntakken te gebruiken de afvoersituaties die horen bij 1020; 1400; 2000; 3000; 4000, 6000 en 8000 m^3/s (Boven-Rijnafvoer) met 2000 als referentieafvoer voor de bepaling van oeverlijnen.

Idem voor de Maas wordt voorgesteld 80; 130; 300; 750; 1300; 1700; 2100; 2500 m^3/s (Boven-Maasafvoer) met 130 m^3/s als referentieafvoer voor bepaling van oeverlijnen.

9) Afleiding kentallen voortplantingssnelheden

Een relevante calibratiefactor in DFAST-MI is de afvoerafhankelijke morfologische tijdschaal. Omdat toepassing van DFAST-MI in veel planstudies functioneert als eerste indicatie van morfologische effecten, al of niet vooruitlopend op completer studie met een numeriek 2DH model voor morfologie, is voor consistentie in planstudies, DFAST-MI idealiter ook geverifieerd op het numeriek model. Ofwel, de morfologische tijdschaal in DFAST-MI wordt zodanig gekozen dat DFAST dynamiek van effecten uit het morfologisch model nabootst. WAQMORF is op die manier ook geverifieerd met het DELFT3D model van de Rijntakken.

Omdat zo'n numeriek model er in DHYDRO nog niet is, is voorlopig de set van het geverifieerde WAQMORF nog het uitgangspunt. Deze sectie beschrijft hoe een set kan worden afgeleid voor de bij DFAST-MI beoogde aanpak met meer afvoeren.

De morfologische tijdschaal is arbitrair gedefinieerd als $T_{mi} = 2B_{hoofdgeul}/w_i$. Daarbij is een jaargemiddelde voortplantingssnelheid $\overline{w}$ uit peilingen beschikbaar.

De toedeling van de morfologische tijdschaal over meerdere afvoerafhankelijkheid is als volgt mogelijk. De jaarlijkse verplaatsing van bodemveranderingen kan worden geschreven als
$\overline{w}T = T\sum p(Q)w_Q$

met	T	[jaar]	
	$\overline{w}$	[m/jaar]	de jaargemiddelde verplaatsingssnelheid
	w_Q	[m/jaar]	de verplaatsingssnelheid bij een afvoer *Q*
`	*p*(*Q*)	[-]	de kans van voorkomen van afvoer *Q*

Een theoretische formulering voor de verplaatsingssnelheid is $w = b\frac{s}{a}$ met *a* [m] de waterdiepte en het sedimenttransport $s = mu^b$ met *u* [m/s] de stroomsnelheid en *m* en *b* coëfficiënten van de transportformule.

Dat betekent dat $w_Q = bm\frac{[u(Q)]^b}{a(Q)}$ en $\overline{w} = \sum mb\, p(Q)\frac{[u(Q)]^b}{a(Q)}$. Als ter wille van eenvoud *m* en *b* onafhankelijk van de afvoer worden aangenomen kan door eliminatie van *m* uiteindelijk worden gevonden $w(Q) = \overline{w}\frac{[u(Q)]^b}{a(Q)}\left(\sum p(Q)\frac{[u(Q)]^b}{a(Q)}\right)^{-1}$

Om consistentie bij toepassing te borgen worden voor $\overline{w}$ de waarden uit WAQMORF gebruikt die zijn afgeleid uit de toenmalige bodempeilingen (zie de tabellen 6,7 en 8) en wordt voor p(Q) de kans van voorkomen gebruikt volgens de toenmalige verdelingen

Boven-Rijn afvoer $T_{overschrijdingsperiode} = 365e^{\left(\frac{800-Q_{Boven-Rijn}}{1280}\right)}$

Maas afvoer $T_{overschrijdingsperiode} = 365e^{\left(\frac{-Q_{Borgharen}}{300}\right)}$

Om *w*(*Q*) voor elk relevant afvoerniveau te kunnen uitrekenen zijn modelwaarden van *u* [m/s] en *a* [m] gebruikt, die met *b*=5, per 100 m zomerbed, voor verschillende afvoeren zijn berekend. Deze waarden voor *w*(*Q*) zijn vervolgens geïnterpoleerd naar de DFAST-MI afvoerwaarden en tenslotte gemiddeld over het bijbehorende riviertraject. Door de interpolaties kan de jaarsom van eindresultaten een beetje afwijken van de beoogde jaargemiddelde verplaatsingssnelheid.

traject	km-raai	$\overline{W}$ [km/jaar]	***w*(Q) [km/jaar]** Boven-Rijn afvoer [m³/s]					
		1974-1999	**1300**	**2000**	**3000**	**4000**	**6000**	**8000**
Bovenrijn	859-867	1,12	0.42	0.98	1.86	2.63	4.79	8.76
Boven-Waal	868-886	1,04	0.63	0.97	1.51	2.06	3.16	5.35
Midden-Waal	887-915	1,13	0.85	1.12	1.43	1.78	2.93	3.83
Beneden-Waal	916-951	1,10	0.47	0.94	1.70	2.70	5.04	6.86
BovenMerwede	951-961	1.08	0.06	0.31	1.21	3.72	11.66	20.51
Pannerdensch Kanaal	868-879	0,97	0.03	0.56	2.10	3.15	5.79	9.99
Nederrijn, stuwpand Driel	880-891	0,77	0.00	0.21	2.17	3.03	3.13	3.59
Nederrijn, stuwpand Amerongen	892-922	1,17	0.79	1.14	1.61	1.99	2.61	3.04
Lek, stuwpand Hagestein	923-947	1,03	0.41	0.90	1.93	3.09	4.56	6.00
Lek *)	948-989	0,96	0.00	0.05	0.85	2.54	11.68	30.62
Boven-IJssel	880-930	1,50	1.23	1.59	1.98	2.37	3.40	3.89
Midden-IJssel	931-970	1,16	0.74	1.18	1.86	2.58	3.50	3.26
Beneden-IJssel	970-1000	1,06	0.26	0.56	1.38	3.12	8.78	18.67

traject	km-raai	$\overline{W}$ [km/jaar]	***w*(Q) [km/jaar]** Maas afvoer [m³/s]					
		1950-1995	**750**	**1300**	**1700**	**2100**	**2500**	**3200**
Grensmaas	16-69	0.001	0.003	0.01	0.01	0.02	0.02	0.03
Linne-Roermond	69-80	0.14	0.58	1.26	1.02	0.75	0.23	0.09
Roermond-Belfeld	81-100	0.26	1.13	2.74	2.13	1.72	1.95	2.22
Belfeld-Sambeek	101-146	0.26	0.95	3.62	3.70	4.04	4.52	5.74
Sambeek-Grave	147-175	0.11	0.29	2.13	2.61	2.59	2.46	2.82
Grave-Lith	176-200	0.28	0.60	5.40	5.98	5.50	5.53	6.34
Lith-Ammerzoden	201-277	0.14	0.40	1.88	2.26	1.83	2.16	2.54
Ammerzoden-Keizersveer**)	278-247	0.14*	0.32	2.44	4.14	4.85	5.96	8.62

Tabel 6 Voorstel verplaatsingssnelheden per afvoerniveau.

*) Zonder invloed van riviergetij
**) Geen waarde beschikbaar uit peilingen; gelijk aan traject Lith-Ammerzoden aangenomen

(geel) Gebaseerd op snelheden en diepten uit een verouderd model
(lichtblauw) Gebaseerd op snelheden en diepten uit huidige schematisering DHydro

Tabel 6 is vanwege consistentie in de toepassing gebaseerd op kentallen zoals ook zijn gebruikt in WAQMORF. Als er geverifieerde morfologische modellen beschikbaar komen van Rijntakken en Maas, is het mogelijk om met deze geverifieerde modellen Tabel 6 te actualiseren en DFAST MI met deze modellen, opnieuw ten behoeve van consistentie te verifiëren.

Bijlage A oude kentallen WAQMORF

Uit de RWS memo *Methodiek inschatting morfologische effecten in het zomerbed door lokale rivieringrepen* <u>*UPDATE December 2011*</u>

traject	**km-raai**	**voortplantingssnelheid [km/jaar]**	
		1950-1973	**1974-1999**
Bovenrijn	859-867	0,97	1,12
Boven-Waal	868-886	0,98	1,04
Midden-Waal	887-915	1,09	1,13
Beneden-Waal	916-951	1,15	1,10
Pannerdensch Kanaal	868-879	0,79	0,97
Nederrijn, stuwpand Driel	880-891	0,97	0,77
Nederrijn, stuwpand Amerongen	892-922	1,36	1,17
Lek, stuwpand Hagestein	923-947	1,16	1,03
Lek	948-989	1,12	0,96
Boven-IJssel	880-930	1,61	1,50
Midden-IJssel	931-970	1,28	1,16
Beneden-IJssel	970-1000	0,94	1,06

Tabel 6 Overzicht gemiddelde voortplantingssnelheden (gebaseerd op km-gemiddelde bodemliggingen en inclusief de invloed van baggeren) RIZA werkdoc 2005.044x.

Traject	**Km-raai**	**voortplantingssnelheid [km/jaar]**	
		voor 1950	na 1950
Grensmaas (km 16-69)	16-69	0,001	0,001
Linne-Roermond (km 69-80)	69-80	0,26	0,14
Roermond-Belfeld (km 81-100)	81-100	0,23	0,26
Belfeld Sambeek (km 101-146)	101-146	0,28	0,26
Sambeek-Grave (km 147-175)	147-175	0,37	0,11
Grave-Lith (km 176-200)	176-200	1,99	0,28
Lith-Ammerzoden (km 201-227)	201-227	0,76	0,14

Tabel 7 Overzicht trajectgemiddelde voortplantingssnelheden (gebaseerd op km-gemiddelde bodemliggingen en inclusief de invloed van baggeren) WD rapport *Kennis en instrumenten Maas morfologie Inventarisatie behoefte monitoring en voorspelgereedschap*)

Traject	Km	Voortplantingssnelheid [km/a]
Beneden Waal& Boven Merwede	934-961	1,08
Beneden Merwede	962-977	0,75
Nieuwe Merwede	962-980	0,84

Tabel 8 Overzicht trajectgemiddelde voortplantingssnelheden (gebaseerd op km-gemiddelde bodemliggingen uit de periode 1975-2000 inclusief de invloed van baggeren) RIZA WSR memo 2007-013 calibratie parameters Merwede.

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