



A crash course on assessing and managing reservoir sedimentation Exercise Delft3D-FM SED/MOR

Amgad Omer (Deltares) Sanjay Giri (RHDHV)



Title

Crash course on reservoir sedimentation Delft3D-FM SED/MOR (IAHR 2023)

Pages 20

Keywords

Reservoir sedimentation, gates operation, Dflow-FM, Morphology, Modelling

Summary

Dams and reservoirs provide a great service to society. Their number continues to increase because of growing demands for water and energy. However, they disturb river flow and morphological processes and thus produce impacts on river system and ecology. Besides, the reservoirs themselves suffer from loss of storage and contamination due to sedimentation. The reduction of storage capacity poses challenges to dam authorities. The requirements for minimizing storage loss (i.e. sediment management) as well as impacts on the downstream ecosystem lead towards the approach of optimum reservoir operational rules. Sediment management practices, such as sluicing and flushing, may generate undesired morphological changes in the reach downstream of the dam. The gate operation rule and patterns are expected to influence this.

Deltares has developed a modelling approach to simulate reservoir gate operation of the dam to understand the effect of different gate opening patterns on the morphological processes at upstream (the reservoir) and downstream river reach. Such modelling capability provides possibility to generate the gate operation rule for the desired reservoir water levels. The aim here is to seek improvements of the flushing process and to understand how this process affects the morphological changes downstream of the dam.

Expected gain:

- 1. Short background about sediment-induced problems in reservoirs and their management (Sluicing, flushing, dredging, etc.)
- 2. A rapid hands-on experience of using Delft3D-Flexible Mesh model (D-FM) with gate operation (RTC).

References 1000173-002

Version	Date	Author	Initials	Review	Initials	Approval	Initials
	Nov 2018	Amgad Omer					
		Sanjay Giri					

State Draft

Contents

2.1	Open Delta-shell and create project (already done for you)	2
2.2	Generate/upload the grid. (Done for you)	3
2.3	Generate/upload the bed level	5
2.4	Boundaries	8
	2.4.1 Upstream boundary	8
	2.4.2 Downstream boundary	10
2.5	Gates operation	11
2.6	Sediment and Morphology	13
	2.6.1 Sediment	13
	2.6.2 Morphology	14
2.7	Start simulation	15
3.1	Visualizing the results (Delta-shell)	17
3.2	Visulalizing the results using QuickPlot	20

1 Introduction

Dams and reservoirs provide a great service to society. Their number continues to increase because of growing demands for water and energy. However, they disturb river flow and morphological processes and thus produce impacts on river system and ecology. Besides, the reservoirs themselves suffer from loss of storage and contamination due to sedimentation. The reduction of storage capacity poses challenges to dam authorities. The requirements for minimizing storage loss (i.e. sediment management) as well as impacts on the downstream ecosystem lead towards the approach of optimum reservoir operational rules. Sediment management practices, such as sluicing and flushing, may generate undesired morphological changes in the reach downstream of the dam. The gate operation rule and pattern are expected to influence this.

Deltares has developed a modelling approach to simulate reservoir gate operation of the dam to understand the effect of different gate opening patterns on the morphological processes at upstream (the reservoir) and downstream river reach. Such modelling capability gives the possibility to generate the gate operation if the reservoir water level is given. The aim here is to seek improvements of the flushing process and to understand how this process affects the morphological changes downstream of the dam

The objective and expected gain of the exercise are as follows:

- Providing a brief background about sediment-induced problems in reservoirs and their management practices (sluicing, flushing, dredging, etc.)
- Familiarizing with Delft3D-Flexible Mesh model (D-FM) with gate operation tool (RTC) including a rapid hands-on exercise

The study area is a reservoir in Tenryuu River (Japan). The dam has 9 gates and powerplant with one turbine. The model domain has been simplified to suit the time allocated for the breakout session, Therefore, instead of 9 gates, three gates will be used and every gate represents the discharge of three gates. In addition, the reservoir length and the downstream reach have been shortened. The figure below shows the model simplification.



Figure 1.1 The model domain simplification

Many input files have already been prepared in order to have the model running with the available time of the session. Ideally, these files have to be prepared from scratch based on the row data. However, in order to set-up a model with morphology the following steps shall be followed:

- 1) Generate/upload the grid
- 2) Generate/upload the bed level
- 3) Prepare/upload the upstream boundary
- 4) Prepare/upload the downstream boundary
- 5) Prepare/upload the gates and gates operation
- 6) Add/upload sediment and morphology
- 7) Add the time-step, roughness, physical parameters, output intervals, observations (stations and cross-sections) processes that you want to model
- 8) Run the model and check the results

In this exercise, you will be able to add, step 2, 3 (partially), 4 (partially), 5 (partially) and 6. For step 3, 4 and 5 you should add the location of the boundary and the gates in addition to the input data of them. We already added the locations and you will upload the input data.

2 Exercise: Funa Model

2.1 Open Delta-shell and create project (already done for you)

Open Delft3D FM suite of 2019. Normally you create a new model, but in this exercise, we will open an existing model, partially, prepared due to the limited session time.

- 1) Go to open folder as shown in Figure 2.1 with number (1).
- 2) Go to the directory and select the file with the name *Funa00* (see Figure 2.2).



Figure 2.1 Upload a model or create a new model

y Open	D FM Suite 2019 HM	= 5
Organize * New folder	• ++ Search FlowFM P	
Organize New folder Favorites Deskop Domiods Recent Places Ubraries Dourinods Personnal Pitures Subversion Videos File name: Funa00.dsproj	Open Cancel Detta Shell Project File (* da) Detta Shell Project File (Deltares

Figure 2.2 Selecting the model and opening it

2.2 Generate/upload the grid. (Done for you)

You can generate the grid using grid Grid . However, in this exercise, the grid has already been made ready for use. Please go to ".. *Vinput\1-grid*" to upload the grid file with the name of "*FlowFM_net.nc*".



Image: Image	funa00 - Delft3D FM Suite 2019 HM	× 5 _
Image: Constraint of the second s	us Map Coordinate System Ft Merge operations tools Spatial Operations Spatial Oper	
Project 🗸 🕈 🗙	Start Page 🗧 FlowFM 🗙	₹ Ga
Course and Sinks Sources and Sinks	Right click to get "Import" Option	1 [Region] Map Operations Toolbox
Properties • ‡ ×		
24 🔤		
		m 200 400 600 800
	Messanes Time Navinator	

Figure 2.3 Import the grid by selecting the file of the grid."FlowFM_net.nc"."



Figure 2.4 The grid is being imported



Figure 2.5 The grid is imported

2.3 Generate/upload the bed level

Normally, the bed level is prepared in format of samples. The samples can be uploaded using the spatial operation in the map icon.

Select bed level in the spatial operation and import the samples as shown in Figure 2.6. Move to operation window on the right side of Delta-shell to see the samples. (see Figure 2.8) Interpolate the samples to the grid to generate the bed topography (see Figure 2.7 to Figure 2.10)

Save the model with bed topography (see Figure 2.11).



3 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	GIS funa00 - Delft3D FM Suite 2019 HM Map	- 5 ×
Image: Construction Image: Construction	oom Previous 🐨 Map Coordinate System oom Next 🕞 Export As Image uery Features 🟦 Query Time Series Tools	■ ▲ → Area Re_
Project	🕶 🖡 🗙 Start Page 🛑 FlowFM 🗙	₹ 🖓
R		1
	Open Search 2-bedievel Open 2 Search 2-bedievel 2 Organize - New folder 2	kojoni Magi O
Processes Our frame Processes Processes Processes Processes Processes Processes Processes Properties Properties	Recent Places Name Documents Music Personnal Richters Subversion Videos Videos No preview available. No preview available.	ranticest Toolbox
	HP Dock (E) + + + + + + + + + + + + + + + + + + +	a

Figure 2.6 Importing the samples to create the bed topography.

ply coordinate trar	sformation	on data?		<
Import without tran	nsformation (a	s-is)		
Transform from:	<none></none>			
to:	<none></none>			
		OK	Cancel	

Figure 2.7 Applying the coordinates transformation if needed.



Figure 2.8 visualizing the samples and start the interpolation



Figure 2.9 Interpolation operation to select "Overwrite" option



Figure 2.10 Interpolation method and options (select "Averaging")



Figure 2.11 Saving the bed topography

2.4 Boundaries

The boundary locations have been already added in this exercise. Normally, you need to add the boundary location yourself. In this exercise, we will only add input data of the boundaries.

2.4.1 Upstream boundary

Go to project window of Delta-shell and click on "*Boundary Condition*". Then select "*Boundary 01*". The boundary window will pop up, click on "*Csv import*" icon to add a csv file contains the boundary. When you click it then you a wizard window (see Figure 2.13) will pop up, you need to click next and follow the instructions to upload the file (*upstream-boundary.csv*) which

is located at your directory "... Vinput\3-upstream-boundary\". The boundary is steady-state discharge time series with a value of 310 m³/s as shown in Figure 2.14.

🖲 🗋 💕 l File	🚽 🤊 🕫 후 Home View To	Chartin pols Char	Funa00 - Delft3D FM Suite 2019 HM		- 5 ×
Export as Image Export	Increase Font Sizes Decrease Font Sizes Style Tools	r s			
Project		• # ×	Start Page 😝 Integrated Model Boundary01 (Boundary conditions) 🗙	₽ Map	• # ×
30	1.1		bundary Condition Location	篇篇篇篇	
	- S Pumps	*	ow Description: Discharge Geometry		
	Gates		Forcing type: Time Series		
	- 1 Embankments				
	Bridge Pillars		Vertical interpolation type:		
	B≇ Grid	100	Reflection parameter:		
	- Bed Level		Therefore Lindowson News Jack		
	- R Processes	11	maculer-halleman lime lag. Journal		
1 1	E Initial Conditions				
	Boundary Conditions	-	Factor: 1.00 [-] Offset: 0.00		
	Boundary02		ischarge 🔹 💌		
	Sources and Sinks	-	Generate series 4 Import from WPS Import from files Export to files 😥 Combined BC view		
Properties		* # ×			
1			c cipboard import a Cav import		
E21 0			ime [-] Discharge [m ³ /s]		
			2		
			0	-	
			00:00:00 Time [J]		
			++ (Record 1 of 1 + + + + + + + + + +		
		Ę	Service Servic	Chart Dari J Mar	Once Test

Figure 2.12 Adding the upstream boundary input data.



Figure 2.13 uploading the boundary data through the wizard.



ting Funa00 - Delft3D FM Suite 2019 HM art	- 5 × a
Start Page 🕞 Integrated Model Boundary01 (Boundary conditions) 🗙	Мар 🕶 🖡 🗙
Boundary Condition Flow Pescription: Discharge Forcing type: Time Series Vertical Interpolation type: Reflection parameter: Thatcher-Harleman time lag: 00:0000 Discharge Foctor: L00 [-] Offset: 0.00	高美瓦谷
© Clipboard import © Crv export	
H	Hing Fund0 - DdH30 FM Suite 2019 HM Start Rage Integrated Model Boundary01 (Boundary conditions) × Start Rage Integrated Model Boundary01 (Boundary conditions) × Forcing Description: Discharge Vertical interpolation type: Integrated Model Forcing type: The Series Vertical interpolation type: Thatcher-Harleman time lag: 000000 Discharge Clipboard import from WPS: Import from Siles. Clipboard import & Cir import from WPS: Import from Siles. Start Reserver Start Reserver Start Reserver

Figure 2.14 The upstream boundary has been added

2.4.2 Downstream boundary

Go to project window of Delta-shell and click on "*Boundary Condition*". Then select "Boundary 02". The boundary window will pop up, click on "Csv import" icon to add a csv file contains the boundary. When you click it then you a wizard window (see Figure 2.13) will pop up, you need to click next and follow the instructions to upload the file (*downstream-boundary.csv*) which is located at your directory "...*Vinput\4-downstream-boundary\V*". The boundary is a Q-h relation and after uploaded successfully it will be seen as shown in Figure 2.16.



Figure 2.15 Adding the downstream boundary input data.



Figure 2.16 The downstream boundary has been added

2.5 Gates operation

The gates locations have been already added to the model because of limited time fo the session. 3 gates will be used in the mode. In this exercise, you will add the input data if the gates.

Go to "**Project**" window and click on "**Area**", then click on "**Gates**". The Gates window will pop up in the middle of Delt-shell screen.

Use right click at every gate and go to "**Open view**" to see the gate input data as shown in Figure 2.19. Click on lower edge level – Time series to add the gate input. Awizard window will pop up follow the instructions to upload the data from csv file (vertical-gate-opening.csv) locationed in your directory "...\input\5-gates\". **Repeat** the bove steps for every gate. Finally, the three gates will have same time series as shown in Figure 2.20. **Save the model.**



Figure 2.17 The dam gates location and shape in the model (the operation is similar to sliding gates)



Figure 2.18 Opening the gate properties to upload the gates operation time series

Start Page 📄 FlowFM	FlowFM (FM mc	odel se	ettings)	gate01 🗙
Name: gate01				
Gate properties				
			Time depender	1
Sill level	42	m		
Door height	15.5	m		
Horizontal opening direction	Symmetric 🔹			
Lower edge level	Time series	m		
Opening width	0	m		
Sill width	59.576702991503559	m		
Use sill width				

Figure 2.19 An example of gate properties input window



Figure 2.20 Gate operation time series (import ready file "vertical-gate-opening.csv")

2.6 Sediment and Morphology

2.6.1 Sediment

In this exercise, we will add one type of sediment "*sand01*" Go to "*Sediment*" window (that you see after double clicking on "*General*") and type "*sand01*" and click on "*New*". The sediment characteristics will be shown. Please change the D50 from 0.0002 to 0.0001. The rest setting keep it as default.



Figure 2.21 Add sediment fraction

Sand Van Rijn (1993) Initial Concentration 0 kg/m³ Ø Spatially varying Option for determining suspended sediment	•
Initial Concentration 0 kg/m³ 🗹 Spatially varying Option for determining suspended sedimer	
	nt diameter 0
Initial sediment layer thickness at bed 3 m 📃 Spatially varying Calibration factor for Van Rijn's reference h	eight 1
Specific density 2650 kg/m ³ Calibration factor wave roughness height	2
Remove Fraction Dry bed density 1600 kg/m³ Current related roughness ks 0.01	m
Median sediment diameter (D50) 0.0001 May Wave related roughness kw 0.02	m
Use Van Rijn's parabolic mixing coefficie	nt

Figure 2.22 Add the sediment characteristics

2.6.2 Morphology

Go to "Morphology" window and change the setting as follows (see: Figure 2.23)

- 1. Morphological scale factor to 10
- 2. Spin-up before morphological changes to 120 min
- 3. Current related transport vector factor to 10
- 4. Factor for erosion of adjacent dry cell to 0.5
- 5. Save the model

General Time Frame Processes I	nitial Conditions Physical Parameters	Wind Numerical Parameters O	utput Parameters	Advanced Miscellaneous	Morphology	Sediment
General		Sediment transport parameters				
Morphological scale factor	10	Threshold sediment thickness	0.05			
Spin-up before morphological changes	120					
Include sediment concentration on density			ple	ase change as p	er the	
Minimum depth for sediment computations	0.1			red squares		
Morphology boundary condition file						
		Bed load transport				
Update bathymetry during simulation	n 🗸	Streamwise bed gradient factor	1			
Update bed composition during simulation	V	Transverse bed gradient factor	1.5			
Neumann boundaries for mud influx						
Neumann boundaries for sand influx	3					
Bed slope formulation	Bagnold formulation					
Hiding and exposure formulation	1	Multiplication (calibration) factor	ors			
Hiding and exposure formulation	No hiding and exposure 🔹	Effect of secondary flow on bed loa direction	d 0.5			
		Current related reference concentration factor	1			
		Current related transport vector factor	10			
		Factor for erosion of adjacent dry cells	0.5			
		HMaxTH	1.5			

Figure 2.23 The morphology setting

Tips:

- Save the model
- Check the time step is equal to 5 min (in "*Time Frame*" window)

2.7 Start simulation

Before you run the mode, you need to validate the model. Go to the "*Project*" window:

- Right click on the "FlowFM"
- Click on "Validate" as shown in Figure 2.24
- New window will pop up as shown in Figure 2.25. If model is ok then all the validation results will be with green icons. Otherwise, you may need to check the model based on the error that would be shown in the validation screen.
- Run the model: right click on the FlowFM"
- Click on "Run Model as shown in Figure 2.26. A new screen will pop up to show the the simulation progress (see Figure 2.27).
- Wait until the model simulation is finished to see the results.



Figure 2.24 validation of the model

🖲 🔐 🗐 🕅 🔻 🖛 File Home View Tools	Funa00 - Dellt3D FM Suite 2019 HM		-	б× a
Paste Copy Clipboard New Folder Clipboard New Folder	Run All 🔒 Find 🔍 Feedback Run Curret 🔲 Show log Run Script Find Help			
Project Image: State of the	Start Page Integrated Model Boundary02 (Boundary conditions) gate01 FlowFM (PM model settings) It PlowFM X It Constrained System Domains Baltymarky Physical Processes If everything is green, go to run your model. Otherwise you need to check your model again! If everything is green, go to run your model. Otherwise you need to check your model again! Water flow FM model definition Estimate and effectives Startures Startures Startures Estimate Startures Startures	Map 高高高 5	20 20	* # ×
Euromode Validate before run Validate before run Use RPC Validate before run Validate before run				
		C R	M 0.	T

Figure 2.25 Check validation results





Figure 2.26 Run the model



Figure 2.27 Model is running.

3 Explore the model results

3.1 Visualizing the results (Delta-shell)

After the simulation is finished you can see the model results as follows:

- Go to the "Project" window and click on "Output".
- Double click on one of the results, for instance, "Water level".
- Use the "Time Navigator" at the bottom to run the change of water level in time.
- Go to the "Map" at the right side of Delta-shell window to explore the output of the map file and the history file as shown in Figure 3.1.
- You may also click on the Open-street map to see the simulated results on it (if it is not there, you can activate by clicking in an icon at "*Map*" window as shown in Figure 3.2.
- You can print the results as "png" as shown in Figure 3.3.
- Figure 3.4 and Figure 3.5 show examples of the model results.



Figure 3.1 Exploring the model results.



Figure 3.2 Activating Open street map (or other maps like Bing map)



Figure 3.3 Print the model results



m 200 400 600 800

Figure 3.4 Sediment thickness after model simulation time.



Figure 3.5 Sediment thickness after model simulation (with background of "Bing Maps-Aerial")

Check the history file:

You can also plot the time-series of many components (at observation point or cross-section location) to compare the results. For instance, you can see the time-series of simulated water level upstream of the dam by:

- Selecting the observation point and then the "Query time series" (see Figure 3.6).
- Then select the type of the data you want to explore (see Figure 3.7).
- Click Ok to visualize the results (see Figure 3.8).



Figure 3.6 History file: check the water level upstream the dam (step A: select the observation point)



Figure 3.7 History file: check the water level upstream the dam (step B: select the water level)



Figure 3.8 History file: check the water level upstream the dam (step C: visualize the results)

3.2 Visualizing the results using QuickPlot

You can also see the results using another postprocessing tool, namely QuickPlot. You can load the map and history files in QuickPlot to check the results.

First load the map file. This file stores the results for every grid point. The easiest way to check the hydrodynamic/ morphological results for this 2D-model is to view results along one grid line. Make sure that you specify the line (xy) and check the variation of the water level, water depth and depth-averaged velocity along the flume.

Now load the history file. This file stores the time series of the results for the observation stations and cross-sections. From the station list, select a station. From the field list, select again any component and plot for the time series.

Question 1

Are the hydrodynamic results as expected?

Question 2

Try to make a colour plot of the magnitude of the velocity in the plane for same line. Describe your findings. Also, try to add the velocity vectors to this plot.

Beside the hydrodynamic results, the map file stores sediment-related outputs as well, e.g. concentration and sediment transport. The name of sediment fraction is also in the list of output fields (in our case "*sand01*"). This field contains the concentration of this fraction.

Question 3

Try to make a colour plot of the suspended sediment concentration in the plane for the same line. Describe your findings.