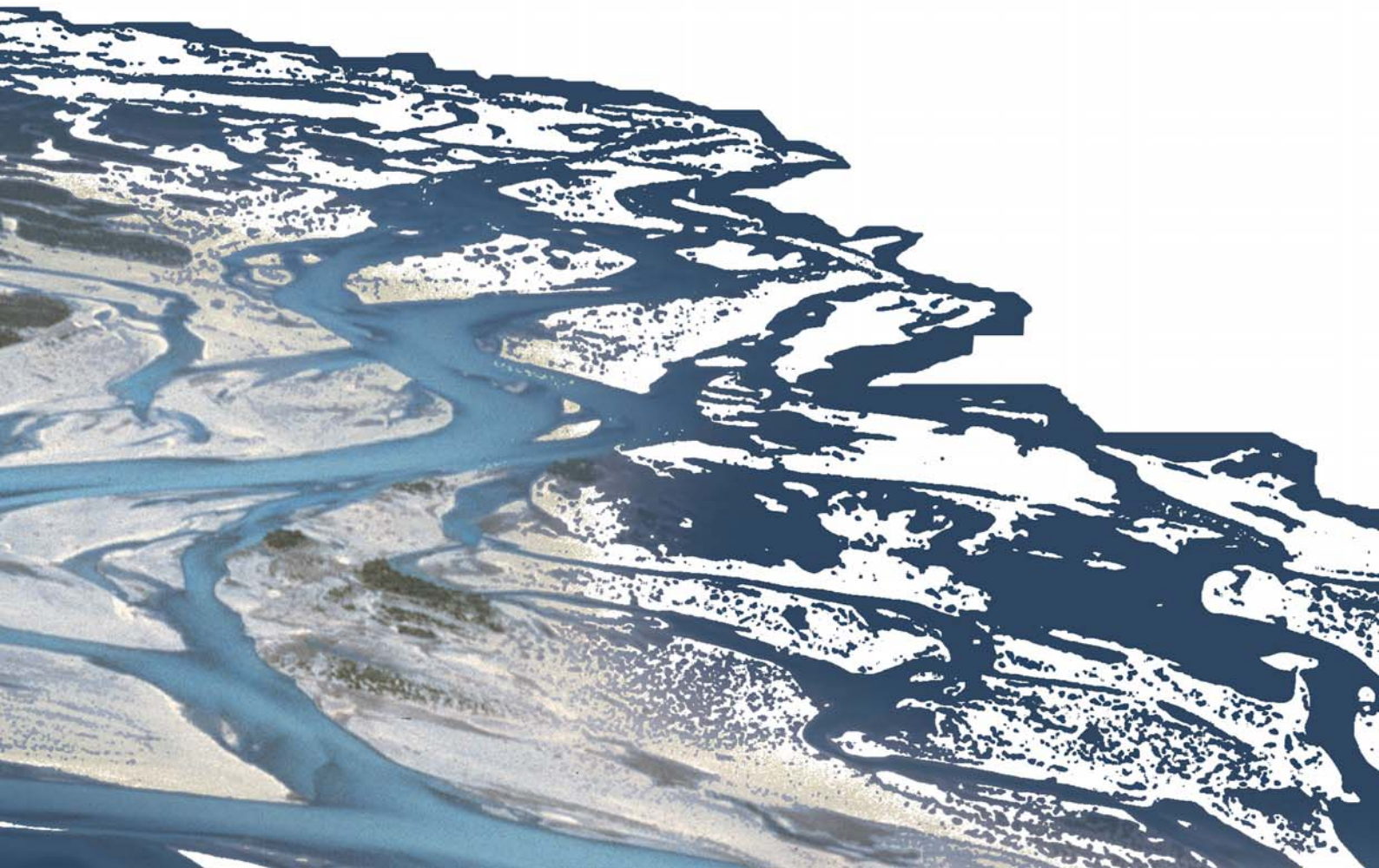## BASEMENT

**BASIC SIMULATION ENVIRONMENT
FOR SIMULATION OF ENVIRONMENTAL FLOW
AND NATURAL HAZRAD SIMULATION**

SYSTEM MANUALS

**VERSION 3.0
September 2019**

Preamble

VERSION 3.0.1

October 2019

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For Website:

BASEMENT – Basic Simulation Environment for Computation of Environmental Flow and Natural Hazard Simulation, 2019. https://www.basement.ethz.ch

For Software:

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INTRODUCTION & INSTALLATION

BASEMENT

Contents

1

Summary of Contents

1.1 Introduction

BASEMENT version 3.0 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 3.0 and guides the user through the process of using BASMENT version 3.0.

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 3.0 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 inside the migration guide for the users already familiars with BASEMENT. The release notes summaries the changes introduced by BASEMENT version 3.0 and the summary of features provides an overview of the available functionalities of BASEMENT version 3.0.

1.2.2 User Manual

The user manual provides information about the simulation environment of BASEMENT version 3.0. 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 3.0.

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 3.0 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 3.0 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 3.0 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 3.0 is **only** possible for CUDA-enabled (Compute Unified Device Architecture) GPUs produced by NVIDIA. BASEMENT version 3.0 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	Quadro P620
Memory [GB]	5	12	11	8	4	2
Architecture	Kepler	Pascal	Pascal	Pascal	Pascal	Pascal
Bandwidth[GB/s]	208	549	484	256	112	80
CUDA cores	2496	3584	3584	2432	768	512

2.1.2 Installing under Windows

BASEMENT version 3.0 is available for Microsoft Windows Windows 10 operating system. Besides the native installation under Windows 10, there is the possibility to run the BASEMENT version 3.0 under a Linux system on Windows 10, e.g. in a Linux-based Docker container or in the Windows Subsystem for Linux (WSL) which is available in the Microsoft Store.

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. Be aware if you want to install BASEMENT on Windows 10 using Docker or the Windows Subsystem for Linux you need the installer for Ubuntu 18.04
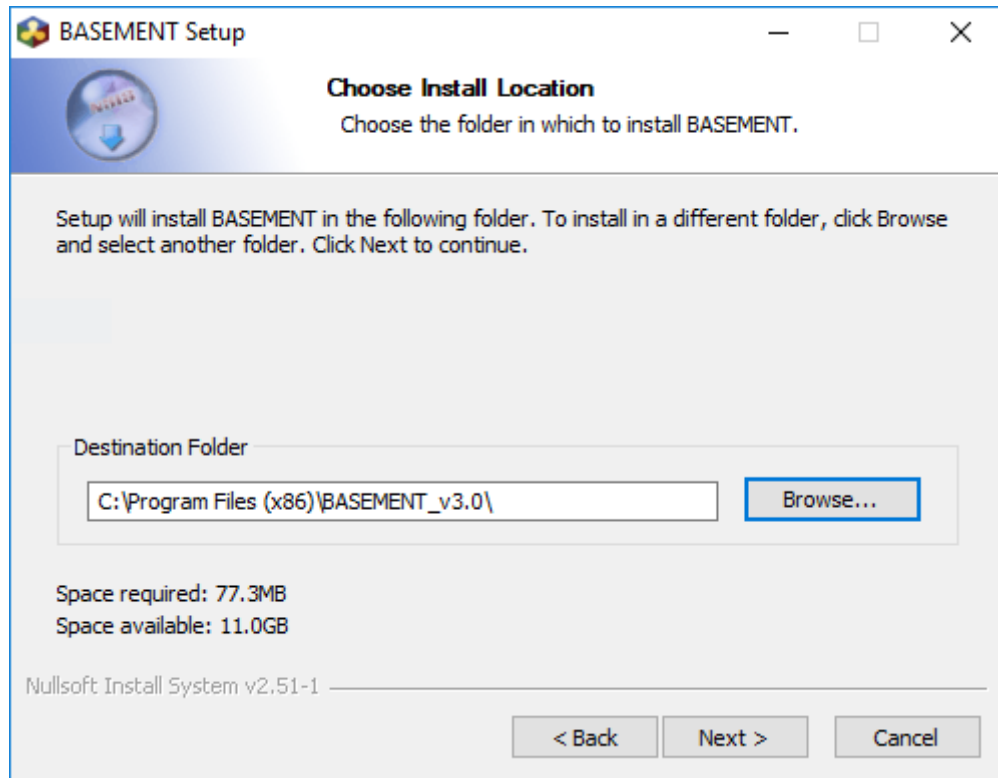
Figure 2.1 *Select the installation folder.*

(LTS). If you want to install BASEMENT version 3.0 under Windows 10 using Docker, also download the provided Dockerfile.

2.1.2.2   Installation procedure under Windows 10

Please note, that existing installations are not automatically detected by the installer. If you have already installed BASEMENT v3.0.0 and would like to install a more recent version, then uninstall BASEMENT v3.0.0 e.g. using the link in the start menu before installing the new version of BASEMENT. 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 locations are "C:\Program Files(x86)\BASEMENT_v3.x" respectively "C:\BASEMENT_v3.x" (Figure 2.1). You are free to choose any other directory.

Step 3: Select program's shortcuts

Select a Start Menu folder to create the program's shortcut (Figure 2.2).

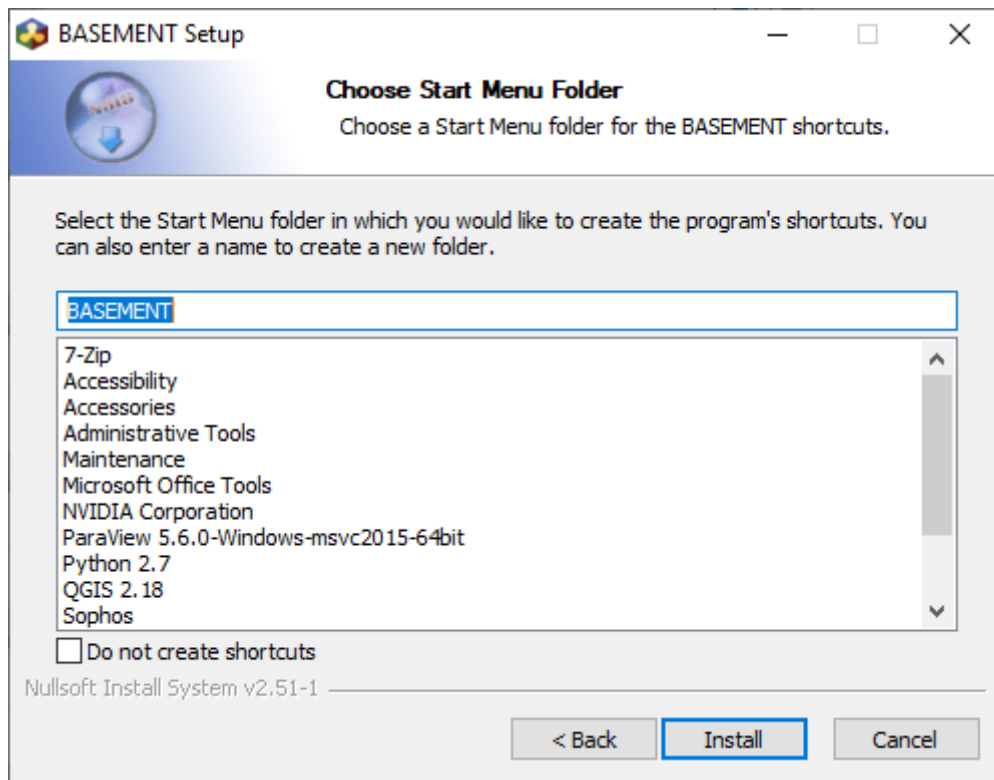*Step 4 and 5: Confirming and finishing the installation*

Figure 2.2 *Select the Start Menu folder.*

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 and launch the program. The graphical user interface should appear as in Figure 2.3.

You can start the program by opening the Start Menu, navigating to the Start Menu Folger of BASEMENT and by clicking on the program icon of BASEMENT version 3.x (Figure 2.4). If you wish to create a Desktop shortcut, simply drag the program icon to your Desktop (Figure 2.5). Clicking on the BASEMENT icon runs the program as a standalone application including a simple graphical user interface (to run BASEMENT in batch mode see the section Run the programm in the User manual documentation part).

2.1.2.3   Installation procedure under Windows 10 using Docker

The Docker engine and the X-server make it possible to run BASEMENT version 3.x on a Windows 10 system. It is recommended to run and save the BASEMENT simulations on the Windows system and give the Docker engine access to the Windows drive/directory where you would like to store the BASEMENT simulations. Data stored in the Docker environment is lost if the Docker container and images are removed.

Step 1: Install and setup X-server (required for GUI)

To make use of the graphical user interface (GUI), the installation of an X-server on the host system (Windows 10) is required. Different X-servers are available for free, e.g. VcXsrv or Xming.

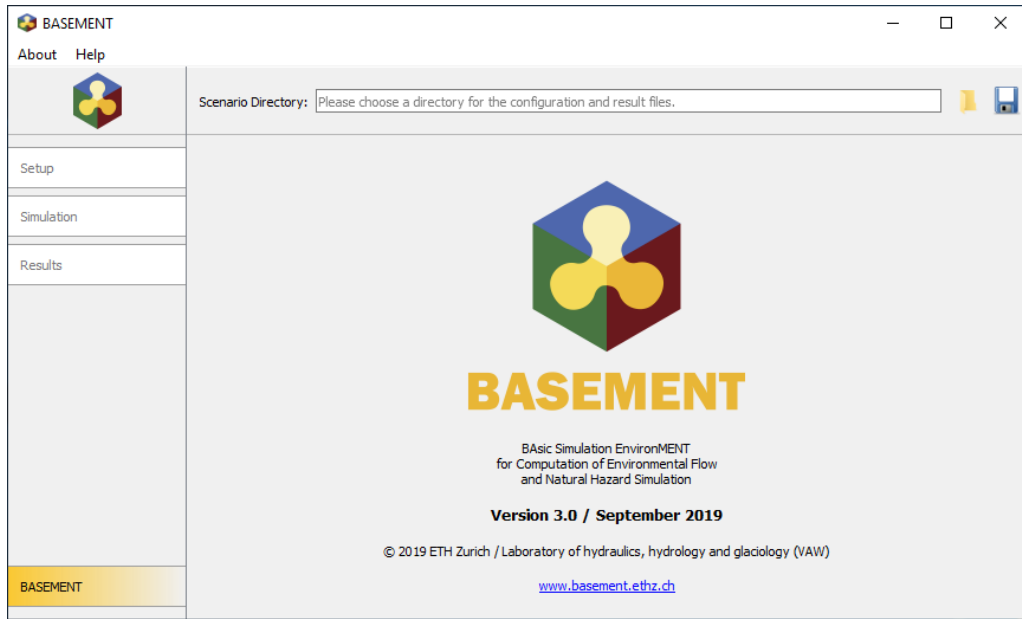Here, instructions are given to install and setup VcXsrv (only one of many X-servers available).

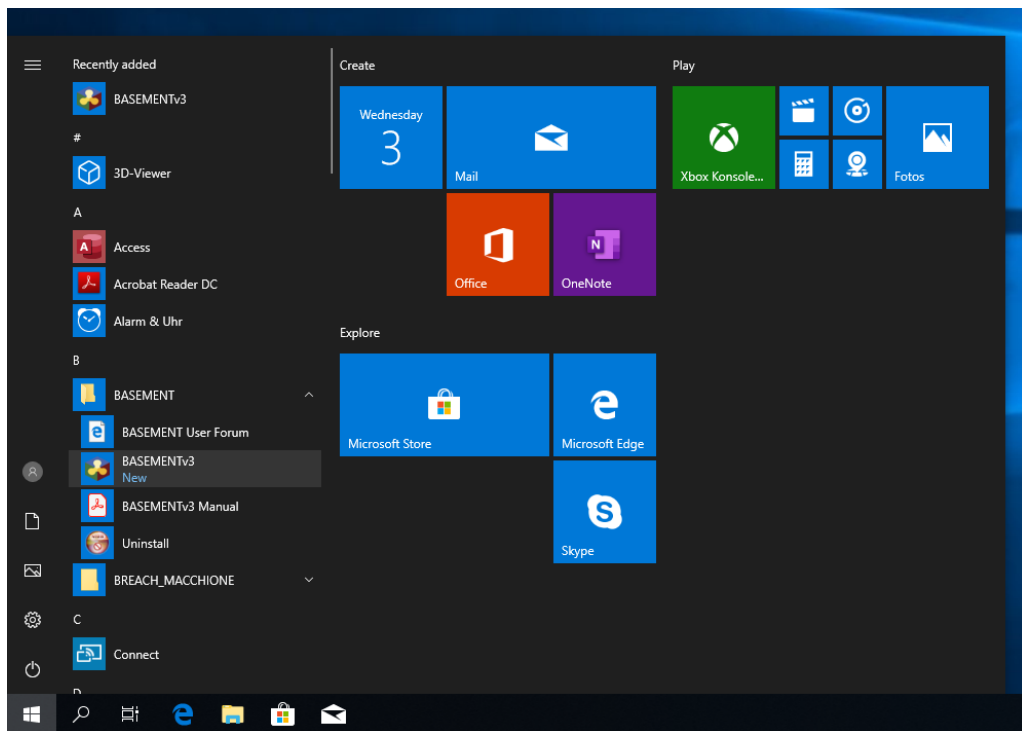**Figure 2.3** *Select the Start Menu folder.*

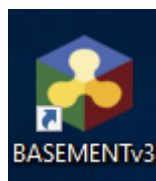**Figure 2.4** *Start BASEMENT over the icon in the Start Menu folder.*

Figure 2.5 *Desktop shortcut.*
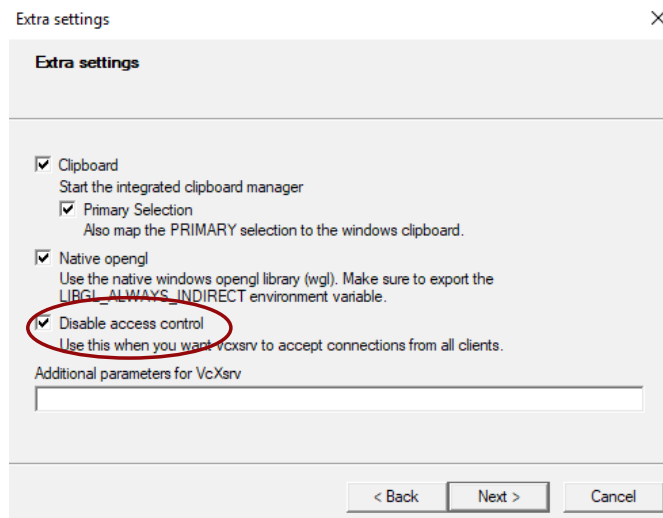
Figure 2.6 *Disable access control under extra settings*

Download the X-server VcXsrv from the website below and run the installer.

https://sourceforge.net/projects/vcxsrv/

Step 2: Start X-server

Start the X-server by starting the application XLaunch. It is recommended to choose the default setting for the "Display settings" and "Client startup". However, to display the graphical user interface (GUI) of BASEMENT requires to disable access control by marking the Field "Disable access control" under the "Extra setting" (Figure 2.6). Note: Only disable access control if this is suitable for your environment.

Check if your X-server is running (under the hidden icons in the taskbar).

Step 3: Installing Docker

Download Docker for Windows (Stable channel) from the website below (under **Install Docker Desktop for Windows desktop app** > click on **download.docker.com**) and follow the installer. It is recommended to choose the default settings.

https://docs.docker.com/docker-for-windows/install/

The installation process might end with an error "Cannot open vmms service on computer" (Figure 2.7). In this case, you need to activate Hyper-V on Windows 10. Therefore, search for "Turn Windows features on or off" in the taskbar and activate Hyper-V by setting a mark and click OK (Figure 2.8).

Restart the computer if prompted.

After the installation of Docker, start "Docker Desktop". The Docker icon will appear in the taskbar (under the hidden icons).

Step 4: Docker Settings

In the Docker settings you can configure drives and computational resources that are accessible to the Docker environment. Therefore, right-click on the Docker icon and go to "Settings" (Figure 2.9).

Share Drives

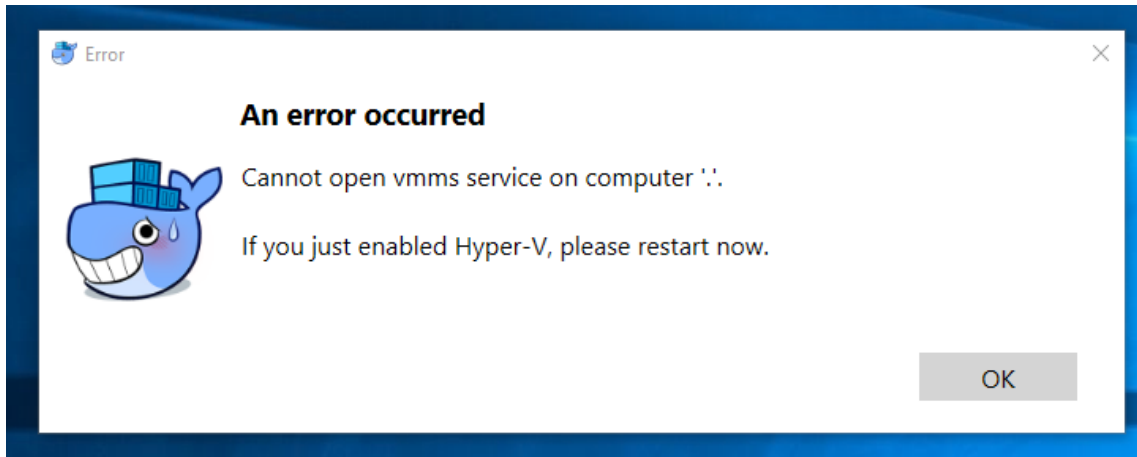**Figure 2.7** *Error during installation process of Docker.*
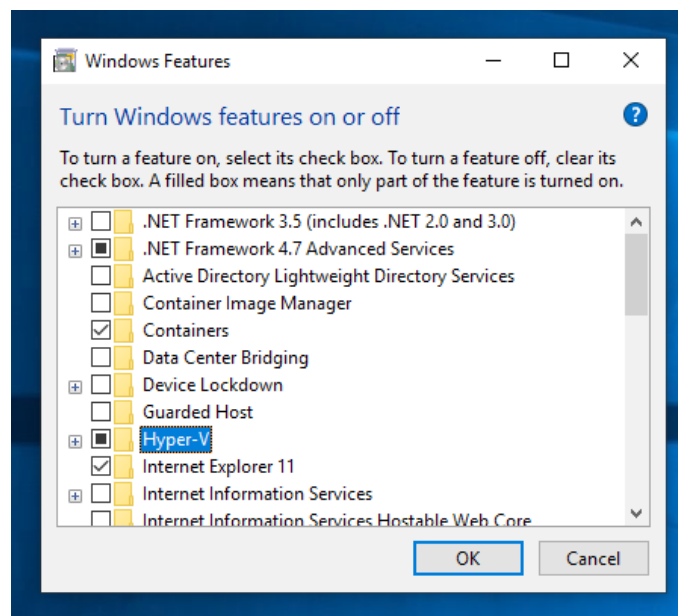
Figure 2.8 *Activation of HyperV under Windows 10.*
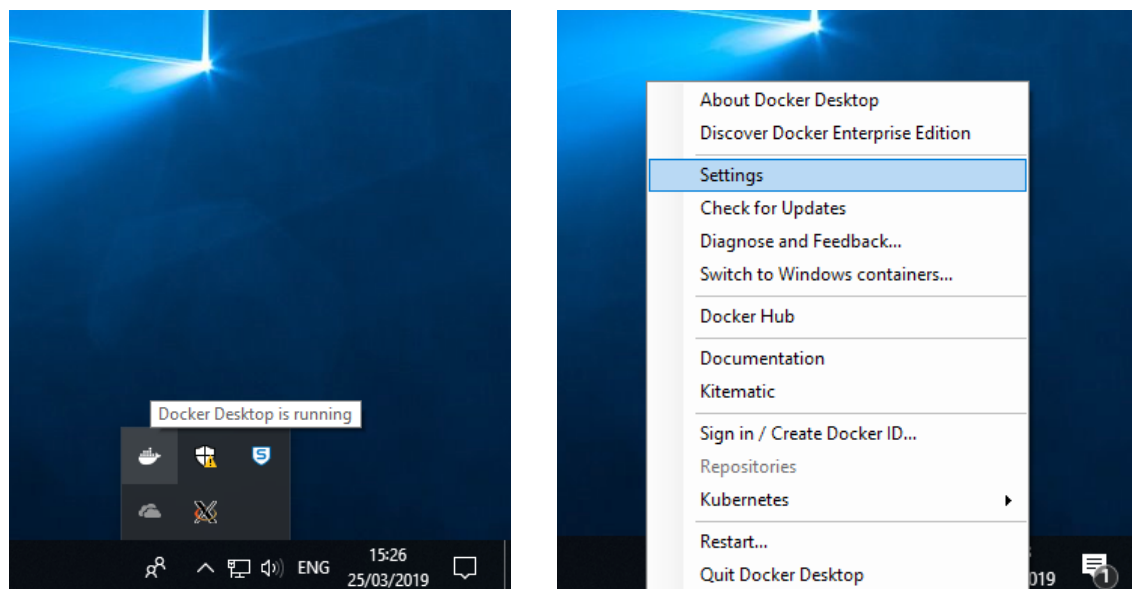
Figure 2.9 *Docker Settings.*

Local drives of your computer can be shared with your docker environment. Go to the tab "Shared Drives" and mark the drives that you would like to share with your Docker environment. You should share the drives on which you want to run and save the BASEMENT simulations.

Resources for the Docker Engine

Under the tab "Advanced", you can manage the computational resources that you would like to make available to your Docker Engine. In order to run simulation on multiple threads, the desired number of threads (CPUs) must be made available to the Docker Engine. The same applies for Memory and Swap. The Disk images location and Disk image size should not be changed.

Click apply to save changes.

Step 5: Build a Docker image with Ubuntu

Download the BASEMENT package *BASEMENT_v3.x_linux64_ubuntu18.zip* and the Dockerfile from the website https://basement.ethz.ch. Extract the content of the .zip file to the same directory as the Dockerfile. Now, open the Windows PowerShell (not ISE) and go to the directory containing the downloaded BASEMENT installer *BASEMENT_v3_linux64_ubuntu18.sh* and the *Dockerfile.*

To create a Docker image with Ubuntu, run the following command (don't forget the '.' at the end!):

```
> docker build -t basementv3:ubuntu .
```

Step 6: Create a Docker container

To create a Docker container based on the Docker image created before run the command below (must be written on one line). During this step, a directory of the Windows 10 system can be directly connected to the Docker container with the argument -v <path\to\Windows10\directory>:<path/in/container>. With the command below, you

have access to your home directory <C:\to\Users\YourUserName> from inside the Docker container under the path </home/YourUserName>, where "YourUserName" is your actual username. If you wish to share a different directory of you Windows 10 system with the Docker container replace <path\to\Windows10\directory> with the full path to the desired directory, e.g. where you want to run simulations with BASEMENT (Note: Paths under Windows are separated by a backslash '\', while in Linux by a normal slash '/').

```
> docker create --name basementv3 -it
            -v C:\Users\$env:UserName\:/home/$env:UserName
            -w /home/$env:UserName
            -e DISPLAY=$(hostname):0.0 basementv3:ubuntu
```

Step 7: Installing BASEMENT

Start the docker container basementv3 with the following command:

```
> docker start basementv3
```

Next, open the bash of the container by running:

```
> docker exec -it basementv3 bash
```

Go to the home directory with:

```
$ cd /home/
```

Make the installation script executable by running:

```
$ chmod +x BASEMENT_v3_linux64_ubuntu18.sh
```

Extract the Debian Package with the command below. You have to read and accept the license text.

```
$ ./BASEMENT_v3_linux64_ubuntu18.sh
```

Install BASEMENT version 3.x with the Debian package (.deb) :

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

After the successful installation, you can start BASEMENT with:

```
$ basement
```

Step 8: 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/

2.1.2.4 Installation procedure under Windows Subsystem for Linux

Step 1: Install and setup X-server (required for GUI)

Here, instructions are given to install and setup VcXsrv (only one of many X-servers available).

Download the X-server VcXsrv from the website below and run the installer.

https://sourceforge.net/projects/vcxsrv/

Step 2: Start X-server

Start the X-server by starting the application XLaunch. It is recommended to choose the default setting for the "Display settings" and "Client startup".

Check if your X-server is running (under the hidden icons in the taskbar).

Step 3: Installing Windows Subsystem for Linux

To enable the Windows Subsystem for Linux (WSL, open the Windows PowerShell (not ISE) as administrator and run (on one line):

```
> Enable-WindowsOptionalFeature -Online
            -FeatureName Microsoft-Windows-Subsystem-Linux
```

Now, open the Microsoft Store application. Search for Ubuntu, choose one the version Ubuntu 18.04 (LTS) and install it. For more information visit:

https://docs.microsoft.com/en-us/windows/wsl/install-win10

Step 4: Setup of BASEMENT

Launch your Ubuntu Version and and change to the downloaded directory (your Windows drives can be found under the path "/mnt"). Make the Installation script executable by running:

```
$ chmod +x BASEMENT_v3_linux64_ubuntu18.sh
```

To run the setup enter

```
$ ./BASEMENT_v3_linux64_ubuntu18.sh
```

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

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

Step 5: Install required packages

For the installation of BASEMENT additional packages are required, namely "libqt5gui5", "libgomp1", and "libhdf5-100". To install these the two commands:

```
$ sudo apt-get update
$ sudo apt-get install -y libqt5gui5 libgomp1 libhdf5-100
```

Step 6: 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 7: Setup display connection

To allow the WSL to forward applications with a graphical user interface to your screen, configure the DISPLAY environmental variable with

```
$ echo "export DISPLAY=localhost:0.0" >> ~/.bashrc
```

For this step to be effective, you are required to restart the WSL. This step is only required once.

Step 8: Finding your data

Usually you can find the data from your Windows Operating System under the path "/mnt/c/Users/USERNAME/", where USERNAME has to be replaced with the name of your Windows user account. To navigate to your directory your can you the command *cd* for "change directory". To move to the mentioned path use

```
$ cd /mnt/c/Users/USERNAME/
```

If you this path does not exit might be stored on a different drive than the "C" drive. You can simply change to the directory "mnt" (*cd*) and look for another drive with the comand *ls* (list), which shows you all files and folders in the current directory.

```
$ cd /mnt
$ ls
```

Step 9: 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/

2.1.3 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
```

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 Windows 10 using Docker

This step is to be repeated every time you want to start BASEMENT. Start Docker Desktop, if not already running. Start the X-server with XLaunch if not already running (set "Disable Access Control" if this is suitable for your environment). Open a Windows PowerShell (not ISE) and start the Docker container with:

```
> docker start basementv3
```

Open the bash of the container by running:

```
> docker exec -it -u BMv3User basementv3 bash
```

Start BASEMENT with:

```
$ basement
```

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.

Notice:

The command filename must not contain any spaces or special characters like ä, ö, ü, è, etc.

2.2.3   Windows Subsystem for Linux

This step is to be repeated every time you want to start the BASEMENT with the Windows Subsystem for Linux. Start the X-server with XLaunch if not already running. Start the Windows Subsystem for Linux (Ubuntu).

To start BASEMENT run

```
$ basement
```

in the Ubuntu console. 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.

2.2.4   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 the scenario directory or to create it by giving the path to the folder inside 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 3.0

3.1 General

Table 3.1 *List of BASEMENT main features*

	Version 2.8	Version 3.0
1-D model	✓	
2-D model	✓	✓
Hydrodynamics	✓	✓
Morphodynamics:		
- Bed load	✓	✓
- Suspended load	✓	
External sub-domain	✓	
Model coupling	✓	
(multi domain)		
Controller	✓	
Subsurface flow	✓	
Vegetation	✓	
SMP hardware	✓	✓
GPU/HPC support		✓[a]

[a]Linux only

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 3.0**
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 3.0**
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 3.0
Single procedure to generate a .2dm file with BASEmesh	Two procedures to generate a .2dm file with BASEmesh according to the mesh resolution
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 3.0
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 3.0
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 3.0**
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
	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 dynamic_wall_internal hqrelation_internal

	Version 2.8	Version 3.0
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 3.0
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 scalling	no	with morphological factor

	Version 2.8	**Version 3.0**
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	over region (index)
Bedload		
Bedload transport	Simple upwind scheme	Godunov-type upwind scheme
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_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)
Direction	lateral_bed_slope	IKEDA
	curvature_effect_static	-

	Version 2.8	**Version 3.0**
	curvature_effect_dynamic	CURVATURE
Inner boundary	yes (weir, open)	no
Incipient motion	angle_of_repose	repose_angle
	local_slope_vanrijn	van_rijn
	local_slope_chen	chen_et_al
Gravitational transport	yes	no
Source		
Type	sediment_discharge	-
	dredge	-

3.2.3   Simulation

Table 3.8 *Main changes regarding simulation parameters*

	Version 2.8	**Version 3.0**
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 3.0**
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	-
	grain_size	-
	grain_bedload	-
	bedload_vec	-
	saturation	-
	sediment_sum	-
	-	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	-

3.2.4 Results

Table 3.9 Main changes regarding the results parameters

	Version 2.8	Version 3.0
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 3.0 (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 3.10.

Table 3.10 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

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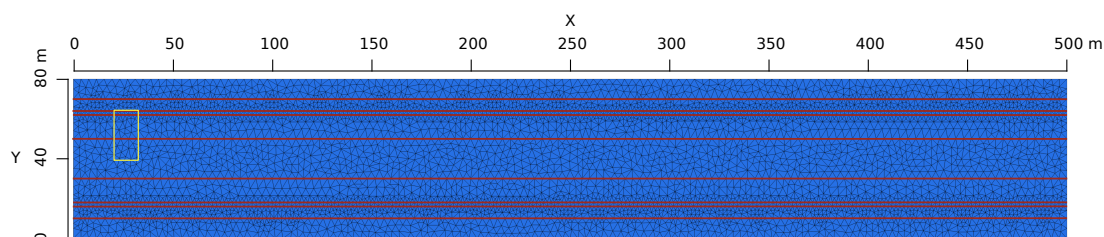
Figure 3.1 *Quality mesh used for the case example with breaklines (red)*

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 3.11 *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 3.11. 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 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
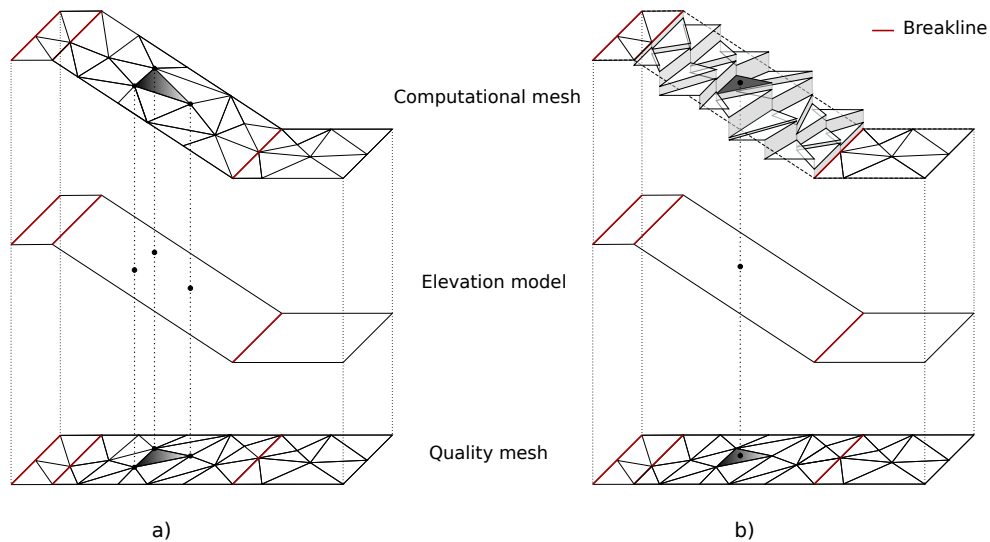
Figure 3.2 *Schematic sketch of the elevation interpolation methods with breaklines (red): a) BASEMENT version 2.x b) BASEMENT version 3.x*

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. 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:
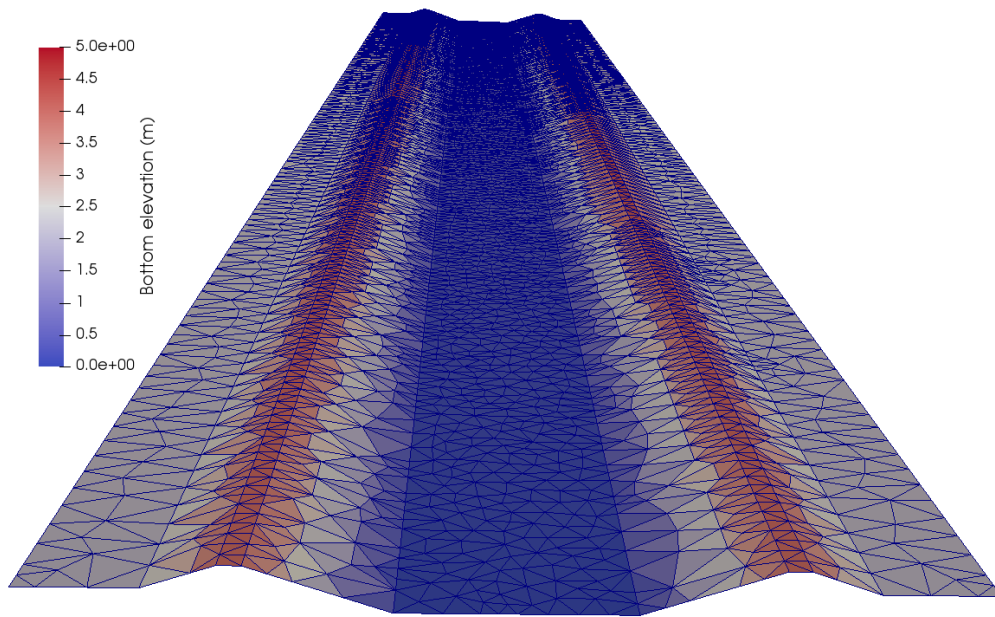
Figure 3.3 *Computational grid BASEMENT version 2.x with breaklines (view from downstream)*
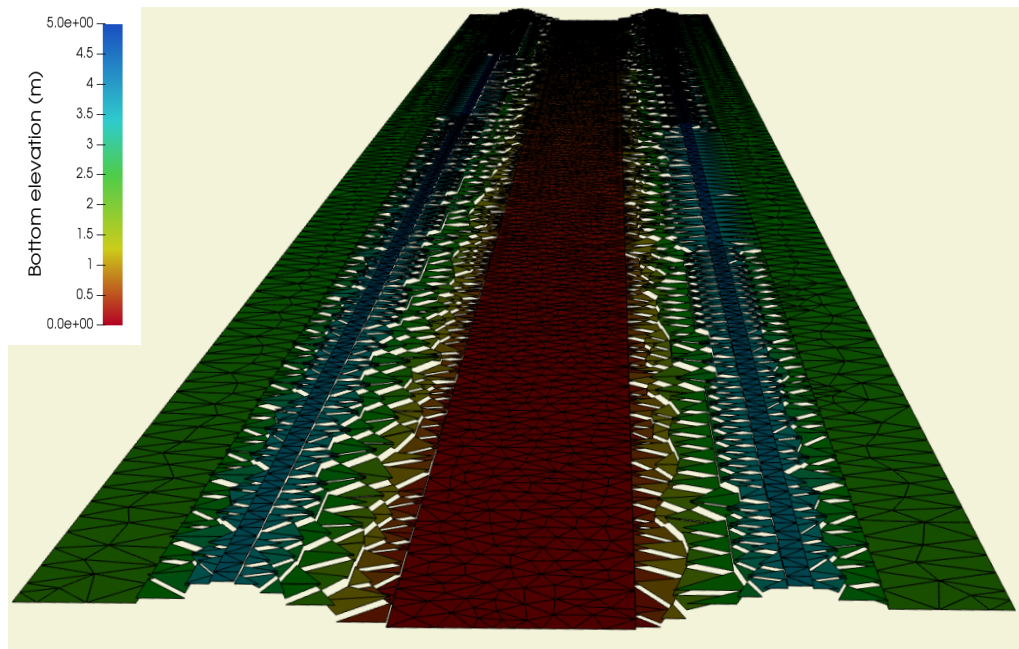
Figure 3.4 *Computational grid BASEMENT version 3.x with breaklines (view from downstream)*

```
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)*

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) 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.

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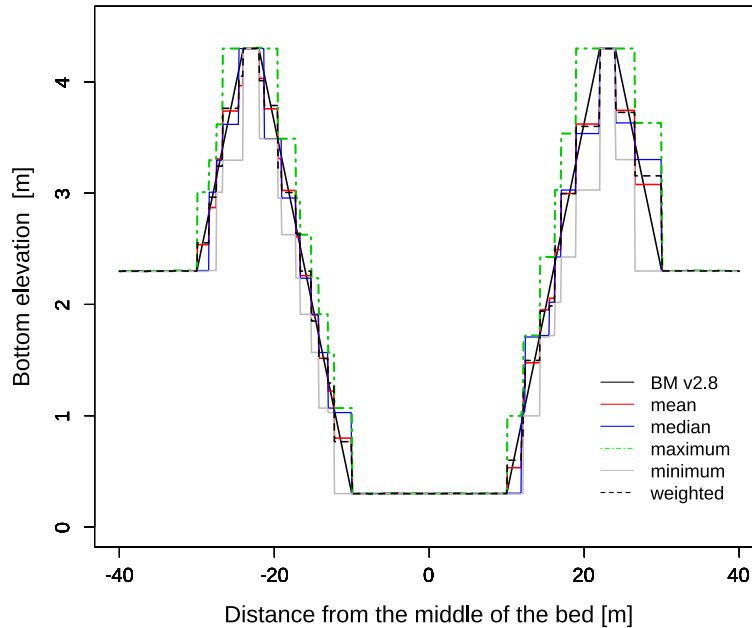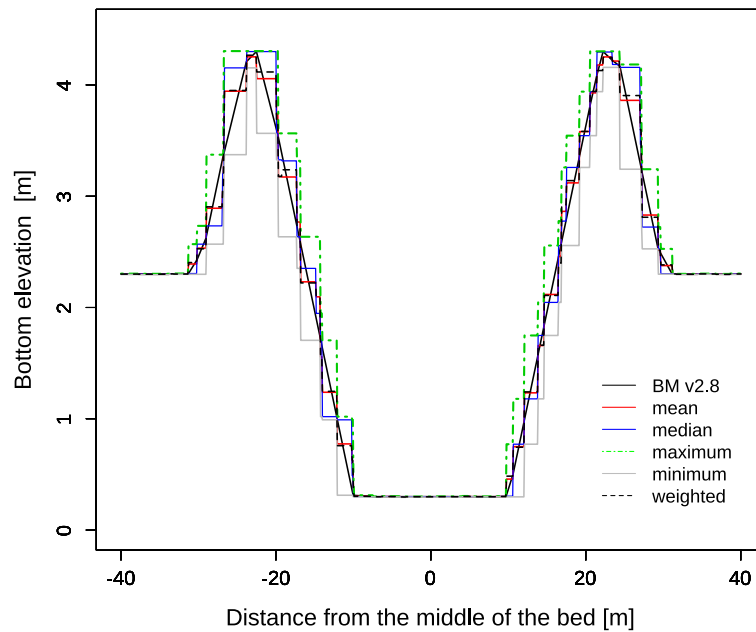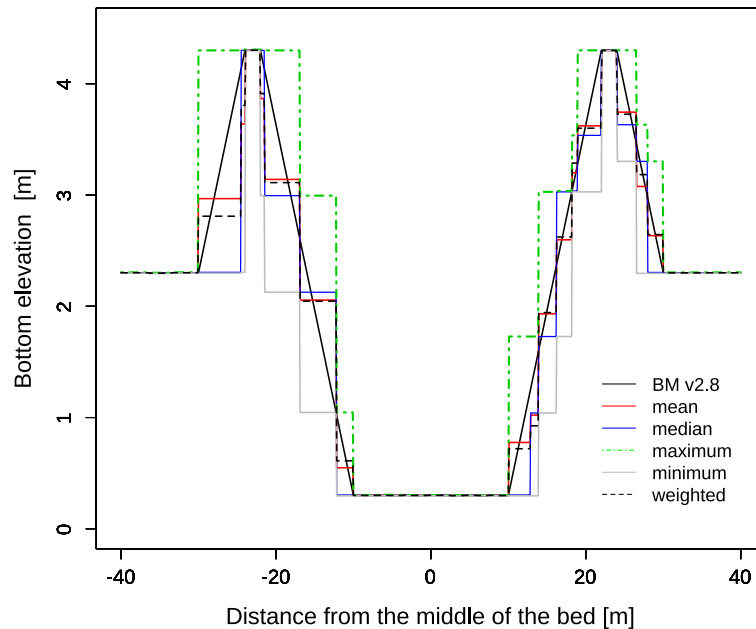
Figure 3.6 *Comparison of interpolation methods with the mesh of BASEMENT version 2.8 (BM v2.8) on a cross section at x= 150 m of the trapezoidal channel with breaklines*

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 3.0. 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 3.0:

- 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

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*
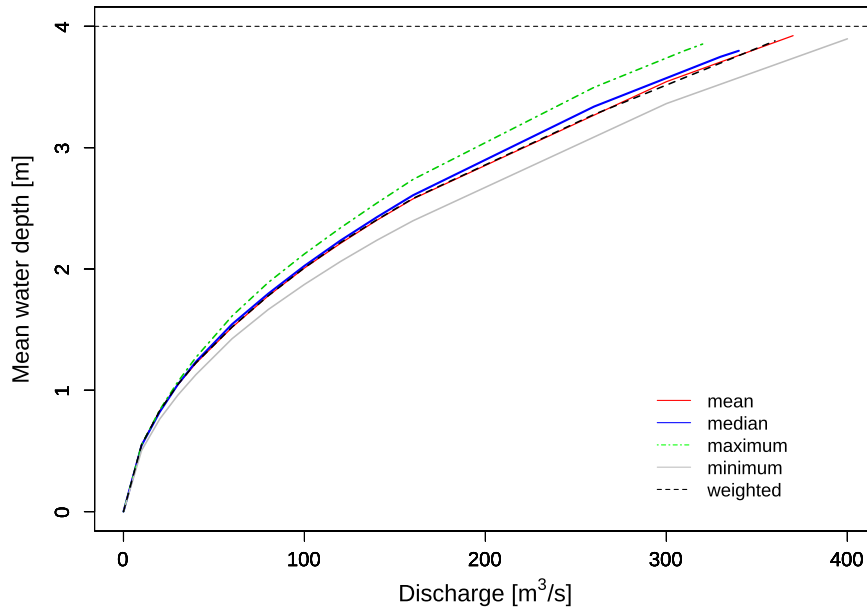
Figure 3.9 *Comparison of H-Q relations between the simulations of BASEMENT v3.0 for different interpolation types on the trapezoidal channel at x = 150 m.*

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 3.9 and Table 3.8).

3.3.4.1   Hydraulic results

The result of the simulations with BASEMENT version 3.0 for different interpolation methods are compared in a stage discharge rating curve (Figure 3.9). The mesh features are summarized in Tables 3.10 and 3.11.

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".

3.3.4.2   Boundary conditions

In BASEMENT version 3.0, 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
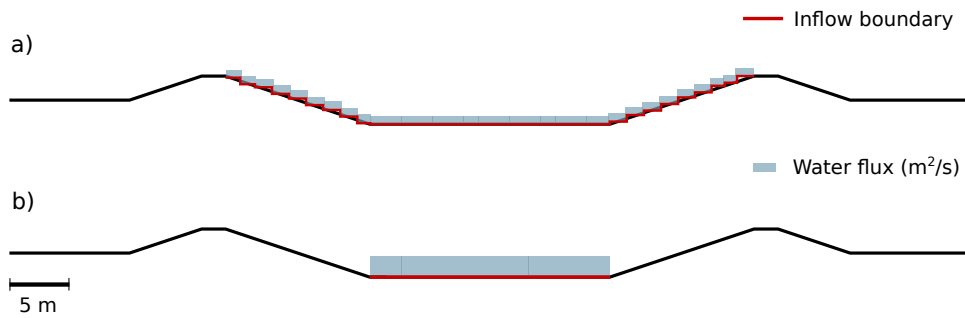
Figure 3.10 *Channel cross section and inflow boundary limit in BASEMENT version 3.0 a) Inflow boundary limit set at levee's highest point b) Reduced inflow boundary limit*
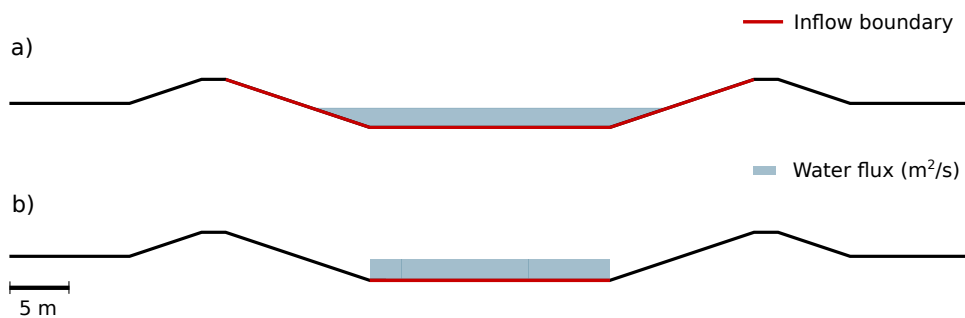
Figure 3.11 *Channel cross section and inflow boundary limit in BASEMENT version 2.8 a) Inflow boundary limit set at levee's highest point b) Reduced inflow boundary limit*

element edges of the inflow boundary cross section for BASEMENT version 3.0 and BASEMENT version 2.8 respectively.

An inflow boundary defined between the top elevation of the two levees in BASEMENT version 3.0 (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 v3.0 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 50 nodes. In case of large computational mesh with fine resolution, the boundaries shall be split into several smaller stringdef of equal length and consequently, the discharge applied to the boundaries has to be adapted.
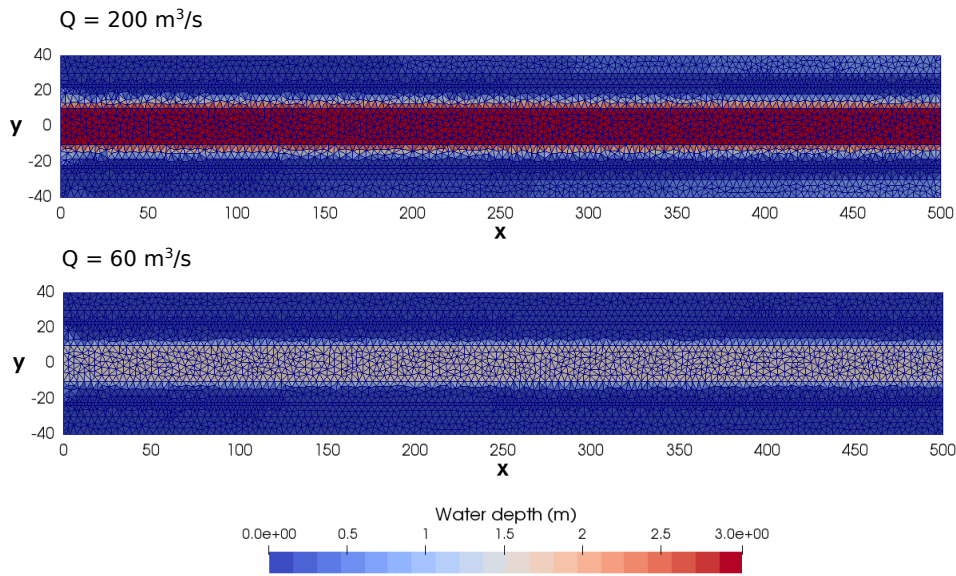
Figure 3.12 *Planar view of the simulation results using BASEMENT v3.0 of the trapezoidal channel with breaklines and for two discharge stages. Inflow boundary (x= 0.0 m) defined between the top elevation of the levees (Figure 3.10, a), inducing a converging flow from the levee towards the channel center and small fluxes towards the floodplains for higher discharge Q= 200 m³/s*
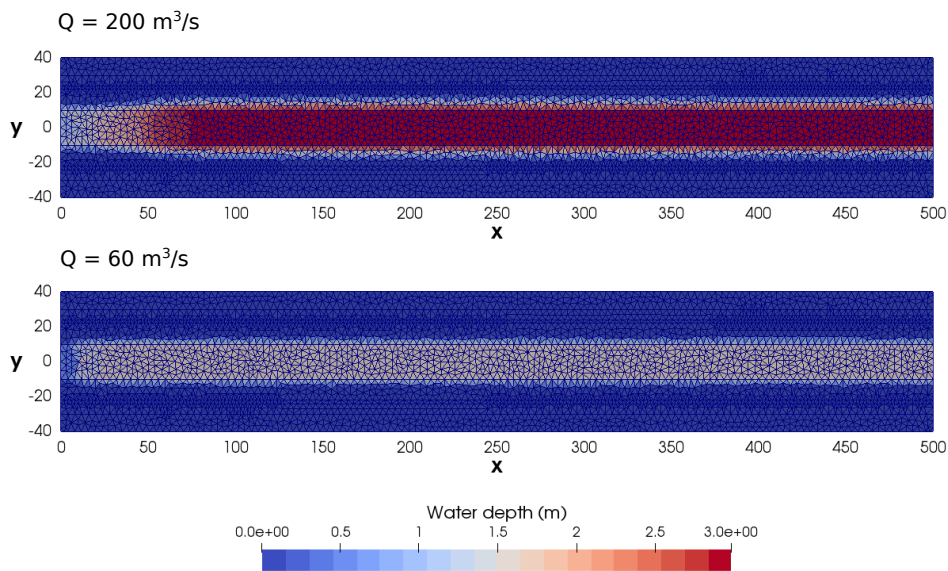
Figure 3.13 *Planar view of the simulation results using BASEMENT v3.0 of the trapezoidal channel with breaklines and for two discharge stages. Inflow boundary (x= 0.0m) restricted to the channel bed (Figure 3.10, b), inducing an increase of the flow velocity.*

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 3.0 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 3.0 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 more in details 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 3.0 using the CPU backend up to 32 cores and different GPU backends on Ubuntu 16.04. The backend types are listed and described in the section "Test case". Beside of that, 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 Speedup

The execution time of all the simulations is shown on Figure 3.14. The execution time increases with the computational mesh size. The CPU simulations performed with BASEMENT version 3.0 are executed faster than those performed with BASEMENT version 2.8. The execution speed increases even more if the simulations are performed on GPU processors with the best performance reached using sinle GPU processors.

The speedup $S = \dfrac{T_1}{T_N}$ is calculated as the ratio between serial and parallel execution time for a similar mesh size with T_1, the sequential execution time (Xeon 1) and T_N the execution time of the Nth different backends types.

3.4.3 Scalability

The speedup of the simulations performed with CPU are shown on Figure 3.15 for an increasing number of threads. The black line represents the ideal speedup according to the increasing number of threads.
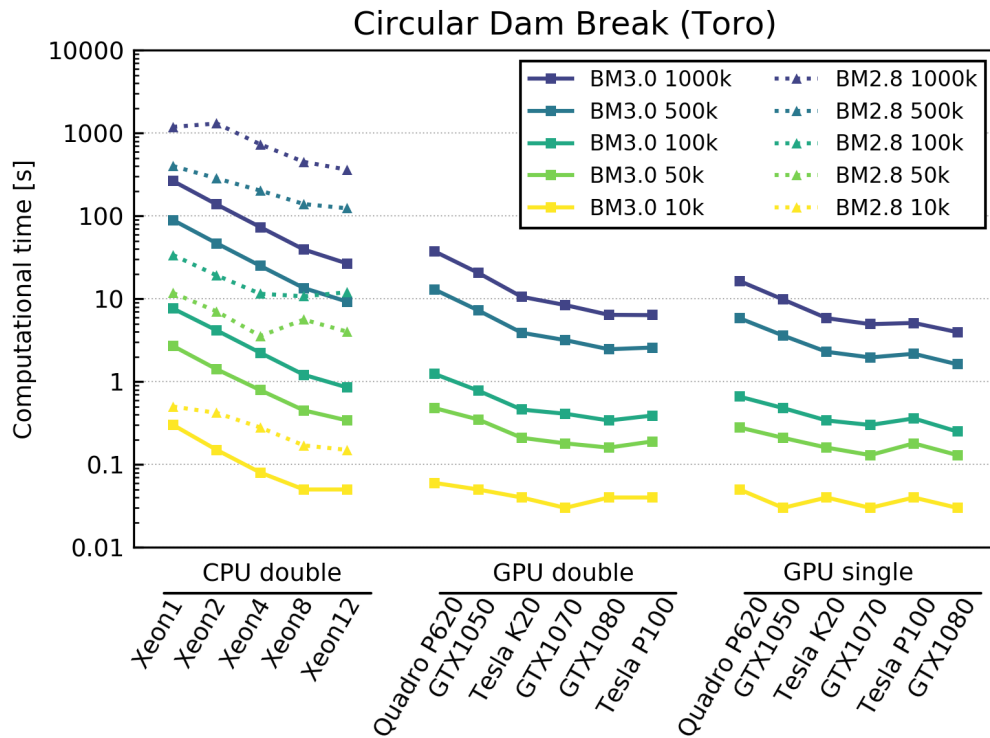
Figure 3.14 *Execution time of the circular dam break test case for different backends and mesh sizes*

The increasing number of threads for simulations performed with BASEMENT version 2.8 does not increase the speedup significally and leads to a maximal speedup (plateau) for small thread number already. The simulations performed with BASEMENT version 3.0 show a significant speedup with increasing number of threads and mesh elements. The speedup is more efficient for large meshes.
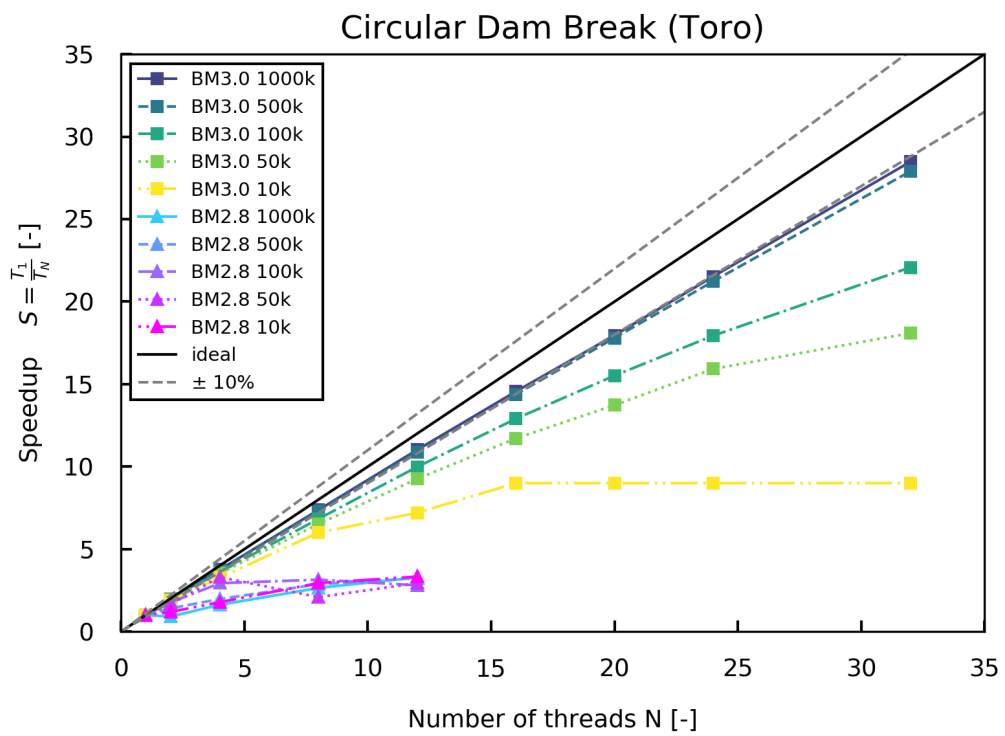
Circular Dam Break (Toro)

Figure 3.15 *Speedup compared to the sequential time (T_1) of the circular dam break test case performed on CPU for an increasing number of threads and different 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.

Note: Existing installations are not automatically detected by the updated installer. Therefore uninstall BASEMENT v3.0.0 e.g. using the link in the start menu before installing the newest version of BASEMENT.

5

Summary of Features Version 3.0

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)

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 (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 (coefficien = 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

Direction

- Lateral bed slope effect (Ikeda, 1982)
- 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

Bed material

- Grain class
- Fixed bed

6

References

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APPENDIX

BASEMENT

1

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OP2

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```
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GCC Runtime Library Exception

```
Version 3.1, 31 March 2009

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