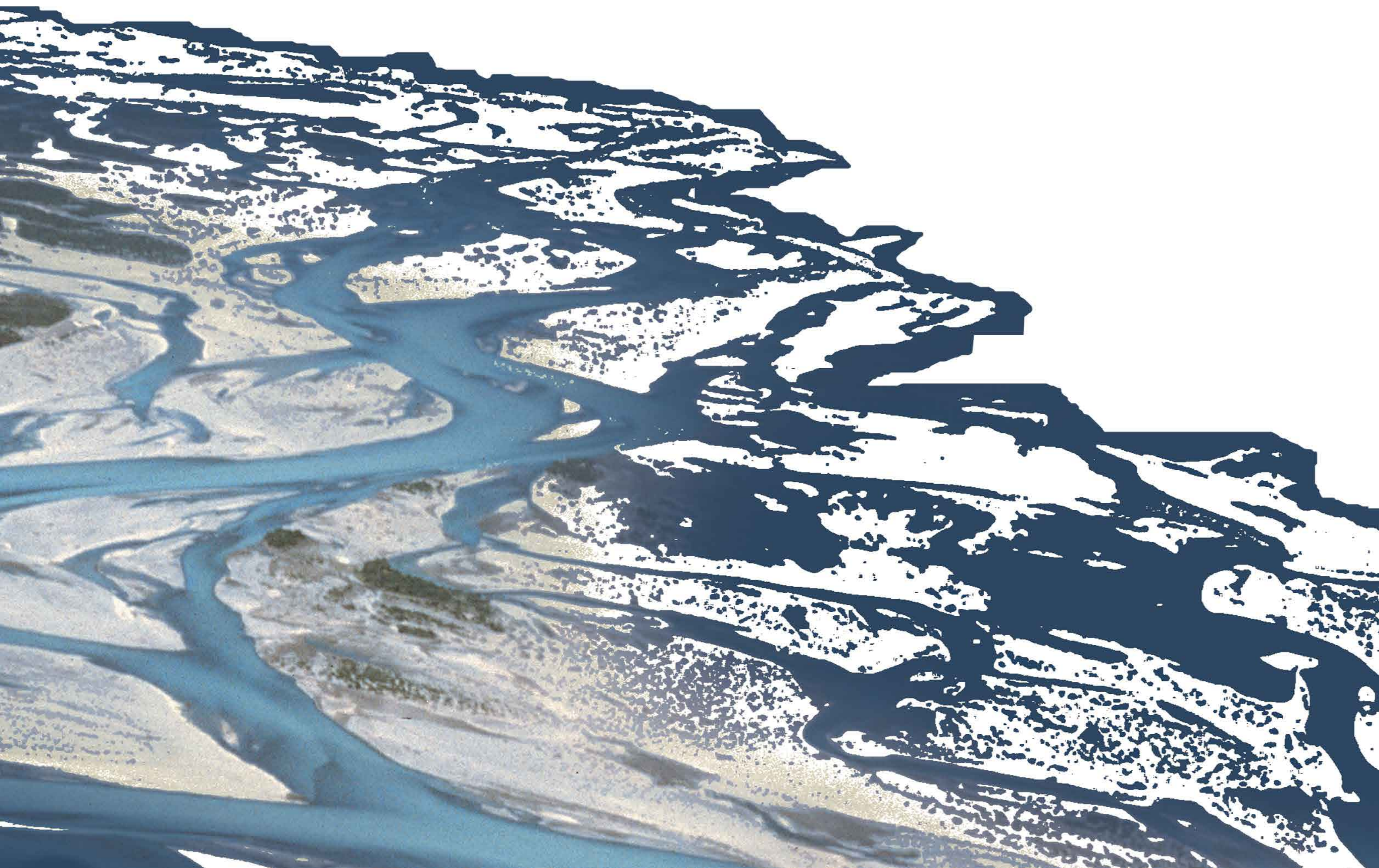
BASEMENT

BASIC SIMULATION ENVIRONMENT
FOR SIMULATION OF ENVIRONMENTAL FLOW
AND NATURAL HAZARD SIMULATION

SYSTEM MANUALS

VERSION 3.1
November 2020



Preamble

VERSION 3.1

November 2020

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Commissioned and co-financed by

Swiss Federal Office for the Environment (FOEN)

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Citation Advice

For System Manuals:

Vetsch D., Siviglia A., Bacigaluppi P., Bürgler M., Caponi F., Conde D., Gerke E., Kammerer S., Koch A., Peter S., Vanzo D., Vonwiller L., Weberndorfer M. 2020. System Manuals of BASEMENT, Version 3.1. Laboratory of Hydraulics, Glaciology and Hydrology (VAW). ETH Zurich. Available from https://www.basement.ethz.ch. [date of access].

For Website:

BASEMENT – Basic Simulation Environment for Computation of Environmental Flow and Natural Hazard Simulation, 2020. https://www.basement.ethz.ch

For Software:

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BASIC SIMULATION ENVIRONMENT
FOR SIMULATION OF ENVIRONMENTAL FLOW
AND NATURAL HAZARD SIMULATION

INTRODUCTION & INSTALLATION

VERSION 3.1
November 2020

Contents

1

Summary of Contents

1.1 Introduction

BASEMENT version 3 is a freeware simulation tool for hydro- and morphodynamic modelling developed at the Laboratory of Hydraulics, Hydrology and Glaziology (VAW) of the ETH Zurich. The software provides a precise and powerful tool for the simulation of river hydro- and morphodynamics. BASEMENT system manual provides information about BASEMENT version 3 and guides the user through the process of using BASMENT version 3.

1.2 Content of System Manuals

The documentation is composed of four parts, the Introduction & Installation, the User Manual, the Reference Manual and the Tutorials & Test Cases.

1.2.1 Introduction & Installation

This part aims at introducing BASEMENT version 3 to the user by presenting the novelties and changes of the released version. First, the installation procedure is explained for Windows and Linux operating systems. Then, the differences between BASEMENT version 2.x and version 3.x are described in the migration guide for the users already familiars with BASEMENT. The release notes summarize the changes introduced by BASEMENT version 3 and the summary of features provides an overview of the available functionalities of BASEMENT version 3.

1.2.2 User Manual

The user manual provides information about the simulation environment of BASEMENT version 3. The modelling procedure presents the three-stage process, namely the pre-processing, the numerical simulation and post-processing. The numerical simulation is carefully described in the simulation workflow section. The graphical user interface (GUI) provides a user-friendly tool to assist the user during the numerical simulation process.

1.2.3 Reference Manual

The reference manual provides information about the mathematical models and numerical approximations implemented in BASEMENT version 3.

1.2.4 Tutorials and Test Cases

This part is composed of three tutorials and two test cases. The tutorials guide the user throught the pre-processing, the numerical simulation and post-processing stages of BASEMENT version 3 by taking a section of the river Flaz in Graubünden as example for the numerical simulation. The test cases aim at testing the performance and acuracy of the simulations performed with BASEMENT version 3 by standardized test cases, namely the circular dam break and the conical dune.

2

Setup and First Start

2.1 Setup and First Start

2.1.1 System operator requirements

2.1.1.1 Microsoft Windows

BASEMENT version 3 has been tested for MS Windows 10. For the latest news concerning new features and current changes, please visit the webpage https://www.basement.ethz.ch.

2.1.1.2 Linux

BASEMENT is available for the following Linux (x86-64) systems:

- Ubuntu 16.04 (LTS), alias “Xenial Xerus”:
  - Kernel version 4.4
  - GNU C Library (glibc) version 2.23
  - VTK-version: 5.10
  - GPU driver version:
    - Kepler architecture and later: at least 418.39
    - Tesla architecture: in [384.111, 385.00) or in [410.72, 411.00)
- Ubuntu 18.04 (LTS), alias “Bionic Beaver”:
  - Kernel version 4.15
  - GNU C Library (glibc) version 2.27
  - VTK-version: 6.3
  - GPU driver version:

  * Kepler architecture and later: at least 418.39
  * Tesla architecture: in [384.111, 385.00) or in [410.72, 411.00)

The binaries were compiled and tested on both Linux systems. Binaries without GUI should run on debian-based linux systems.

2.1.1.3 Hardware Configuration

We recommend the following hardware configurations:

2.1.1.3.1 CPU multi-core processors (x86/x86-64)

- Intel (Xeon, 12 to 18 Cores, dual socket)
- 1 GB per core
- Minimum of 2.8 GHz

2.1.1.3.2 Graphical Processing Units (GPUs)

Please note that the GPU-support of BASEMENT version 3 is **only** possible for CUDA-enabled (Compute Unified Device Architecture) GPUs produced by NVIDIA. BASEMENT version 3 has been specifically tested with GPUs listed in 2.1.

Table 2.1 *GPU hardware used for the numerical simulations*

Card	Tesla K20	Tesla P100	GTX 1080 Ti	GTX 1070 Ti	GTX 1050 Ti	RTX 2080Ti
Memory [GB]	5	12	11	8	4	11
Architecture	Kepler	Pascal	Pascal	Pascal	Pascal	Turing
Bandwidth[GB/s]	208	549	484	256	112	616
CUDA cores	2496	3584	3584	2432	768	4352

2.1.2 Installing under Windows

BASEMENT version 3 is available for Microsoft Windows Windows 10 operating system.

2.1.2.1 Getting the binaries

First of all, you need to get a copy of the latest software package. Therefore go to the project webpage https://basement.ethz.ch and download the latest version (BASEMENT version 3.x) free of charge.

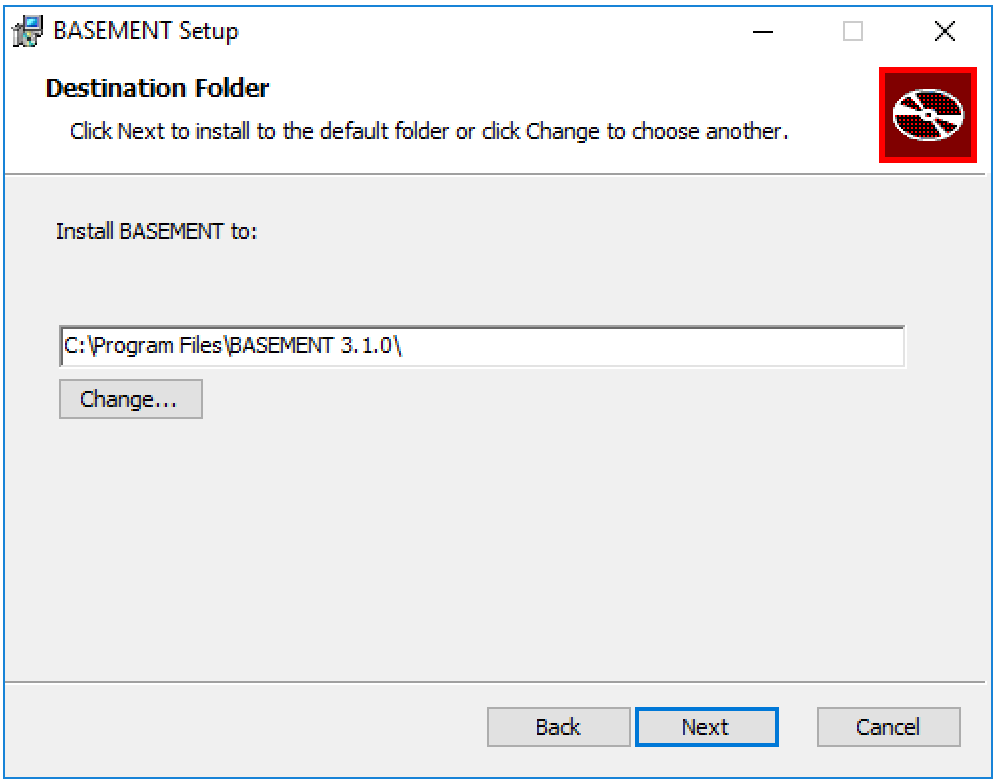

Figure 2.1 *Select the installation folder.*

2.1.2.2 Installation procedure under Windows 10

Please note, that existing installations are not automatically detected by the installer. Therefore, uninstall any previous BASEMENT version before installing a more recent version e.g. using the link in the start menu. After downloading the version 3.x from the project webpage, start the installation by double-clicking on the BASEMENT installer.

Step 1: Accepting the license agreement

Please read the License Agreement carefully and click on the 'I accept' button if you accept the terms and conditions and proceed with the installation.

Step 2: Select the installation folder

After accepting the License agreement, you can choose where to install the binaries. The recommended location is "C:\Program Files\BASEMENT 3.1.0" (Figure 2.1). You are free to choose any other directory.

Step 3 and 4: Confirming and finishing the installation

Clicking 'Install' will start the installation process. After all files are copied, a final window informs about the success of the installation. Click 'Finish' to close the installer.

Step 5: Start BASEMENT

You can start the program by opening the Start Menu, navigating to the Start Menu folder of BASEMENT and clicking on the program icon of BASEMENT version 3.x (Figure 2.2). To create a Desktop shortcut, simply drag the program icon to your Desktop. Clicking on the BASEMENT icon runs the program as a standalone application including a simple

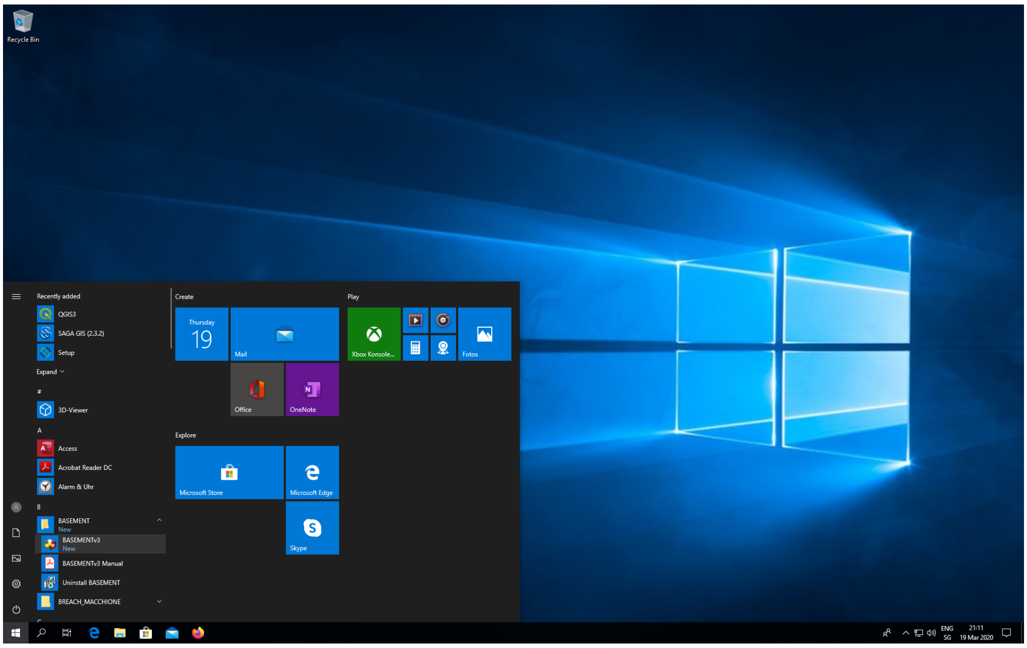

Figure 2.2 *Start BASEMENT over the icon in the Start Menu folder.*

graphical user interface (to run BASEMENT in batch mode see the section Run the programm in the User Manual documentation part).

The graphical user interface should appear as in Figure 2.3.

2.1.3 Installing under Linux

2.1.3.1 Getting the binaries

You need to get a copy of the actual distribution as described in the Windows installation section. You can download the most recent version from the projects webpage https://basement.ethz.ch.

2.1.3.2 Installation procedure

Step 1: Preparation of the installation

Extract the downloaded package and change to the directory containing the installation script. Make the installation script executable by running (replace * by the BASEMENT and Ubuntu version number):

```
$ chmod +x BASEMENT_v*_linux64_ubuntu*.sh
```

To run the setup enter

```
$ ./BASEMENT_v*_linux64_ubuntu*.sh
```

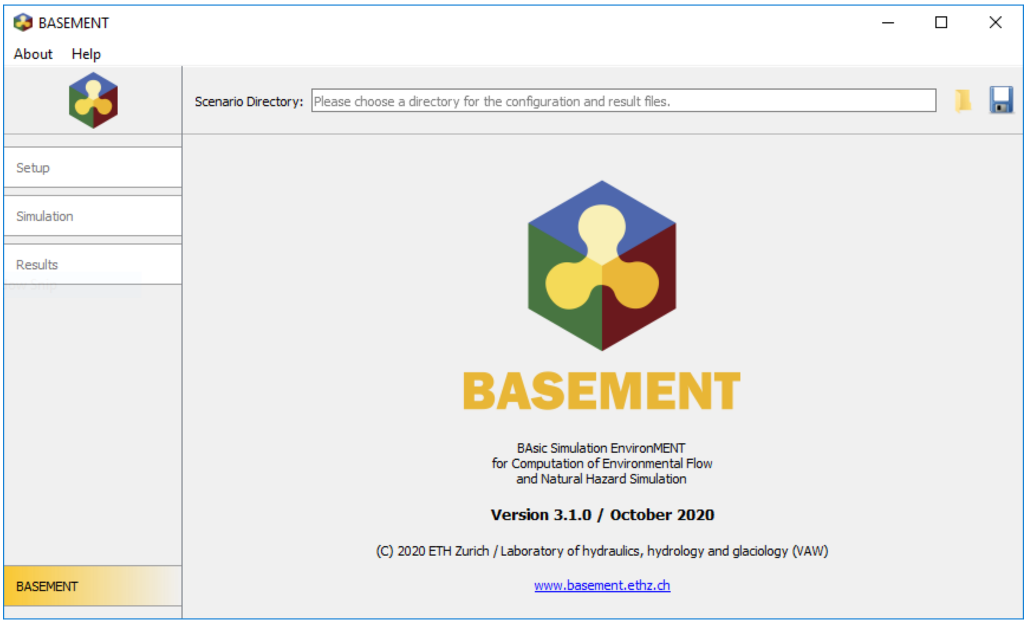

Figure 2.3 *The graphical user interface.*

and follow the instructions. You have to read and accept the license text.

The BASEMENT Debian package file (*.deb) is extracted.

Step 2: Install the Debian package

Administrative rights are required to install the package using dpkg. Therefore prefix the command with “sudo” (replace *** by the version number):

```
$ sudo dpkg -i BASEMENT-***.deb
```

The Debian package automatically detects if your configuration misses one of the required packages. In such a case you can either use

```
$ sudo apt-get -f install
```

to install all missing packages automatically or, in case you want to install dependencies manually, you can perform

```
$ sudo apt-get install MISSING_PACKAGE
```

to install the missing packages from the repository. Replace MISSING_PACKAGE with the missing package name.

Previous versions of basement are automatically detected by the installer and deleted before the installation starts.

Step 3: Run basement

If the installation of the package was successful, than the executables are copied to

/usr/bin

and the other program files are copied to

/usr/share/basement

You can now run Basement from the console by typing:

```
$ basement
```

Step 4: In case of trouble

Report your issue and get in touch with other users in the BASEMENT forum: https://people.ee.ethz.ch/~basement/forum/

2.2 Running BASEMENT

2.2.1 Windows 10

When running BASEMENT under Microsoft Windows operating system, the easiest way to start a simulation is by clicking on BASEMENT icon. After running, BASEMENT will open the graphical user interface. You have to select the scenario directory that contains all the configuration files and binaries by pressing on the folder icon, where you can load the path to the scenario directory.

The configuration is done in three steps (three .json files) that can be edited using BASEMENT graphical user interface or JSON editors. Each step is executed independently (setup, simulation and results) and the generated files are saved in the scenario directory containing the command and auxiliary files. The procedure to run numerical simulations with BASEMENT using the graphical user interface (GUI) or in batch mode is explained in the User manual.

2.2.2 Linux

BASEMENT runs as a console application without program icon. On Linux, open a console and type:

```
$ basement
```

to start the program (if no environment variables have been set, change into your ‘bin’ directory of the installation path). The GUI starting page is appearing. You have now to select or create the scenario directory in the scenario directory field. The configuration of the .json files (3 steps) is the same as for Microsoft Windows (see Section 2.2.1) and information about the use of the GUI is given in the section ‘BASEMENT Graphical User Interface’ of the User Manual. Selecting the executables and running a simulation on Linux or using batch mode works the same way as it does on Windows explained in the User Manual. *Notice:* **The command filename must not contain any spaces or special characters like ä, ö, ü, è, etc.**

3

Migration Guide Version 2.8 to 3.1

3.1 General

Table 3.1 *List of BASEMENT main features*

	Version 2.8	Version 3.1
1-D model	✓	
2-D model	✓	✓
Hydrodynamics	✓	✓
Morphodynamics:		
- Bed load	✓	✓
- Suspended load	✓	
Tracer advection		✓
External sub-domain	✓	
Model coupling (multi domain)	✓	
Controller	✓	
Subsurface flow	✓	
Vegetation	✓	
SMP hardware	✓	✓
GPU/HPC support		✓

3.2 Major Changes from version 2.x to 3.x

3.2.1 Workflow

Table 3.2 *Major changes in workflow*

	Version 2.8	**Version 3.1**
Configuration files	one command file with arbitrary name: *.bmc	three command files with fixed name: model.json, simulation.json and results.json
Data storage	results stored in a specified format	setup and result stored in HDF5 container (.h5)
Rerun	modify *.bmc file and run simulation	modify simulation.json and run simulation
Restart	modify *.bmc and select restart file	modify model.json and select restart file (.h5)
Executables	one executable (basement.exe) for CPU & SMP computing	separate executables for GUI, setup, results and for each simulation backend, e.g. for CPU, SMP and GPU

3.2.2 Input data

3.2.2.1 Mesh features

Table 3.3 *Main changes regarding the computational mesh*

Version 2.8	**Version 3.1**
Triangular and quadrilateral cells	Triangular cells
Dual mesh (cell vertex and cell centered)	Cell centered mesh
Variable bottom elevation over the cell	Constant bottom elevation over the cell
Computational mesh in 2dm format (SMS), including material indices (stringdefs defined separately in *.bmc file)	Computational mesh in 2dm format (SMS), including material indices and stringdefs
Domain differentiation with element_ids	Domain differentiation with regiondef

Table 3.4 *Main changes regarding the grid generation with BASEmesh*

Version 2.8	Version 3.1
Single procedure to generate a .2dm file with BASEmesh	Single procedure to generate a .2dm file with BASEmesh
Elevation information stored per mesh node (node z-coordinate)	Elevation information stored per cell
Stringdefs can be saved in separate *.bmc file for further usage	Stringdefs must be included at the end of the .2dm file
Manual editing of mesh in Qgis	Not available
View of the mesh in 3D	View of the mesh in 2D

3.2.2.2 Model setup

Table 3.5 *Main changes regarding model setup*

	Version 2.8	Version 3.1
Command file type	run.bmc	model.json
Physical properties	gravity viscosity rho_fluid	gravity - -
Geometry	mesh file stringdef movable bed index_table -	mesh file stringdef - regiondef interpolation

Table 3.6 *Main changes in the* ***hydraulics*** *block of the domain BASEPLANE_2D*

	Version 2.8	Version 3.1
Parameters:		
Riemann Solver	exact, HLL and HLLC	HLLC
Fluid density	no (physical properties block)	yes
Max time step	no (timestep block)	yes
CFL	no (timestep block)	yes

	Version 2.8	**Version 3.1**
Dynamic depth solver	water depth from left and right side of the cell edge and from center of the right and left cells	water depth from center of the right and left cells
Safe mode	no	yes
Friction		
Type	Manning Strickler Chezy Yalin Darcy-Weissbach Bezzola	Manning Strickler Chezy - - Bezzola
Wall friction	yes	no
Grain size friction	yes	no
Boundary		
Type	- hydrograph	**Standard** uniform_in uniform_out
	- zhydrograph	**Standard** zhydrograph **Linked** zhydrograph_linked, zhydrograph_linked_kinE
	zero_gradient weir	zero_gradient_out weir_out_constant, weir_out_dynamic **Linked** weir_linked_constant, weir_linked_dynamic
	gate	-
	- HQ_relation	**Standard** hqrelation_out **Linked** 2way_hqrelation_linked, hqrelation_linked
	coupling	-
	- wall	**Internal**: wall_internal wall_internal hqrelation_internal

	Version 2.8	**Version 3.1**
File type	hydrograph, weir, gate, hqrelation	discharge, weir elevation, hqrelation, wse
Boundary inside the computational domain	Inner boundary (weir, gate and hqrelation)	**Internal** boundary:
		wall, dynamic wall and h-Q relation **Linked** boundary: weir, h-Q relation
Turbulence model	yes	no
External source		
Type	source discharge	total and distributed
Sink behavior	negative source discharge values	exact, available, infinity
Initial		
Type	dry continue index_table	dry continue region_defined
Flood tracking	no	yes

Table 3.7 *Main changes in the* ***morphology*** *block of the domain BASEPLANE_2D*

	Version 2.8	**Version 3.1**
Parameter		
Active layer	yes (control_volume)	no
Porosity	porosity	sediment_porosity
Density	density	sediment_density
Starting time	- (bedload)	morphodynamic_start
morph_cycle	yes	no
morphological factor	no	yes
time scaling	no	with morphological factor

	Version 2.8	**Version 3.1**
Create new layers	yes	no
Grid perturbation (random)	distortion	-
Bedmaterial		
Grain class	Single or multi grain classes	Single grain class
Layer	Multiple layers	Single layer
Fix bed elevation	.2dm mesh or node list	.2dm mesh or over region (index)
Bedload		
Bedload transport	Simple upwind scheme	HLL-type Approximate Riemann Solver (Soares-Frazão and Zech, 2011)
Closure formula	mpm	MPM
	-	MPM-like (adaptable)
	engelundhansen	Engelund and Hansen
	mpmh	-
	power_law	Grass-like (adaptable)
	mpm_multi	-
	wilcockcrowe	-
	ashidamichiue	-
	parker	-
	rickenmann	-
	smartjaeggi	smartjaeggi
	smartjaeggi_multi	-
	wu	-
	vanrijn	-
Boundary		
- Inflow	-	**Standard**
	sediment_discharge	sedimentograph
	-	sedimentograph_warea
	-	sedimentograph_conveyance
	IOUp	equilibrium_in
	transport_capacity	transport_capacity
	-	transport_capacity_warea
	-	transport_capacity_conveyance
- Outflow	IODown	equilibrium_out
Parameters	upwind factor	-
	cell average bedload flux	cell average bedload flux (default)

	Version 2.8	**Version 3.1**
Direction	lateral_bed_slope curvature_effect_static curvature_effect_dynamic	LATERAL_SLOPE - CURVATURE
Inner boundary	weir, open -	**Internal**: equilibrium_linked
Incipient motion	angle_of_repose local_slope_vanrijn local_slope_chen	repose_angle van_rijn chen_et_al
Gravitational transport	yes	yes
Source		
Type	sediment_discharge dredge	sediment_discharge -

Table 3.8 *Introduction of the* ***tracers*** *block in the domain BASEPLANE_2D*

	Version 2.8	**Version 3.1**
Parameters:		
Number of species	no	num_tracers (max. 5)
Starting time	no	tracers_start
Boundary		
Type	no	**Standard** discharge_in discharge_in_warea concentration_in zero_gradient_out
External source		
Type	no	total and concentration
Sink behavior	no	exact, available, infinity
Initial		
Type	no	zero uniform continue region_defined

3.2.3 Simulation

Table 3.9 *Main changes regarding simulation parameters*

	Version 2.8	**Version 3.1**
Command file type	run.bmc	simulation.json
Simulation time	start_time	start
	total_run_time	end
	output_time_step	out
	restart_time_step	-
	console_time_step	-
	reference_time	-
Timestep	initial_time_step	init
	minimum_time_step	minimum

	Version 2.8	**Version 3.1**
Simulation outputs	wse	water_surface
	depth	water_depth
	velocity	flow_velocity
	abs_velocity	flow_velocity_abs
	abs_momentum	-
	z_element	bottom_elevation
	z_node	-
	friction	friction_chezy
	deltaz	delta_z
	tau	-
	specific_discharge	spec_discharge
	concentration	-
	susp_load	-
	susp_net_deposition_rate	-
	susp_grain_conc	-
	susp_deltaz	-
	susp_total_pickup	-
	susp_total_deposition	-
	susp_grain_pickup	-
	susp_grain_deposition	-
	theta_critical	theta_critical
	grain_size	-
	grain_bedload	-
	bedload_vec	-
	saturation	-
	sediment_sum	-
	-	bed_gradient
	-	theta
	-	trsp_capacity
	-	trsp_capacity_abs
	-	flow_radius
	-	flow_curvature
	-	flood_tracking
	pore_pressure	-
	-	ns_hyd_discharge
	-	ns_mor_discharge
	external_source_discharge	-
	radius_curvature	-
	radius_curvature_abs	-
	momentum	-
	water_table	-
	biomass	-
	carrying_cap	-
	source_friction	-
	source_wall_friction	-
	source_internal_friction	-
	source_bed	-
	balance_discharge_fluxes	-
	balance_momentum_fluxes	-
	-	tracer1
	-	tracer2
	-	tracer3
	-	tracer4
	-	tracer5

	Version 2.8	Version 3.1

3.2.4 Results

Table 3.10 *Main changes regarding the results parameters*

	Version 2.8	Version 3.1
Command file type	run.bmc	results.json
Format	ascii, sms, tecplot, shape, vtk	xdmf
Output Type	node_centered	-
	element_centered	element_centered
	BASEviz	-
	node_history	-
	element_history	-
	stringdef_history	nodestring
	edge_history	-
	boundary_history	nodestring
	balance	-
	avs_ucd	-
	sediment_grid	-

3.3 Case example

3.3.1 Description

This section provides helpful hints for the users already familiarised with BASEMENT. For beginners, please have a look at the User Manual and the Tutorials first. The objective of this test case is to illustrate the main changes between BASEMENT version 2.8 (v2.x) and 3.1 (v3.x). A hydraulic simulation of a simple straight trapezoidal channel illustrates the changes and differences between the two versions. The geometry of the channel is specified in Table 3.11.

Table 3.11 *Geometry of trapezoidal channel*

Type	Value	Unit
Length	500	m
Bed width	20	m
Bank slope	1/3	-
Bank height	4	m
Bank crest width	2	m
Bed slope	0.2	%
Flood plain width	10	m

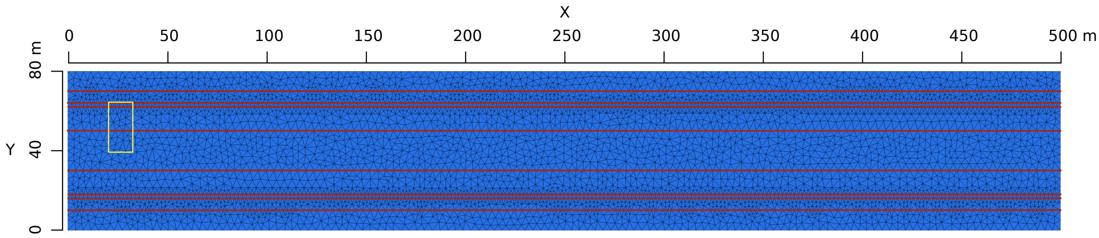

Figure 3.1 *Quality mesh used for the case example with breaklines (red)*

3.3.2 Computational mesh

The topology of the computational mesh used for BASEMENT v3.x is different than for version 2.x, see Tables 3.3 and 3.4. This section describes the differences between the two mesh types and provides a guideline on how to import a v2.x mesh into BASEMENT version 3.x.

3.3.2.1 Quality mesh

Table 3.12 *Quality mesh attributes*

Type	Value
Number of cells	9418
Number of vertices	4862
Minimum triangle angle	30
Cell maximum area	10
Number of breaklines	8
Regiondefs	3 (channel bed, banks and floodplains)

The quality mesh contains all the mesh attributes defined by the user, i.e. cell size, breaklines, regiondefs, minimum triangle angle and maximum cell area, but has no elevation information. The quality mesh of the simple straight trapezoidal channel (Figure 3.1) is identical for both versions, v2.x and v3.x and its attributes are listed in Table 3.12. The procedure to generate a quality mesh with QGIS using the BASEmesh plugin is explain in the Tutorial of BASEMENT v2.8 documentation.

3.3.2.2 Computational mesh

The elevation information can be provided by cross sections, height contour lines, raster data or elevation functions. The computational mesh is generated by interpolating the elevation data at specific points of the quality mesh.

The main difference between the computational mesh of BASEMENT version 3.x and version 2.x lies in the process of attributing the elevation information to the mesh cells. A small surface area (yellow rectangle, Figure 3.1) is schematically reproduced on Figure 3.2 in order to illustrate the two approaches used to create the computational mesh.

In BASEMENT version 2.x, the topographic elevation is attributed to the cell vertices (Figure 3.2 a). The quality mesh defines the location on the elevation model at which

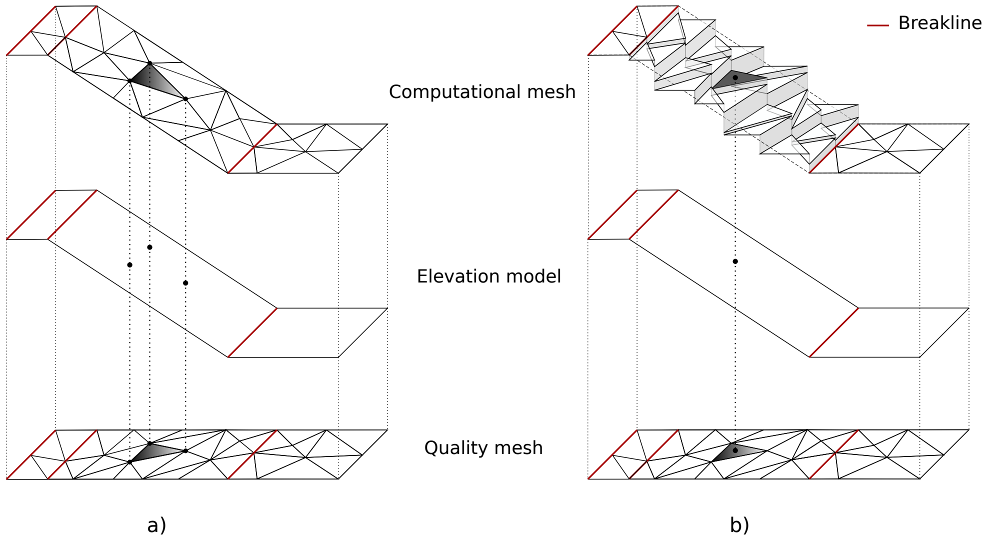

Figure 3.2 *Schematic sketch of the elevation interpolation methods with breaklines (red): a) BASEMENT version 2.x b) BASEMENT version 3.x*

the elevation information will be assigned to create the computational mesh. It results in a continuous interpolation of the topography between the vertices, displaying a variable elevation over the cell. In contrast, for BASEMENT version 3.x, the elevation information is assigned to the coordinate of the cell center, resulting in a constant elevation over the cell surface (Figure 3.2 b).

Breaklines are used to shape the mesh by separating the domain into specific zones (river bed, banks and floodplains) of similar feature (e.g. friction, cell mesh density,. . .). The edges of cells adjacent to the breakline lie on the breakline. In BASEMENT version 2.x, the elevation information of the breakline is exactly similar to that of the vertices along it, which allows to represent clear changes in slope as for example between the bed and the bank. This is not the case in version 3.x, as the elevation information is not assigned to vertices anymore but to the coordinate of the cell center. Therefore, the definition of breaklines deserves some particular attention in BASEMENT version 3.x, where two or more breaklines need to be defined in order to obtain cells at desired elevation (e.g. the elevation at the bank crest has to be garanteed by two breaklines).

The computational mesh of the trapezoidal channel for the simulation with BASEMENT version 2.x is represented on Figure 3.3 and the computational mesh for the simulation with BASEMENT version 3.x on Figure 3.4. The flow direction is from top to bottom.

3.3.2.3 Import of a 2.x to a compatible 3.x computational mesh

The computational mesh of BASEMENT version 3.x can be obtained using a computational mesh of BASEMENT version 2.x. The import of a 2.x mesh to a mesh compatible with BASEMENT version 3.x consists of defining a unique elevation value to each cell from the elevation information of the 2.x mesh vertices.

First of all, the computational mesh version 2.x has to be composed of triangular elements. The QGIS plugin BASEmesh is used to generate a computational mesh for BASEMENT version 2.x, the tutorial is provided in the Tutorial of BASEMENT v2.8 documentation.

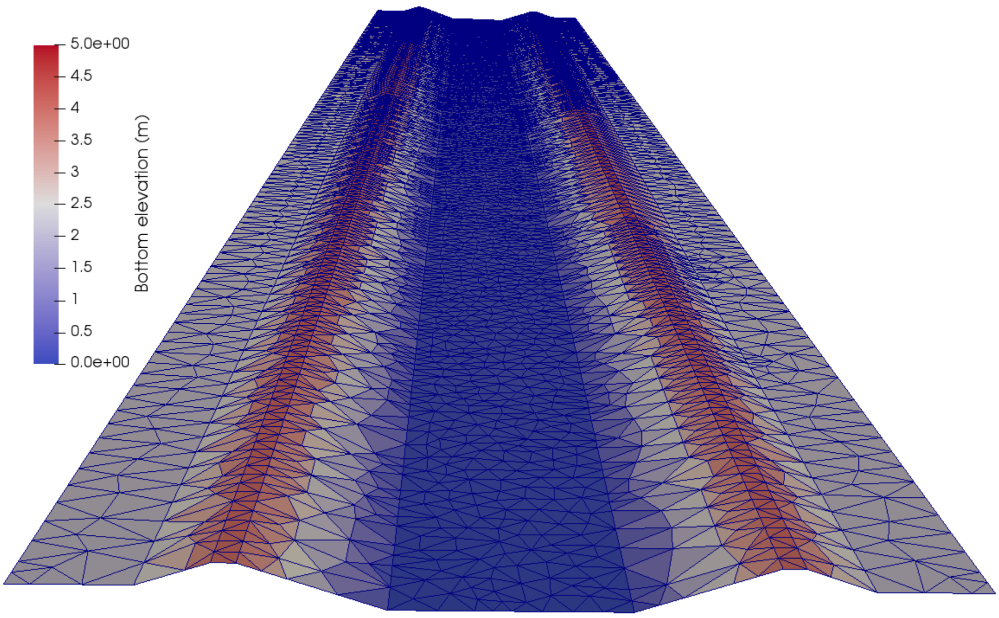

Figure 3.3 *Computational grid BASEMENT version 2.x with breaklines (view from downstream)*

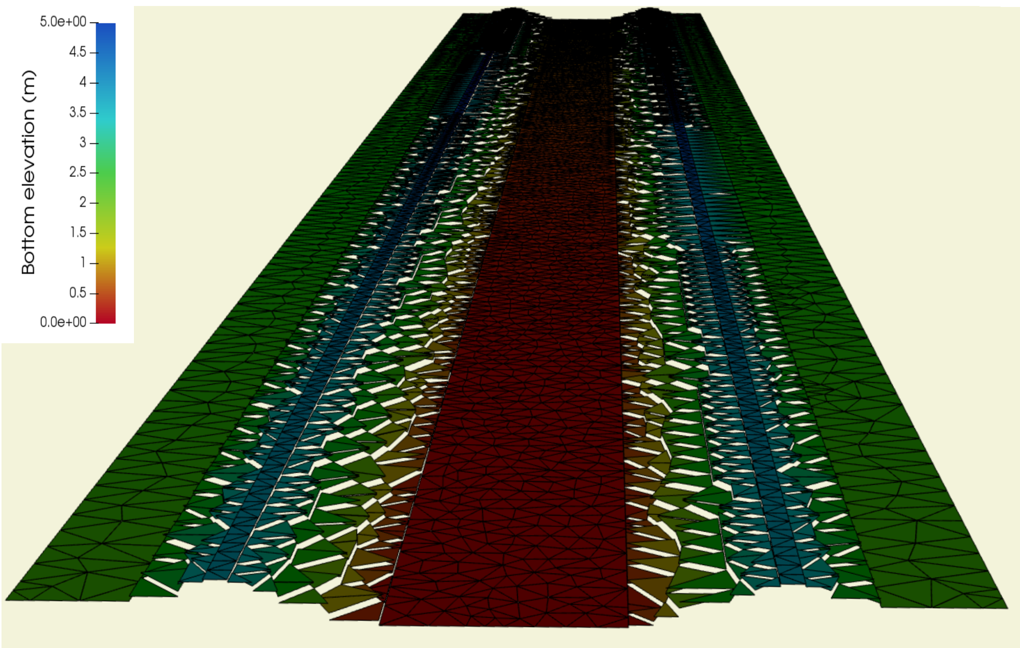

Figure 3.4 *Computational grid BASEMENT version 3.x with breaklines (view from downstream)*

```
MESH2D   #created automatically via meshModel tool
NUM_MATERIALS_PER_ELEM 1
E3T      1    1155     861    1154      2
E3T      2     137    3166    2145      3
 ...      ...   ...       ...   ...    ...
 ...      ...   ...       ...   ...    ...
 ...      ...   ...       ...   ...    ...

ND    3510 401.701104  0.719666  0.803402
ND    3511 292.228530 35.734722  2.584457
NS 3 6 34 65 123 654 -7 Stringdef_name
```

Figure 3.5 *Lines to add manually to the 2dm mesh file (orange)*

The computational mesh is saved in a .2dm file and the stringdefs list is saved in a separate .txt file. In order to use the computational mesh version 2.x for simulations with BASEMENT version 3.x, the .2dm mesh file has to be modified:

1. Add manually the line *NUM_MATERIALS_PER_ELEM 1* after the 1st line of the 2dm file and copy the stringdefs (list of nodes or nodestring) saved in the separate text file to the end of the 2dm file (see example Figure 3.5). The “Stringdef_name” must be replaced accordingly. Please Note: The number of nodes per nodestring is limited to 40. Larger nodestrings must be split up.

2. Inside the model.json file (model setup, see Section 3.3.3), give the name of the modified .2dm mesh file in the GEOMETRY block and choose between the interpolation methods:

- Mean: the average elevation of the three cell vertices is calculated
- Median: the median elevation of the three cell vertices is calculated
- Maximum: the maximum elevation value of the cell vertices is allocated to the cell.
- Minimum: the minimum elevation value of the cell vertices is allocated to the cell.
- Weighted: same as for the mean interpolation method, it calculates the average elevation of the three vertices after applying a weight factor that accounts for the cell geometry (triangle). The mean and weighted interpolation methods give the same results in case of equilateral triangle.

The interpolation method defines how the elevation information stored on the nodes of the computational mesh version 2.x is interpolated in order to generate a computational mesh compatible with BASEMENT version 3.x. The choice of the interpolation method and its relevance in the numerical simulation is let to the user.

The result of the different interpolation methods is displayed in Figure 3.6, where a cross section of the trapezoidal mesh illustrates the local differences between the mesh of BASEMENT version 2.x and the different interpolated meshes used in simulations with BASEMENT v3.x.

Moreover, Figure 3.7 represents the same cross section on the trapezoidal mesh for the same mesh resolution but with only 2 breaklines defined on each side of the bank crest. The change in slope at the levee bottom and crest is less distinct compared to Figure 3.6

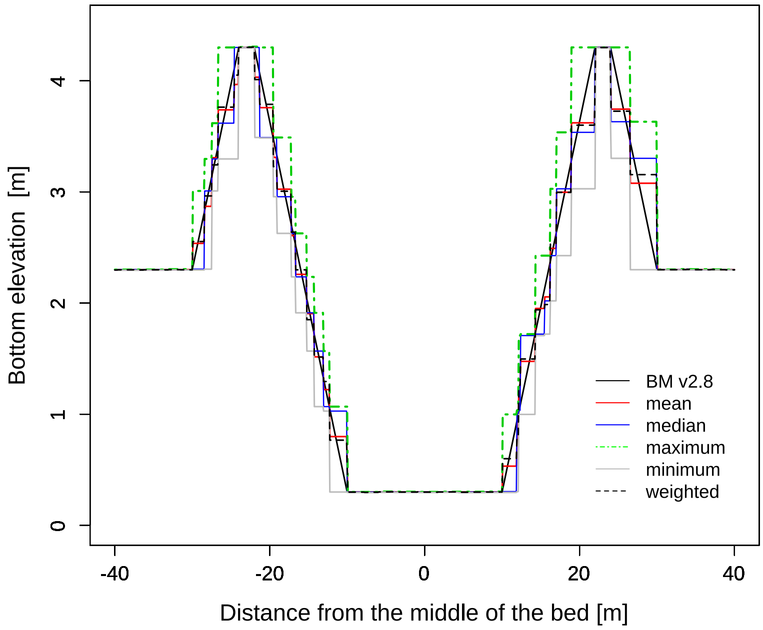

Figure 3.6 *Comparison of interpolation methods with the mesh of BASEMENT version 2.8 (BM v2.8) on a cross section at x= 150 m of the trapezoidal channel with breaklines*

and most of the interpolation methods can't preserve the bank elevation. In the case of a numerical simulation where the exact elevation of the bank is required (e.g. to calculate the bordfull discharge), the definition of breaklines ensures the conservation of the bank elevation, independently from the chosen interpolation methods. Otherwise, the interpolation methods "maximum" and "median" can be appropriate in the situation with only one breakline defined at the crest.

The regions delimited by breaklines e.g. the levees or the river bed, can be assigned to different interpolation methods over the computational mesh. Figure 3.8 illustrates the same cross section but for the trapezoidal mesh with a coarser mesh resolution and with breaklines. In this example, the bank side facing the river bed could be defined as "mean" while the other sides (facing the floodplain) could be defined as "maximum".

3.3.3 Setup and simulation

The simulations were performed for all the interpolation methods using BASEMENT version 3. A simple hydraulic simulation starting from dry initial conditions and with a progressive discharge from zero to the bankfull discharge (water depth around 4 m) was running for 20000 seconds. The output data was recorded every 2000 seconds for which the steady state condition was ensured. The Strickler friction type is used with a value of 30. Standard boundaries are used with the inflow boundary of type 'uniform_in' and the outflow boundary defined as 'uniform_out'. The numerical simulation is performed with the HLLC Riemann solver.

Different files are needed to setup the numerical simulation of BASEMENT version 3:

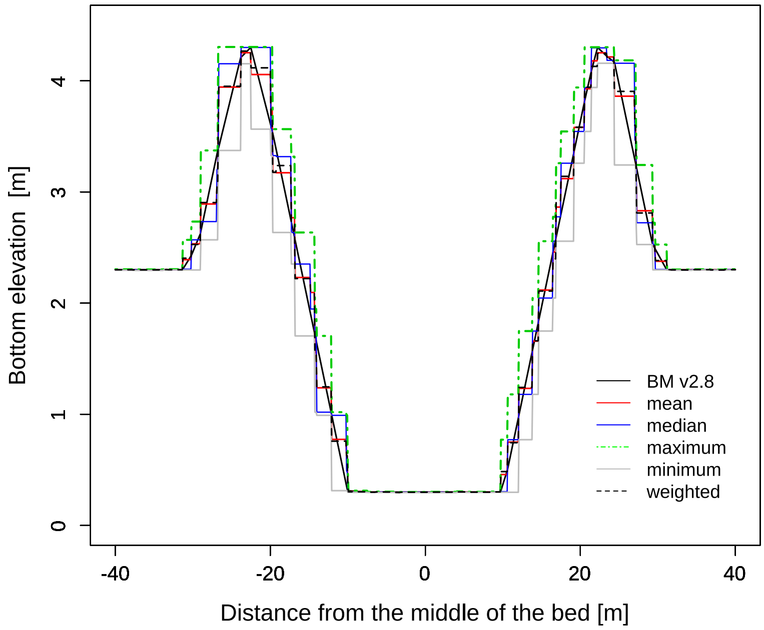

Figure 3.7 *Comparison of interpolation methods with the mesh of BASEMENT version 2.8 (BM v2.8) on a cross section at x= 150 m of the trapezoidal channel with only one breakline defined at the bank crest*

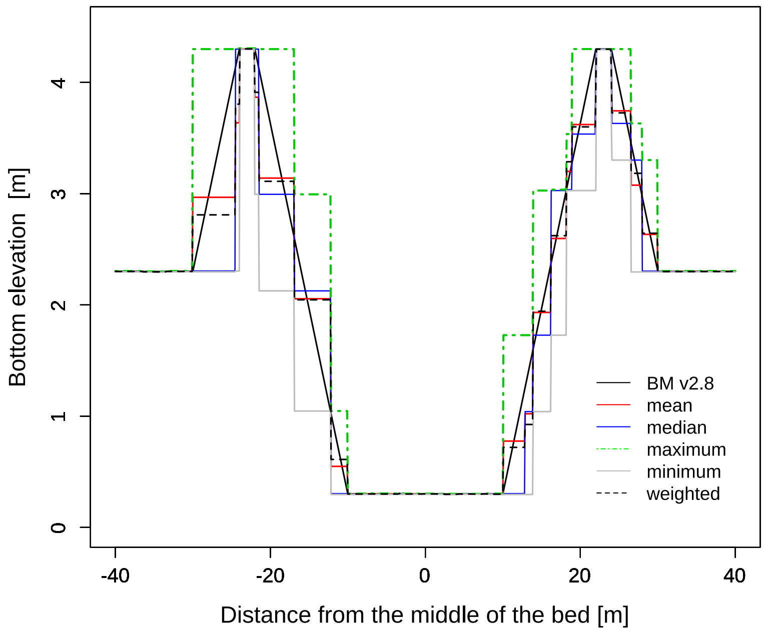

Figure 3.8 *Comparison of interpolation methods with the mesh of BASEMENT version 2.8 (BM v2.8) on a cross section at x= 150 m of the trapezoidal channel with breaklines and for a coarser mesh resolution*

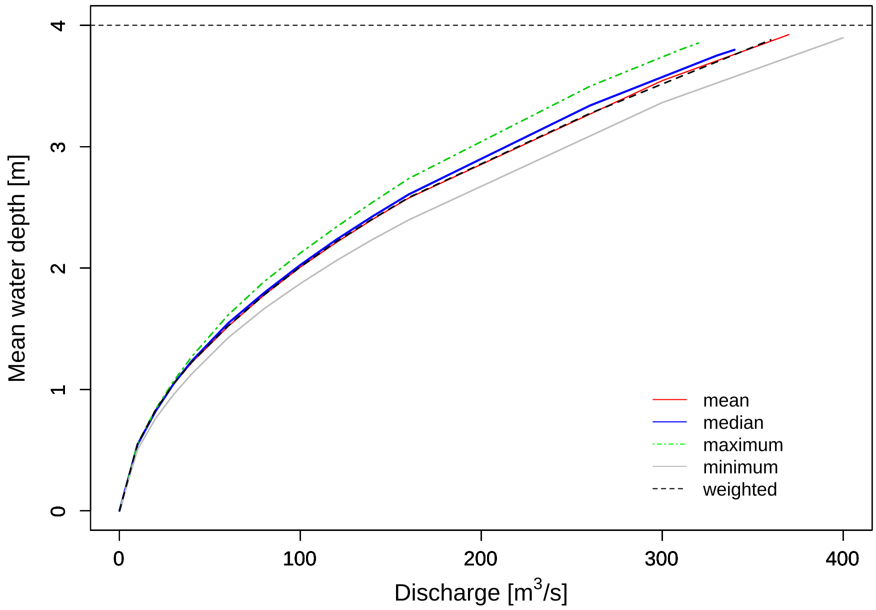

Figure 3.9 *Comparison of H-Q relations between the simulations of BASEMENT v3 for different interpolation types on the trapezoidal channel at x = 150 m.*

- Computational mesh (2dm), including stringdef specification
- Configuration files (model.json, simulation.json and results.json)
- Boundary condition data (.txt)

Three configuration files, model.json, simulation.json and results.json replace the command file (*.bmc) of BASEMENT version 2.x. See the User Manual for more information about their attributes. As decribed in Section 3.3.2.3, the specification of stringsdefs, i.e. the list of nodes is included in the computational mesh (.2dm) in BASEMENT version 3.x.

3.3.4 Results and discussion

In BASEMENT version 3.x, the output data are generated either on cells (cell centered) or at the boundaries (stringdefs). Various results are available (see Table 3.10 and Table 3.9).

3.3.4.1 Hydraulic results

The result of the simulations with BASEMENT version 3 for different interpolation methods are compared in a stage discharge rating curve (Figure 3.9). The mesh features are summarized in Tables 3.11 and 3.12.

The bankfull water depth is 4 m and is represented by the dashed horizontal line. The bankfull discharge represents the capacity maximum of the channel before water overflows the channel banks. The smaller channel capacity is reached with the interpolation type “maximum” and the maximum capacity with the interpolation type “minimum”.

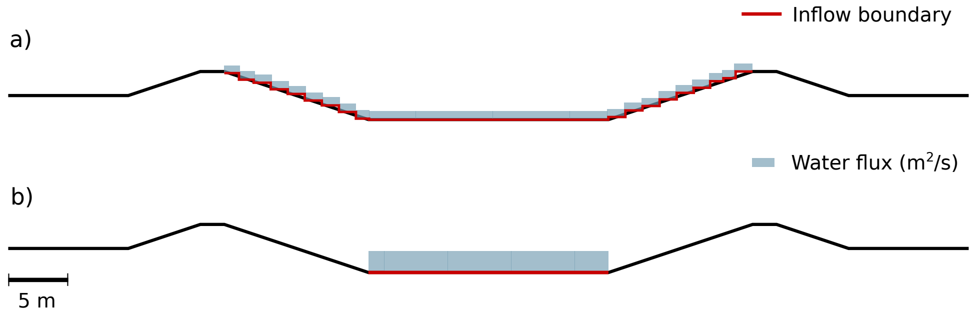

Figure 3.10 *Channel cross section and inflow boundary limit in BASEMENT version 3 a) Inflow boundary limit set at levee's highest point b) Reduced inflow boundary limit*

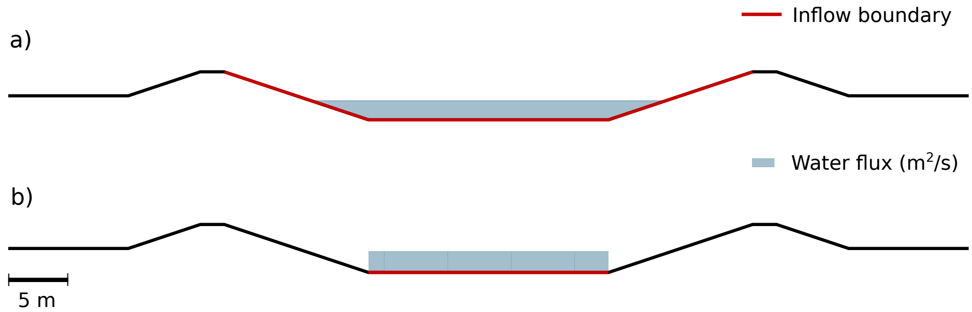

Figure 3.11 *Channel cross section and inflow boundary limit in BASEMENT version 2.8 a) Inflow boundary limit set at levee's highest point b) Reduced inflow boundary limit*

3.3.4.2 Boundary conditions

In BASEMENT version 3, the inflow data is averaged over the boundary length and the mean value is uniformly distributed over the cell edges. This assumption simplifies the boundary conditions compared to BASEMENT version 2.8. Figure 3.10 and Figure 3.11 show two simplified representation of the averaged discharge value distribution on the element edges of the inflow boundary cross section for BASEMENT version 3 and BASEMENT version 2.8 respectively.

An inflow boundary defined between the top elevation of the two levees in BASEMENT version 3 (red line in Figure 3.10, a) generates an undesired converging flow from the bank towards the channel center (Q= 60 m^3/s) and small flux towards the floodplains as represented on Figure 3.12 for a discharge value Q= $200m^3/s$. An inflow boundary restricted to the channel bed width (Figure 3.10, b) will locally increase the flow velocity at the inflow boundary as the discharge increases. In this case, stable flow conditions are obtained after a distance of 20-30 meters from the inflow boundary. Figure 3.13 illustrates the location of high flow velocity by an area of low water level. The water depth at boundary conditions (inflow and outflow) depends on the stringdef length, the friction value and the boundary condition type (froude, uniform,. . .).

The boundary conditions in BASEMENT v3 are more sensitive to the domain geometry and boundary parameters than those in BASEMENT v2.8, therefore, the resulting values located near the boundary conditions should be interpreted with caution and enough space should be provided to reach stable flow conditions. The stringdef length is limited to a maximum of 40 nodes. In case of large computational mesh with fine resolution, the

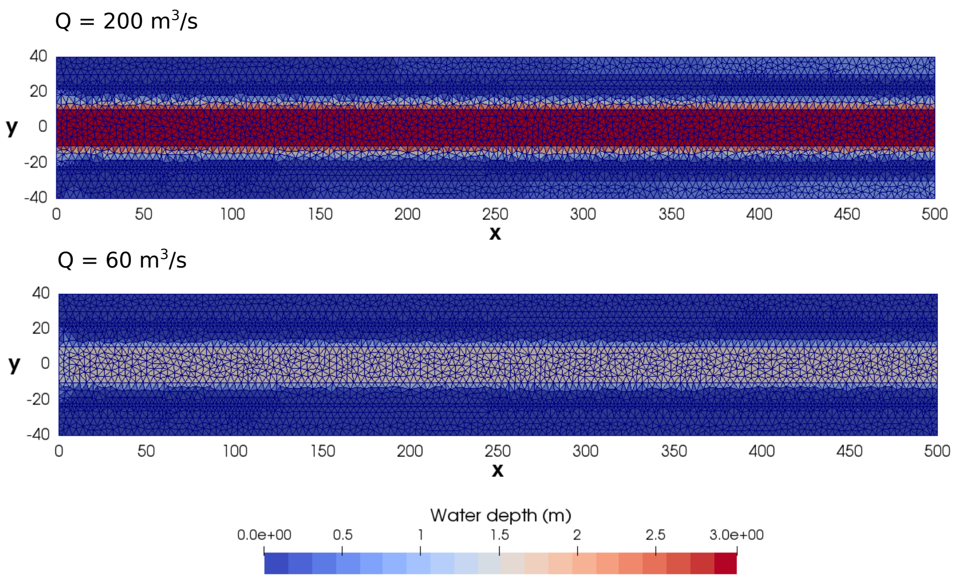

Figure 3.12 *Planar view of the simulation results using BASEMENT v3 of the trapezoidal channel with breaklines and for two discharge stages. Inflow boundary (x= 0.0 m) defined between the top elevation of the levees (Figure 3.10, a), inducing a converging flow from the levee towards the channel center and small fluxes towards the floodplains for higher discharge Q= 200 m^3/s*

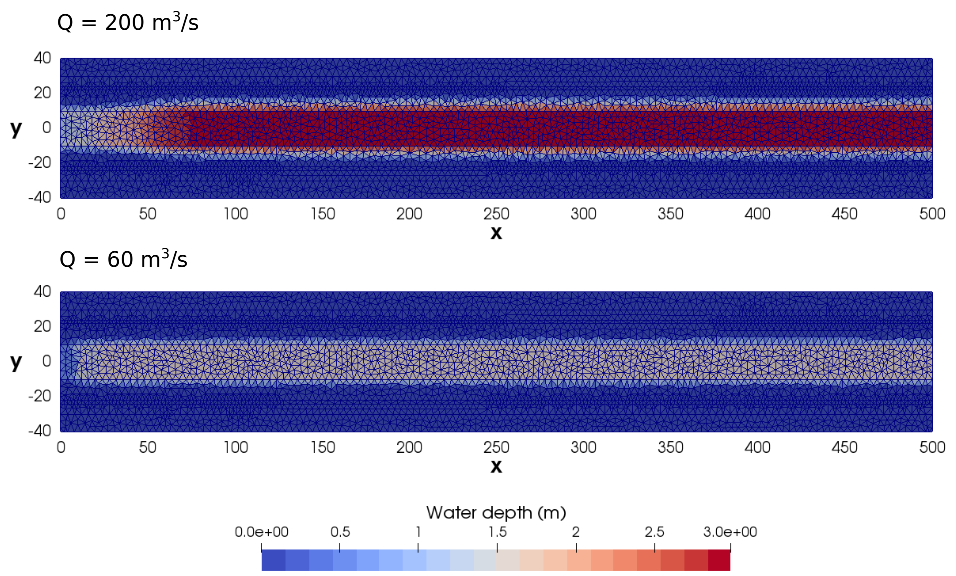

Figure 3.13 *Planar view of the simulation results using BASEMENT v3 of the trapezoidal channel with breaklines and for two discharge stages. Inflow boundary (x= 0.0m) restricted to the channel bed (Figure 3.10, b), inducing an increase of the flow velocity.*

boundaries shall be split into several smaller stringdef of equal length and consequently, the discharge applied to the boundaries has to be adapted.

3.3.4.3 Discussion

This case example of the hydraulic simulation of a trapezoidal channel pointed out the differences between BASEMENT version 2.8 and 3 for the topology and the boundary setup. The use of a BASEMENT v2.x mesh into BASEMENT v3.x is possible by interpolation but the simulation results may differ between the two versions due to the new topology. The simulation with BASEMENT v3.x based on the topology of version 2.x must be calibrated and must be considered as a new model. Moreover, the inflow boundary should be carefully defined in order to avoid unexpected flow behaviour at the boundary. Finally, additional breaklines might be required in order to attribute a precise elevation to the edges or to some parts of the mesh.

3.4 Performance

3.4.1 Introduction

The performance of BASEMENT versions 2.8 and 3 is assessed by comparing the execution time of simulations based on a common test case. The circular dam break test case is introduced here but explained in more detail in the "Test case" section of this documentation. The circular dam break is a hydrodynamic simulation that reproduces the wave propagation induced by the break of a circular dam located at the center of the computational mesh. The reference solution of the circular dam break is given by Toro (2001). The simulation was performed for BASEMENT version 2.8 using a CPU backend on 1, 2, 4, 8 and 12 cores and for BASEMENT version 3 using the CPU backends with up to 32 cores and different GPU cards on Ubuntu 18.04. The backend types are listed and described in more detail in the section "Test case". Besides, five different mesh resolutions were defined for the circular dam break, with 10'000 cells (10k), 50'000 cells (50k), 100'000 cells (100k), 500'000 cells (500k) and 1'000'000 cells (1000k).

3.4.2 Scalability

The speedup of the simulations performed on CPU hardware is shown in Figure 3.14. The speedup S of the respective version is calculated as the division of the sequential runtime T_1 by the runtime with a certain number of cores T_N. The black line represents the ideal speedup according to the increasing number of threads. The speedup is a measure for the parallelizability of the respective version and indicates how the computing time scales with the number of used processor cores. A linear or ideal increase in speed S results for S = N.

For the smallest computational grid (10k), the speedup of both BASEMENT versions only scale linearly up to approximately 4 threads before reaching a plateau. For version 2.8, the scalability does not change significantly for the larger mesh sizes and hence, the performance does not increase significantly anymore when using more than 4 threads. In contrast, the speedup of BASEMENT version 3 scales almost linearly up to 16 threads for the four larger meshes and up to 32 cores for the two largest meshes. Overall, BASEMENT version 3 exhibits significantly improved scalability compared to version 2.8.

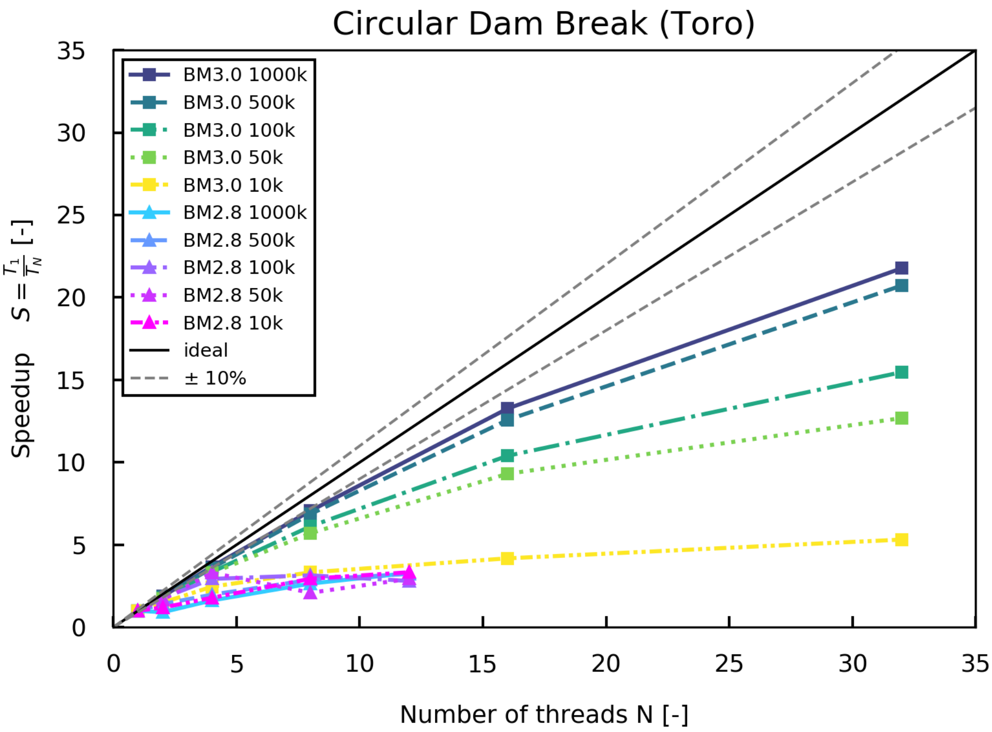

Figure 3.14 *Speedup of the circular dam break test case performed on CPU for an increasing number of threads and different mesh sizes*

3.4.3 Computational Time

The execution time of all the simulations is shown in Figure 3.15. The execution time increases with the computational mesh size for all backends. The execution times obtained on the CPU hardware indicate the significantly improved performance of BASEMENT version 3 compared BASEMENT version 2.8. This increase in performance by a factor of up to 13 is the results of completely restructuring the software. The performance of BASEMENT version 3 can be improved even further by the use of GPU hardware. For example, the runtime for the largest grid (1000 k) on the Intel processor with 32 cores is 8.7 s, while with the RTX2080Ti graphics card (single precision) only 3.6 s are required, which corresponds to a reduction of the runtime by a factor of 2.4. It should be noted that the results of simulations with single and double precision can vary greatly depending on the problem. When using GPUs, however, the significantly better price/performance ratio should be emphasized. For example, the GeForce GTX1080Ti card with double precision has about the same performance as the Intel Xeon Gold 6154 processors when using 32 cores, but with a 6 times lower purchasing price.

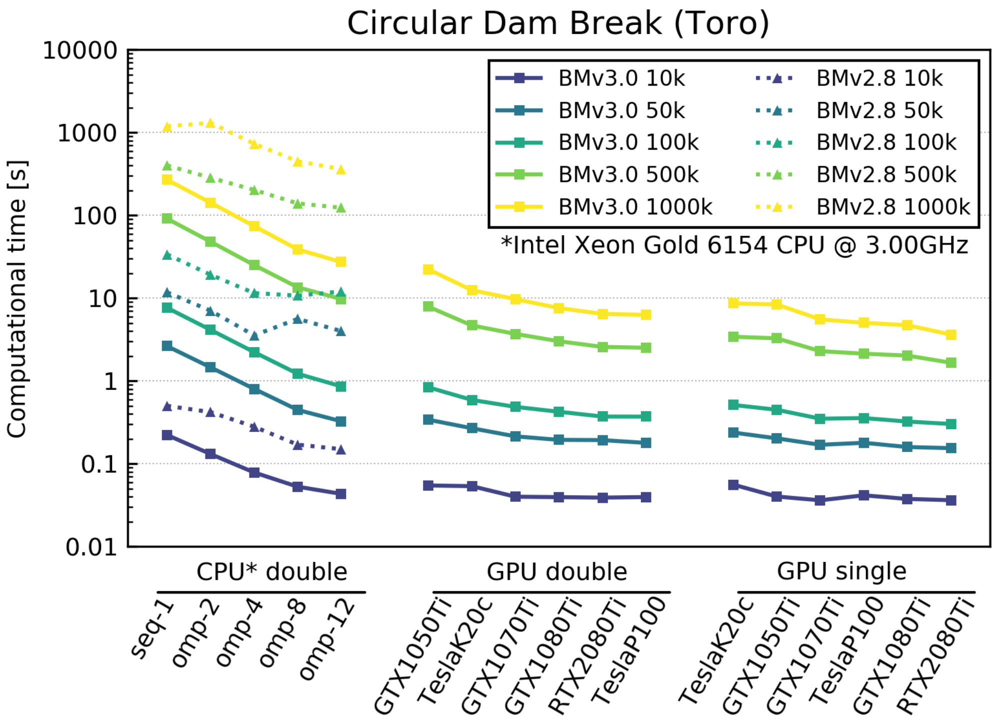

Figure 3.15 *Execution time of the circular dam break test case for different backends and mesh sizes*

4

Release Notes

4.1 Version 3.0

4.1.1 General

- Supported operating systems: Windows 10, Linux Ubuntu 16.04 and 18.04
- Backend types: CPU, GPU (linux only), OpenMP
- New GUI (Graphic User Interface)
- New simulation workflow: numerical simulation in 3 steps (Setup, Simulation, Results) with separate executables for GUI, setup, results and for each simulation backend, e.g. for CPU, SMP and GPU
- Storage of setup and results files in HDF5 container (*.h5)
- New mesh (element centered, 1st order)
- Same mesh used for hydrodynamics and morphodynamics simulations
- Pre-processing: two procedures to generate a mesh using BASEmesh (QGIS plugin)
- Stringdef list and material indices included in the 2dm file
- json command files
- Restart and rerun
- Results in xdmf format
- The value at boundary condition is averaged over the stringdef length (hydraulics and morphology)

4.1.2 Hydraulics

- Boundary types: Wall (default), Standard, Linked (new) and Internal (new)
- Riemann Solver: HLLC, with hydrostatic reconstruction based on modified states (Duran et al., 2013)

- Sources with sink behaviours: exact, available and infinity
- Flood tracking
- Safe mode parameter

4.1.3 Morphology

- Bedload transport: HLL-type Approximate Riemann Solver (Soares-Frazão and Zech, 2011) with Godunov-type upwind scheme
- MPM-like and GRASS-like bedload formula
- Boundary conditions: Wall (default), Standard
- Geometrical (default), wetter area or conveyance weighting schemes for inflow boundary conditions 'sedimentograph' and 'transport capacity'.
- Fix bed elevation over regions (index)

4.1.4 System manuals

- Complete new manuals (Introduction and Installation, User manual, Reference Manual, Tutorials and Test cases)
- New logo
- Migration guide from version 2.x to 3.x
- Simulation workflow
- Tutorials: Flaz river for the pre-processing, setup of an hydrodynamic and morphologic simulation and post-processing
- Test cases: Circular dam break (hydraulics) and Conical dune (morphology)

4.2 Version 3.0.1

4.2.1 Bug Fixes

- The system manuals are now installed by the installers on Linux and are available in the graphical user interface (GUI).

- Correction of the structure of the file result.json in section "Tutorials and Test Cases" of the system manuals.

- Some Windows registry settings were put at incorrect locations by the Windows installer. In particular, the list of installed software provided by Windows did not include BASEMENT. This problem has been fixed.

4.3 Version 3.0.2

4.3.1 General

- BASEMENT now natively supports CUDA on Windows. This allows the use of CUDA-enabled GPUs for computation under Windows 10.
- In addition, many third party libraries and the installers have been updated. In particular, the version for Microsoft Windows uses a new installer, therefore we recommend to use the link in the start menu to uninstall previous versions of BASEMENTv3 before you update.

4.3.2 Bug Fixes

- Vector data are now loaded correctly in Paraview Versions 5.7.0 and newer.
- The setup binary does not produce an error anymore during restart simulations if the .h5 file extension is provided in the path for the restart.h5 file. The .h5 extension should explicitly be provided in the file name.
- The number of decimal places for doubles in the GUI has been increased from 3 to 6 digits.
- Minor corrections to the System Manual.

4.3.3 Known Issues

- Model setup fails if there is a dot '.' in the working directory path. For example: *"MySimulations/Sim1.1/"* does not work, while *"MySimulations/Sim1_1/"* works.
- Aborting a simulation using Ctrl+C can corrupt the HDF5 result file.
- Currently, there is a known, but not yet resolved issue in the sediment transport solver. More specifically, the flux calculation exhibits an asymmetrical behavior depending on the orientation of the flux vector with respect to the edge normal. Up to now, we have not observed a significant impact of this on the simulation of sediment transport. We will fix this issue as soon as possible and recommend to examine the plausibility of morphodynamic simulation results critically as always.

4.4 Version 3.1

In BASEMENT Version 3.1 the bed load transport has been extensively revised and supplemented (e.g. slope collapse). The new features include the transport of passive tracers and additional output variables (e.g. transport capacity or bed shear stress). In general, extensive bug fixes were made and the documentation was revised.

4.4.1 General

- The console output now displays the most recent output of the programs by default.
- Pressing Ctrl+C now aborts the simulation after the current time step.
- Implementation of a tracer transport module.
- Implementation of the bedload transport capacity as output variables (trsp_capacity and trsp_capacity_abs).
- Implementation of Smart & Jaeggi (1983) bedload transport formula.
- Implementation of the LINKED morphology boundary condition *equilibrium_linked*.
- Implementation of the LINKED hydraulic boundary condition *zhydrograph_linked_kinE*.
- Implementation of the of passive scalar transport by advection
- Implementation of max. bed shear stress as tracking variable (via FLOOD in model.json).
- Implementation of gravitational transport (e.g. bank collapse) due to the local bed slope exceeding a critical angle.
- An improved method for the local bed gradient calculation has been implemented. The newly implemented method secondary_mesh calculates the bed gradient based on (i) the bed elevation of the neighbouring cells in case of 3 neighbouring cells, (ii) the bed elevation of the two neighbouring cells and the cell itself in case of 2 neighbouring elements or (iii) the bed elevation of the neighbouring cell and the cell itself in case of one neighbouring element. The improved method is used by default, while the previous method (area_weighted) is still available but not recommended. The method for the bed gradient calculation can be selected unter MORPHOLOGY/PARAMETERS/bed_gradient_type. The bed gradient has an influence on the bedload transport direction if the block LATERAL_SLOPE is activated and on the threshold of incipient motion for bedload transport if the block INCIPIENT_MOTION is activated.
- The local bed gradient is available as output variable under the names bed_gradient in the simulation.json (only if the INCIPIENT_MOTION or LATERAL_SLOPE blocks are activated).
- During the bedload flux computation, the bedload transport flux is split in an advective part (same direction as flow direction) and a diffusive part (due to bedload direction correction from lateral transport and curvature). The advective part is solved with the existing HLLC solver, while an upwind scheme is applied for the diffusive flux. This makes the solver more stable when using bedload transport direction correction due to local slope effects or curvature.
- An improved method for the local velocity gradient calculation has been implemented. The newly implemented method calculates the velocity gradient based on (i) the velocity of the neighbouring cells in case of 3 neighbouring cells, (ii) the velocity of the two neighbouring cells and the cell itself in case of 2 neighbouring elements or (iii) the velocity of the neighbouring cell and the cell itself in case of one neighbouring element. The new method replaces the previous calculation method and results in improved predictions of the curvature effect on the bedload transport direction.
- 2dm-mesh files are now supported as input for the fixed bed elevation. The topology of the fixed bed mesh must be identical with that of the computational mesh and

must only differ in the elevation information.
- The documentation has be revised and updated.

4.4.2 Bug Fixes

- Xdmf output files that are created using the UI now reference the auxiliary results file using a relative file path.
- A bug in the bedload transport flux calculation has been fixed. The bug resulted in an asymmetrical behavior depending on the orientation of the flux vector with respect to the edge normal.
- The parameter max_time_step is now taken into account in the computation of the integration time step.
- The missing file browser for the 'hqrelation_file' tag of the STANDARD hydraulic boundary condition 'hqrelation_out' has been added.
- During the calculation of the uniform flow depth in the uniform_out boundary condition, incorrect cell dimensions might have been used. This problem has been fixed.
- For elements which (1) did not belong to any of the regions from REGIONDEF or (2) for elements whose region was not listed under FRICTION/regions, the default_friction value should have be used. However, this has not been the case. Instead, for case (1) an "out of range" error occurred, while for case (2) a friction value of 0.0 has been used. With the fix, the default_friction value is used in both cases (1) and (2).
- In the case of "region_defined" initial conditions, the initial water surface elevation and the specific fluxes in x- and y-direction were set to 0.0 for elements which did not belong to any of the regions in REGIONDEF. With the bugfix, the initial conditions for cells which do not belong to any regions or whose region is not listed under INITIAL/regions "dry" initial conditions are set and the user is informed with a warning.
- A bug in the calculation of the lateral transport direction (Block IKEDA) has been fixed. The bug led to an underestimation of the lateral transport. Further, a more general approach has been implemented for the influence of lateral bed slopes on the bedload transport direction. The block IKEDA has been renamed to LATERAL_SLOPE.
- An inconsistency in the setup resulted in the approach of Van Rijn (1989) being chosen automatically when the INCIPIENT_MOTION block was activated.
- Mathematical operations of incorrect precision (single/double precision) were used by the kernels.
- The non-dimensional bed shear stress and the critical non-dimensional bed shear stress are now available as output variables under the names theta and theta_critical in the simulation.json (only if the MORPHOLOGY block is activated).

4.4.3 Known Issues

- Model setup fails if there is a dot '.' in the working directory path. For example: *"MySimulations/Sim1.1/"* does not work, while *"MySimulations/Sim1_1/"* works.

Note: Existing installations of BASEMENT version 3.0.1 (or earlier) are not automatically detected by the updated installer. Therefore uninstall any previous version of BASEMENT e.g. using the link in the Start Menu before installing the newest version.

5

Summary of Features Version 3.1

5.1 Hydrodynamic features

Riemann Solver

- HLLC, with hydrostatic reconstruction based on modified states (Duran et al., 2013).

Hydraulic Initial Conditions

- Dry
- Continue
- Region defined (regiondef) for water surface elevation or water depth, u and v

Parameters

- CFL
- Minimum water depth
- Fluid density
- Maximum time step

Boundary Conditions

- WALL : inviscid, default
- STANDARD (in parenthesis user-required data):
  - INFLOW: uniform (discharge; slope), froude (discharge, froude number), hq_relation (H-Q relation), zhydrograph (water surface elevation, inflowPossible)

  - OUTFLOW: uniform (slope), zero_gradient (-), weir (weir height, constant or dynamic poleni factor), hq_relation (H-Q relation), dynamic wall (collapse time), zhydrograph (water surface elevation, inflowPossible)

- INTERNAL: dynamic wall (collapse time), internal wall (-), hq_relation (H-Q relation)
- LINKED: hq_relation (H-Q relation), 2 way hq_relation (2 H-Q relations, time lag, water surface elevation upstream and downstream), weir (weir height, constant or dynamic poleni factor), zhydrograph (water surface elevation) zhydrograph with kinetic energy (water surface elevation)

Friction

- Type: implicit Runge-Kutta 2nd order integration
- Closure types:
  - Manning
  - Strickler
  - Chezy
  - Bezzola

All require a default (or index defined) friction value.

Flood

- Flood tracking of water front arrival time, maximum water depth, maximum flow velocity, maximum specific discharge, maximum bed shear stress (tracking time step)

Source (water volume)

- Type: total (as discharge, m3/s), distributed (as rain, mm/h)
- Sink behaviors:
  - Exact (as prescribed)
  - Available (as prescribed or less)
  - Infinity (as much as possible)

5.2 Morphodynamic features

Bedload transport

- HLL-type Approximate Riemann Solver (Soares-Frazão and Zech, 2011)

Parameters

- Morphodynamic start time
- Sediment porosity
- Sediment density

Initial conditions

- Mesh file
- Continue

Incipient motion

- van Rijn (1989) and Chen et al. (2010)
- Angle of repose

Closure formula

- MPM (coefficient = 8, exponent = 15, critical threshold = 0.047)
- MPM-like (coefficient, exponent, critical threshold are adaptable)
- GRASS-like (coefficient, exponent, critical threshold are adaptable)
- Engelund and Hansen
- Smart and Jaeggi (1983)

Direction

- Lateral bed slope effect (e.g. Ikeda, 1982, Talmon1995)
- Curvature effect

Bedload boundary conditions

- WALL: inviscid, default
- STANDARD:
  - INFLOW: equilibrium (reference_bed_elevation), sedimentograph (sediment_discharge), transport capacity (boudary_factor)
  - OUTFLOW: equilibrium (reference_bed_elevation)
  - Weighting scheme for transport capacity and sedimentograph: geometrical (default), wetted area, conveyance
- LINKED: equilibrium (reference_bed_elevation at upstream boundary)

Bed material

- Grain class

- Fixed bed

Gravitational Transport

- Critical angle for wet/dry material
- update time step
- maximum settling velocity
- minimum bed elevation change

Source (sediment volume)

- Type: total (as discharge, m3/s)
- Sink behaviors:
  - Exact (as prescribed)
  - Available (as prescribed or less)
  - Infinity (as much as possible)

6

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BASIC SIMULATION ENVIRONMENT
FOR SIMULATION OF ENVIRONMENTAL FLOW
AND NATURAL HAZARD SIMULATION

APPENDIX

VERSION 3.1
November 2020

1

Third Party Software

1.1 Third party software copyright notices

Abseil

Bzip2

Double-conversion

Egl-registry

Freetype

```
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The gzip module uses the zlib license (see src/gzip/zlib.h) which too is
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Glibc-queue

Google Test

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JSON for Modern C++

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linked subprograms that the work is specifically designed to require,
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The Corresponding Source need not include anything that users
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  Corresponding Source fixed on a durable physical medium
  customarily used for software interchange.

  b) Convey the object code in, or embodied in, a physical product
  (including a physical distribution medium), accompanied by a
  written offer, valid for at least three years and valid for as
  long as you offer spare parts or customer support for that product
  model, to give anyone who possesses the object code either (1) a
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  product that is covered by this License, on a durable physical
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  more than your reasonable cost of physically performing this
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  alternative is allowed only occasionally and noncommercially, and
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  with subsection 6b.

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  Corresponding Source in the same way through the same place at no
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  copy the object code is a network server, the Corresponding Source
  may be on a different server (operated by you or a third party)
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