

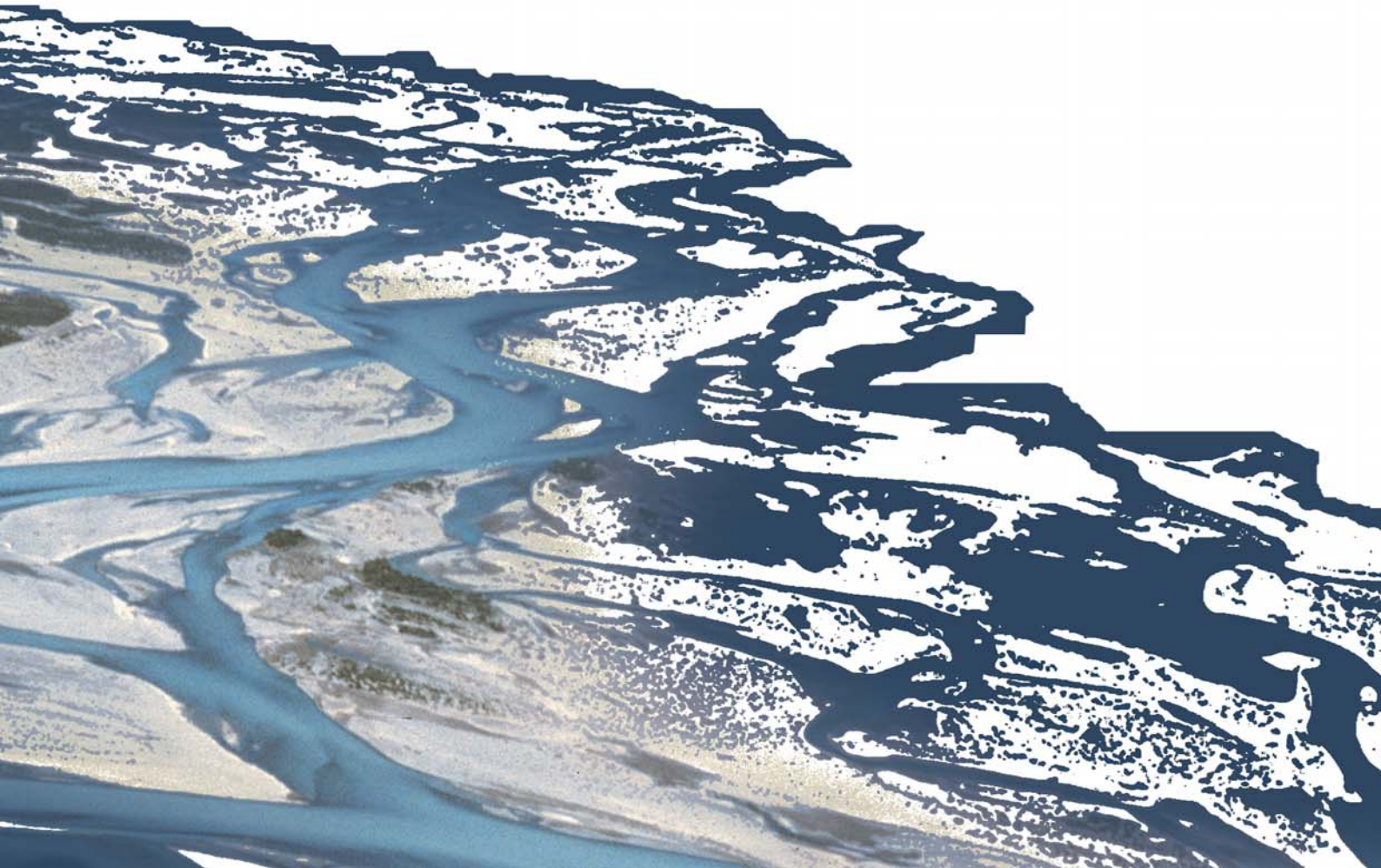


BASEMENT

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

SYSTEM MANUALS

**VERSION 3.0
September 2019**



Preamble

VERSION 3.0

September 2019

Credits

Current Team Members

Software Development, Documentation and Test (alphabetical)

Dr. P. Bacigaluppi, MSc. Aeronautical Eng.
M. Bürgler, MSc. ETH Environmental Eng.
F. Caponi, MSc. Environmental Eng.
Dr. D. Conde, MSc. Civil Eng.
E. Gerke, MSc. ETH Civil Eng.
S. Kammerer, MSc. ETH Environmental Eng.
Dr.techn. M. Weberndorfer, MSc.

Scientific Board

Prof. Dr. R. Boes, Director VAW, Member of Project Board
Dr. A. Siviglia, MSc, Scientific Advisor
Dr. D. Vanzo, MSc. Environmental Eng., Scientific Advisor
Dr. D. Vetsch, Dipl. Ing. ETH, Project Director

Former Project Members

See <https://www.basement.ethz.ch/people>

Commissioned and co-financed by

Swiss Federal Office for the Environment (FOEN)

Contact

Website: <https://www.basement.ethz.ch>

User forum: <https://people.ee.ethz.ch/~basement/forum>

© 2019 ETH Zurich / Laboratory of Hydraulics, Glaciology and Hydrology (VAW)

For list of contributors see <https://www.basement.ethz.ch>



Laboratory of Hydraulics,
Hydrology and Glaciology



Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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. 2019. System Manuals of BASEMENT, Version 3.0. 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, 2019. <https://www.basement.ethz.ch>

For Software:

BASEMENT – Basic Simulation Environment for Computation of Environmental Flow and Natural Hazard Simulation. Version 3.0. © ETH Zurich, VAW, 2019.

License

End-User License Agreement (EULA)

THIS EULA IS INTENDED FOR COMMERCIAL AND NON-COMMERCIAL PURPOSES. FOR QUESTIONS RELATED TO THIS AGREEMENT PLEASE CONTACT: Dr. David Vetsch, basement@ethz.ch

This End-User License Agreement (“EULA”) is a legal agreement between you (“You”) (an individual or acting on behalf of a company) and ETH Zurich, Raemistrasse 101, 8092 Zurich (Switzerland) (“ETH Zurich”) for the binary software code of **BASEMENT** and associated media, and may include “online” or electronic documentation (“SOFTWARE”).

The SOFTWARE simulates water flow, sediment and scalar transport in rivers and according interaction in consideration of movable boundaries and morphological changes. Further information and description of the SOFTWARE is available here: <https://basement.ethz.ch/>

The SOFTWARE is protected by copyright laws. The SOFTWARE is hereby licensed, not sold.

In order to install and use the SOFTWARE, You must indicate agreement with the following terms and conditions by clicking “ACCEPT” at the end of this EULA during the installation process.

1 LICENSE GRANT

- (i) ETH Zurich hereby grants to You, and in case You are acting on behalf of a company also to the employees of such company, a free-of-charge, single, non-exclusive, world-wide, non-transferable, non-sublicensable right to install, execute and display the SOFTWARE on device(s) running a validly licensed copy of the operating system for which the SOFTWARE was designed. Such rights are granted for commercial and non-commercial purposes.
- (ii) With respect to electronic documents included with the SOFTWARE, You may make an unlimited number of copies (either in hardcopy or electronic form), provided that such copies shall be used only for internal purposes and are not republished or distributed to any third party.

2 USE OF RESULTS GENERATED BY THE SOFTWARE

You are allowed to use the content generated by the SOFTWARE (“SOFTWARE RESULTS”) for commercial and non-commercial purposes.

Note that any attribution (e.g. ETH Zurich logo) on the SOFTWARE RESULTS must be retained. You are not allowed to alter, cancel or fade, after a few seconds, such attribution.

3 THIRD PARTY CODE

The SOFTWARE may contain other program code from third parties. A list of other third party code and libraries used by this SOFTWARE is available here: <https://basement.ethz.ch/about/thirdpartysoftware>

Their license applies to such third party code and libraries contained herein. Refer to the above internet site for the licenses and copyrights.

4 DURATION OF LICENSE AND TERMINATION

This EULA enters into effect on the date of acceptance of this EULA by You. This EULA,

- (i) may be terminated by ETH Zurich at any time for any reason;
- (ii) will terminate automatically without notice from ETH Zurich if (a) You fail to comply with any term(s) of this EULA or (b) You refuse, after the notification in accordance with clause 10 (i), to accept the new EULA term and conditions provided by ETH Zurich;
- (iii) is terminated as soon as You cease to use the SOFTWARE and destroy all copies, full or partial, of the SOFTWARE;

Upon termination pursuant to (i) and (ii), you must cease all use of the SOFTWARE and destroy all copies, full or partial, of the SOFTWARE.

5 OBLIGATIONS OF YOU

- (i) You may not remove or alter any copyright notices on any and all copies of the SOFTWARE.
- (ii) You may not distribute or assign the SOFTWARE or any copy thereof to third parties. You may not rent, lease, sell, lend, transfer, redistribute, or sublicense the SOFTWARE to any third party.
- (iii) You may not reverse engineer, decompile or disassemble the SOFTWARE, except and only to the extent that such activity is expressly permitted by applicable law despite this limitation.
- (iv) You may not reproduce, modify or adapt the SOFTWARE, except and only to the extent that such activity is expressly permitted by applicable law despite this limitation.
- (v) You must comply with all applicable laws.

6 OWNERSHIP

Except as expressly licensed to You in this EULA, ETH Zurich and its licensors retains all right, title, and interest in and to the SOFTWARE. All title and copyrights in and to the SOFTWARE (including but not limited to any images, photographs, animations, video, audio, music, text, and “applets” incorporated into the SOFTWARE), the accompanying materials, and any copies of the SOFTWARE are owned by ETH Zurich and its licensors. The SOFTWARE is protected by copyright laws. Therefore, You must treat the SOFTWARE like any other copyrighted material. All rights not expressly granted are reserved by ETH Zurich.

7 MAINTENANCE, SUPPORT, UPGRADES OR NEW RELEASES

ETH Zurich has no obligation to provide maintenance, support, upgrades, new releases, enhancements or modifications and disclaims all costs associated with service, repair or correction of the SOFTWARE. If any supplemental software code is provided to You by ETH Zurich, this supplemental software code shall be considered part of the SOFTWARE and is subject to the terms and conditions of this EULA if not otherwise explicitly written. It is expressly acknowledged by You that no rights to receive maintenance, support, upgrades, new releases, enhancements or modifications may be derived from this EULA.

8 NO WARRANTY

YOU EXPRESSLY ACKNOWLEDGE AND AGREE THAT USE OF THE SOFTWARE IS AT YOUR SOLE RISK AND THAT THE ENTIRE RISK AS TO SATISFACTORY QUALITY, PERFORMANCE, ACCURACY, AND EFFORT IS WITH YOU. TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, THE SOFTWARE AND ANY SERVICES PERFORMED OR PROVIDED BY THE SOFTWARE ARE PROVIDED “AS IS” AND “AS AVAILABLE”, WITH ALL FAULTS AND WITHOUT WARRANTY OF ANY KIND, AND ETH ZURICH HEREBY DISCLAIMS ALL WARRANTIES AND CONDITIONS WITH RESPECT TO THE SOFTWARE AND ANY SERVICES, EITHER EXPRESS, IMPLIED, OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES AND/OR CONDITIONS OF MERCHANTABILITY, OF SATISFACTORY QUALITY, OF FITNESS FOR A PARTICULAR PURPOSE, OF ACCURACY, OF QUIET ENJOYMENT, AND OF NON-INFRINGEMENT OF THIRD-PARTY RIGHTS. ETH ZURICH DOES NOT WARRANT AGAINST INTERFERENCE WITH YOUR ENJOYMENT OF THE SOFTWARE, THAT THE FUNCTIONS CONTAINED IN OR SERVICES PERFORMED OR PROVIDED BY THE SOFTWARE WILL MEET YOUR REQUIREMENTS, THAT THE OPERATION OF THE SOFTWARE OR SERVICES WILL BE UNINTERRUPTED OR ERROR-FREE, OR THAT DEFECTS IN THE SOFTWARE OR SERVICES WILL BE CORRECTED. NO ORAL OR WRITTEN INFORMATION OR ADVICE GIVEN BY ETH ZURICH OR ITS AUTHORIZED REPRESENTATIVE SHALL CREATE A WARRANTY. SHOULD THE SOFTWARE OR SERVICES PROVE DEFECTIVE, YOU ASSUME THE ENTIRE COST OF ALL NECESSARY SERVICING, REPAIR, OR CORRECTION. SOME JURISDICTIONS DO NOT ALLOW THE EXCLUSION OF IMPLIED WARRANTIES OR LIMITATIONS ON APPLICABLE STATUTORY RIGHTS OF A CONSUMER, SO THE ABOVE EXCLUSION AND LIMITATIONS MAY NOT APPLY TO YOU.

9 LIABILITY

In no event shall ETH Zurich be liable for any damages (including, without limitation, lost profits, business interruption, or lost information) arising from the use of or inability

to use the SOFTWARE through You or the employees of the company You are legally representing. In no event will ETH Zurich be liable for loss of data or for indirect, special, incidental, consequential (including loss of profit), or other damages based in contract, tort or otherwise.

The above limitation of liability shall not be construed to amend or limit any party's statutory liability.

10 GENERAL PROVISIONS

- (i) ETH Zurich reserves the right to change the terms and conditions of this EULA at any point in time. In such event, ETH Zurich will notify You in due time of the changes to the terms of the EULA.
- (ii) Rights and duties derived from this EULA shall not be transferred to third parties without the written acceptance of the ETH Zurich.
- (iii) You shall not infer from this EULA any other rights, including licenses, than those that are explicitly stated herein.
- (iv) This EULA shall exclusively be governed by and interpreted in accordance with the laws of Switzerland, without reference to its conflict of laws principles. The exclusive place of jurisdiction is Zurich (Switzerland).

11 ACKNOWLEDGMENT

You acknowledge that you have read this EULA, understand it, and had an opportunity to seek independent legal advice prior to agreeing to it. In consideration of ETH Zurich agreeing to provide the SOFTWARE, You agree to be bound by the terms and conditions of this EULA. You further agree that it is the complete and exclusive statement of the agreement between you and ETH Zurich, which supersedes any proposal or prior agreement, oral or written, and any other communication between you and ETH Zurich relating to the subject of this EULA.

Notice:

Third party software copyright notices and third party software licenses can be found in the appendix.

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

INTRODUCTION & INSTALLATION

**VERSION 3.0
September 2019**



BASEMENT

Contents

1	Summary of Contents	3
1.1	Introduction	3
1.2	Content of System Manuals	3
1.2.1	Introduction & Installation	3
1.2.2	User Manual	3
1.2.3	Reference Manual	4
1.2.4	Tutorials and Test Cases	4
2	Setup and First Start	5
2.1	Setup and First Start	5
2.1.1	System operator requirements	5
2.1.1.1	Microsoft Windows	5
2.1.1.2	Linux	5
2.1.1.3	Hardware Configuration	6
2.1.2	Installing under Windows	6
2.1.2.1	Getting the binaries	6
2.1.2.2	Installation procedure under Windows 10	7
2.1.2.3	Installation procedure under Windows 10 using Docker	9
2.1.2.4	Installation procedure under Windows Subsystem for Linux	14
2.1.3	Installing under Linux	16
2.1.3.1	Getting the binaries	16
2.1.3.2	Installation procedure	16
2.2	Running BASEMENT	17
2.2.1	Windows 10	17
2.2.2	Windows 10 using Docker	17
2.2.3	Windows Subsystem for Linux	18
2.2.4	Linux	18
3	Migration Guide Version 2.8 to 3.0	21
3.1	General	21
3.2	Major Changes from version 2.x to 3.x	21
3.2.1	Workflow	21
3.2.2	Input data	22
3.2.2.1	Mesh features	22
3.2.2.2	Model setup	23
3.2.3	Simulation	27
3.2.4	Results	29
3.3	Case example	29

3.3.1	Description	29
3.3.2	Computational mesh	29
3.3.2.1	Quality mesh	30
3.3.2.2	Computational mesh	30
3.3.2.3	Import of a 2.x to a compatible 3.x computational mesh . .	31
3.3.3	Setup and simulation	34
3.3.4	Results and discussion	36
3.3.4.1	Hydraulic results	36
3.3.4.2	Boundary conditions	36
3.3.4.3	Discussion	39
3.4	Performance	39
3.4.1	Introduction	39
3.4.2	Speedup	39
3.4.3	Scalability	39
4	Release Notes	43
4.1	Version 3.0	43
4.1.1	General	43
4.1.2	Hydraulics	43
4.1.3	Morphology	44
4.1.4	System manuals	44
5	Summary of Features Version 3.0	45
5.1	Hydrodynamic features	45
5.2	Morphodynamic features	46
6	References	49

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

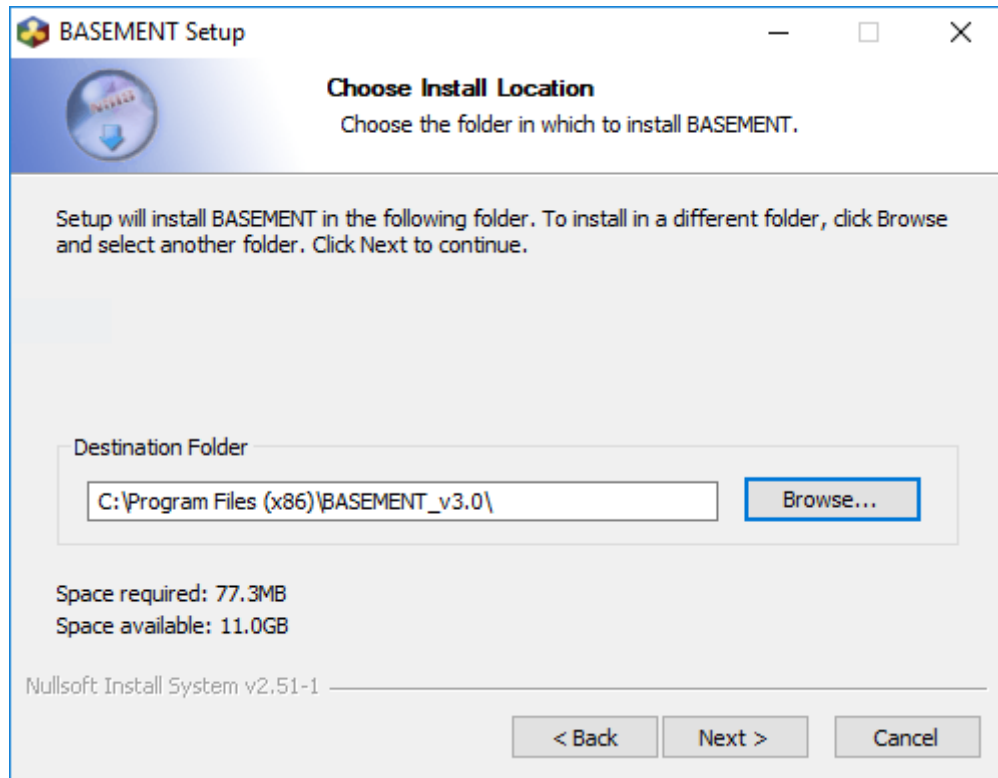


Figure 2.1 Select the installation folder.

2.1.2.2 Installation procedure under Windows 10

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.Y” respectively “C:\BASEMENT_v3.Y” (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

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 Folder 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

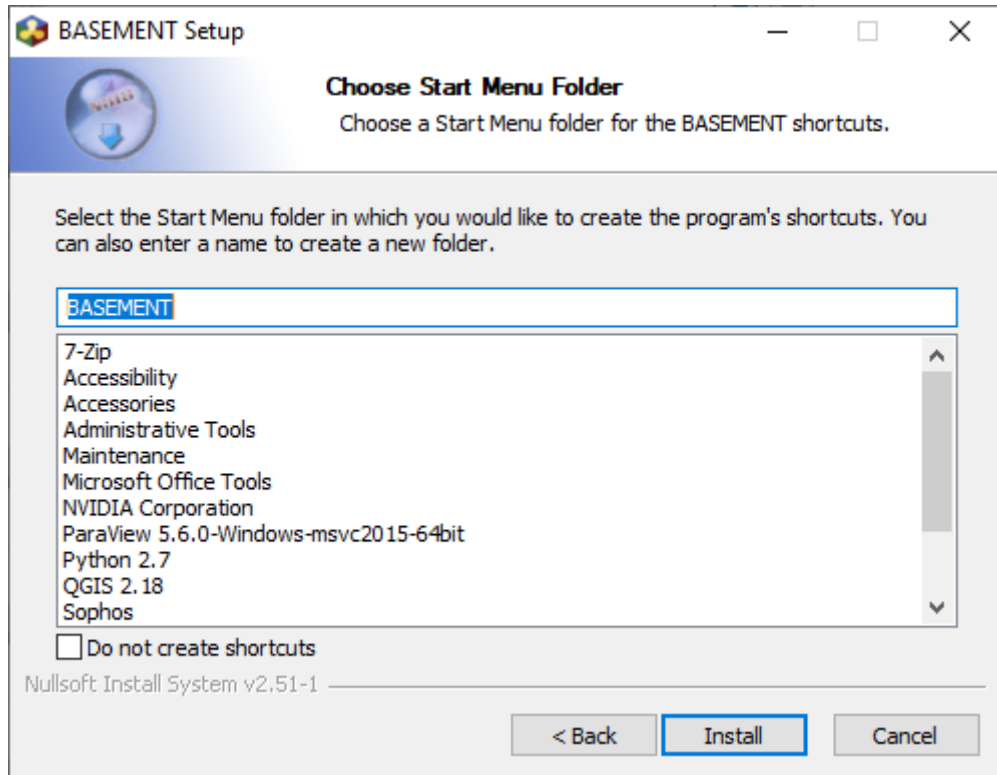


Figure 2.2 Select the Start Menu folder.

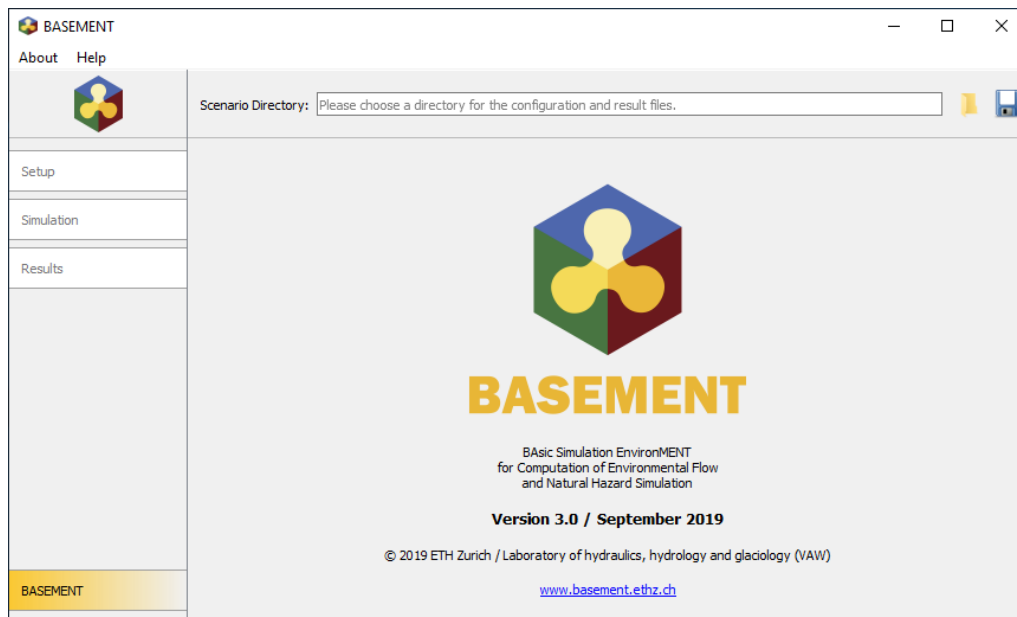


Figure 2.3 Select the Start Menu folder.

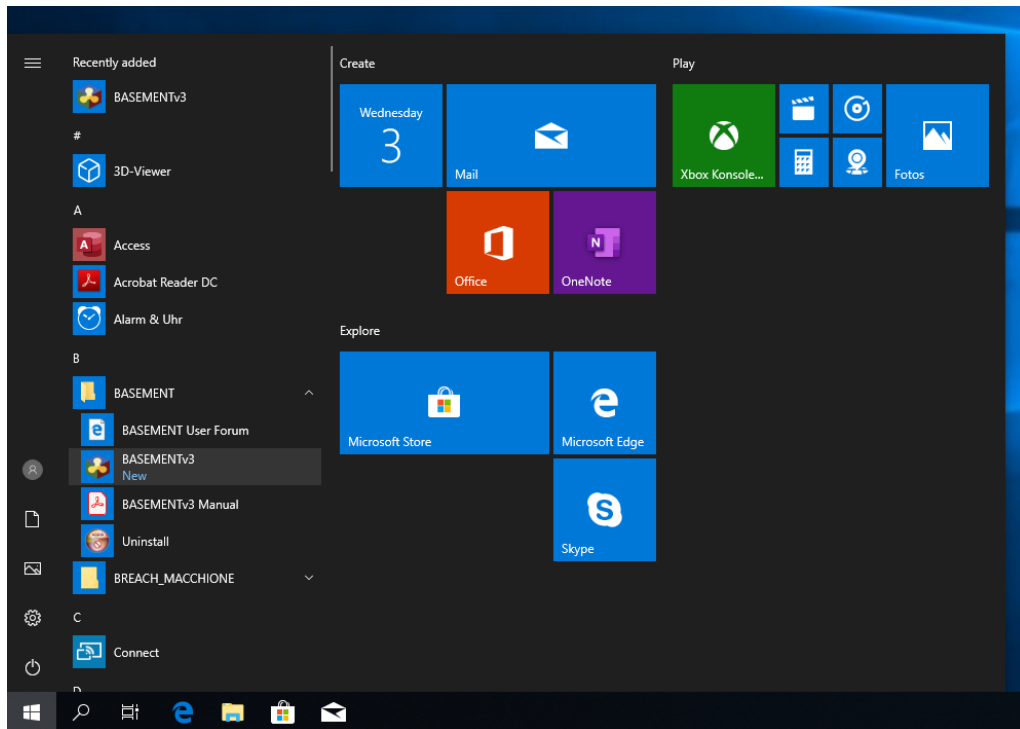


Figure 2.4 Start BASEMENT over the icon in the Start Menu folder.

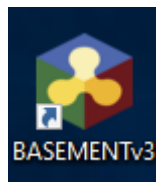


Figure 2.5 Desktop shortcut.

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).

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

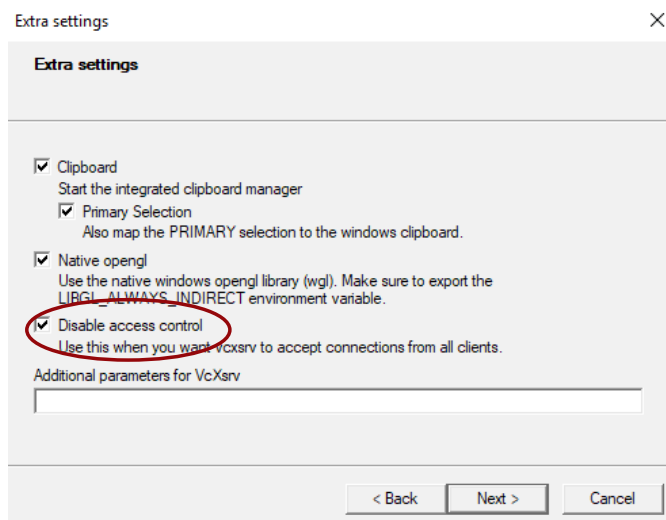


Figure 2.6 Disable access control under extra settings

<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

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

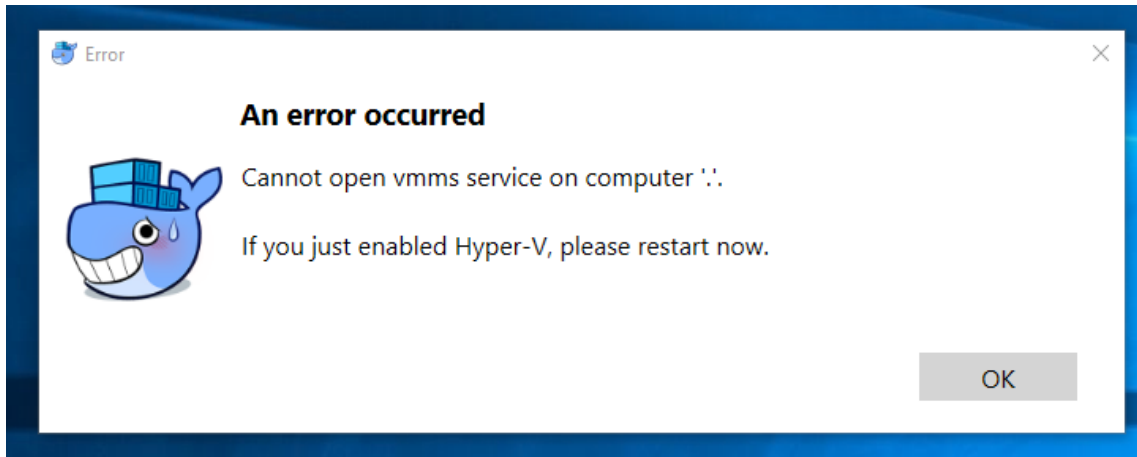


Figure 2.7 Error during installation process of Docker.

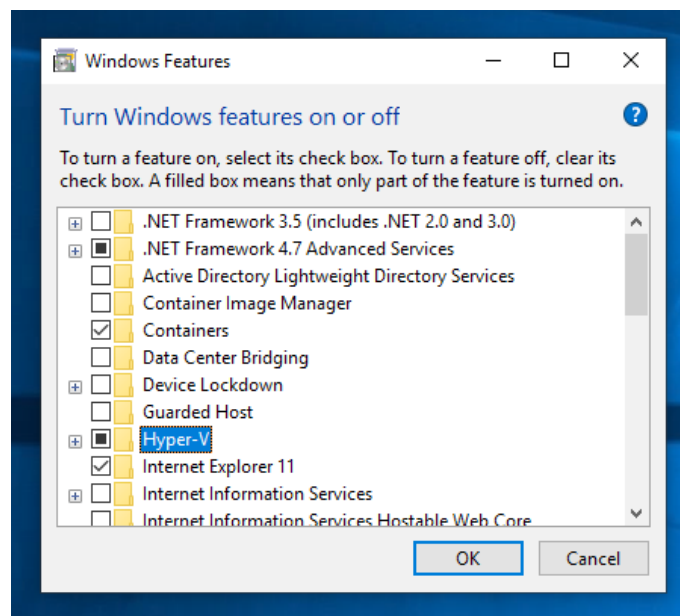


Figure 2.8 Activation of HyperV under Windows 10.

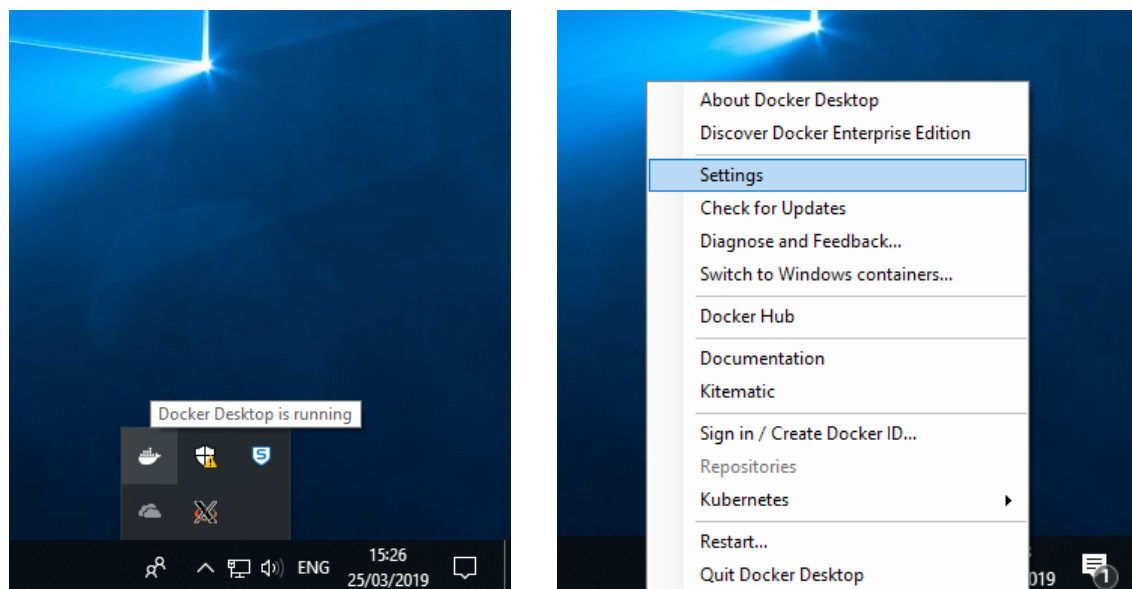


Figure 2.9 Docker Settings.

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 your 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 you can use the command `cd` for “change directory”. To move to the mentioned path use

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

If you this path does not exist 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 command `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

^aLinux 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 - engelundhansen mpmh power_law mpm_multi wilcockcrowe ashidamichiue parker rickenmann smartjaeggi smartjaeggi_multi wu vanrijn	MPM MPM-like (adaptable) Engelund and Hansen - Grass-like (adaptable) - - - - - - - -
Boundary		
- Inflow	- sediment_discharge - - IOUp transport_capacity - -	Standard sedimentograph sedimentograph_warea sedimentograph_conveyance equilibrium_in 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 curvature_effect_static	IKEDA -

	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 BASEviz node_history element_history stringdef_history edge_history boundary_history balance avs_ucd sediment_grid	- element_centered - - - nodestring - nodestring - - -

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

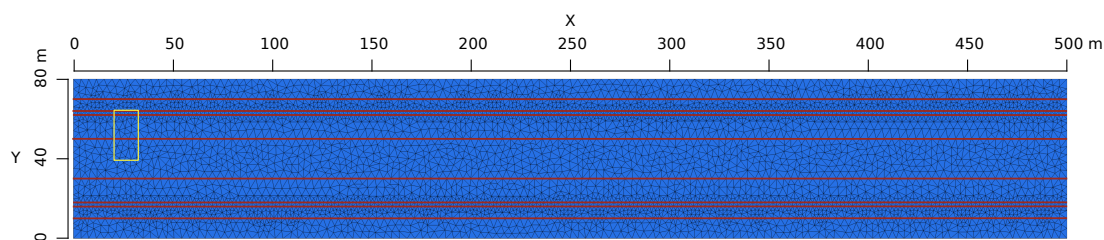


Figure 3.1 Quality mesh used for the case example with breaklines (red)

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

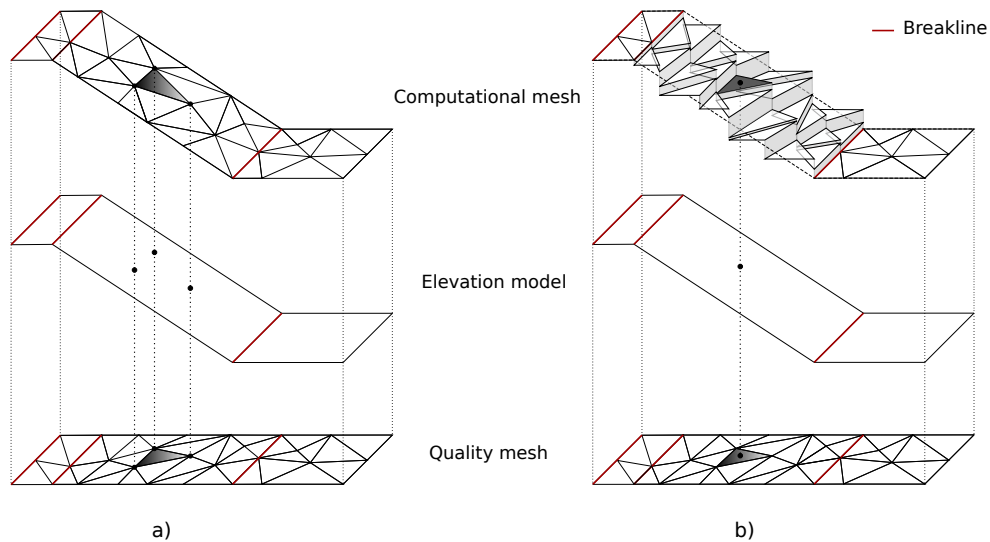


Figure 3.2 Schematic sketch of the elevation interpolation methods with breaklines (red):
 a) BASEMENT version 2.x b) BASEMENT version 3.x

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 guaranteed 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:

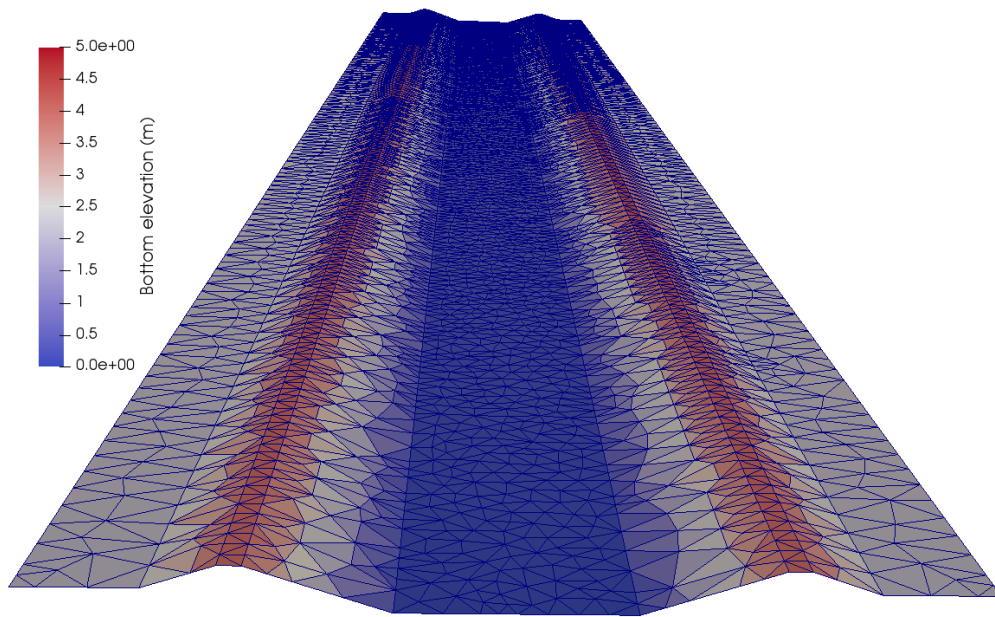


Figure 3.3 Computational grid BASEMENT version 2.x with breaklines (view from downstream)

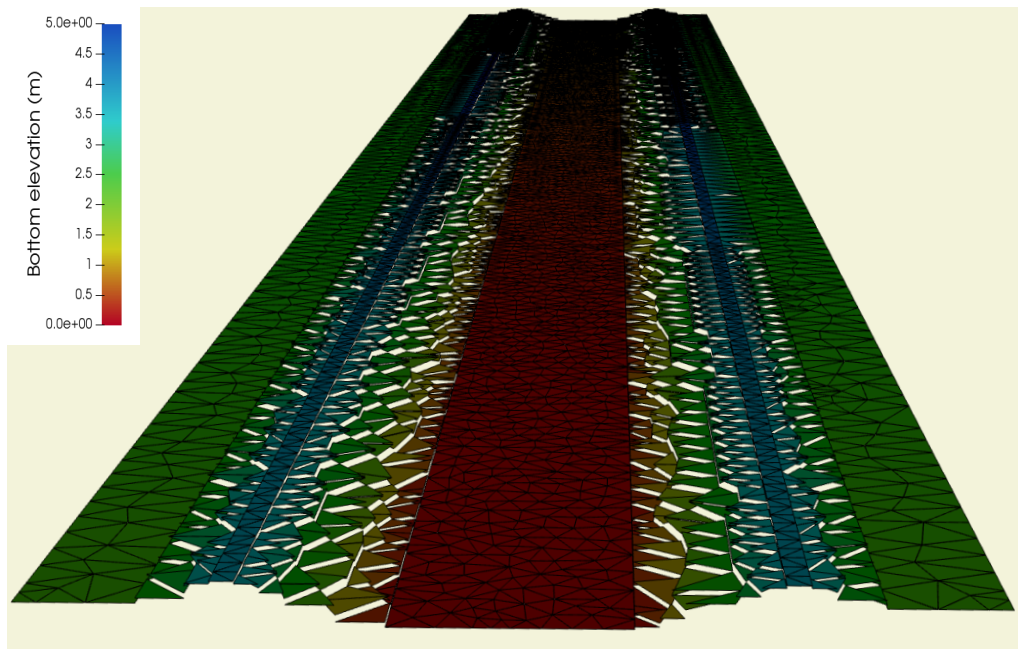


Figure 3.4 Computational grid BASEMENT version 3.x with breaklines (view from downstream)

```

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.

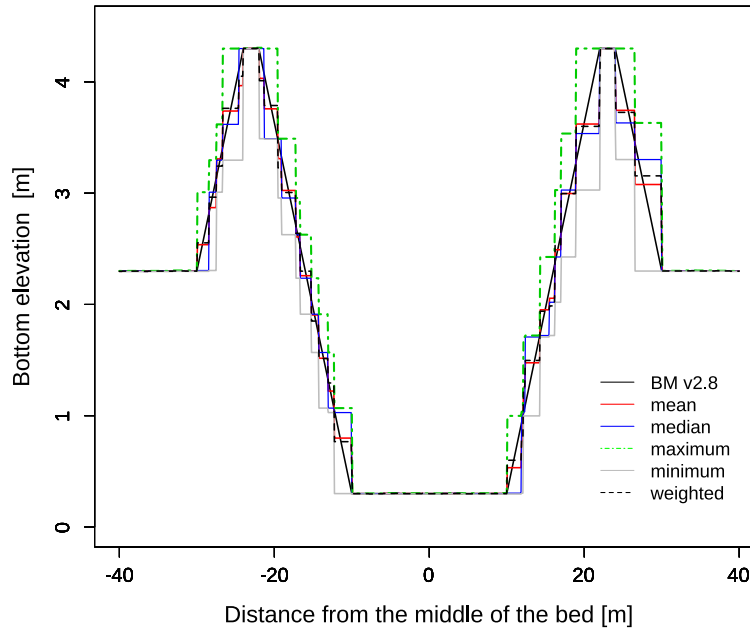


Figure 3.6 Comparison of interpolation methods with the mesh of BASEMENT version 2.8 (BM v2.8) on a cross section at $x=150$ m of the trapezoidal channel with breaklines

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

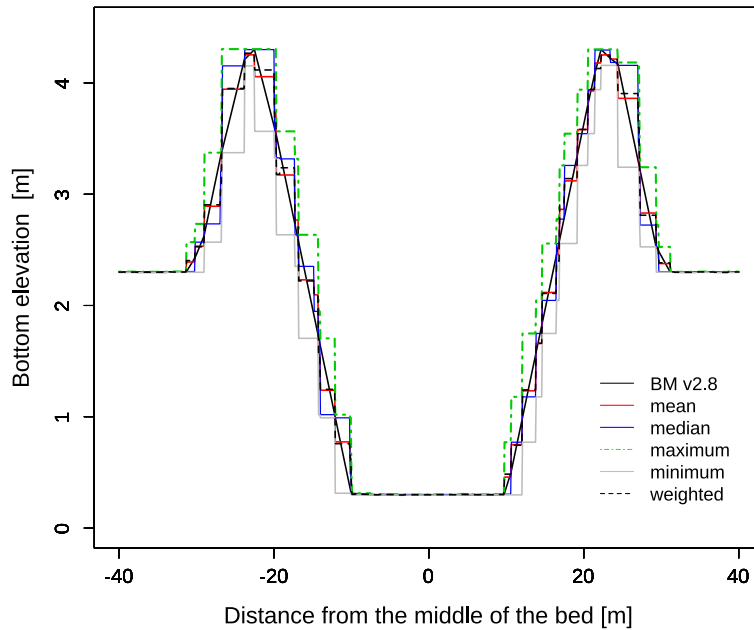


Figure 3.7 Comparison of interpolation methods with the mesh of BASEMENT version 2.8 (BM v2.8) on a cross section at $x=150$ m of the trapezoidal channel with only one breakline defined at the bank crest

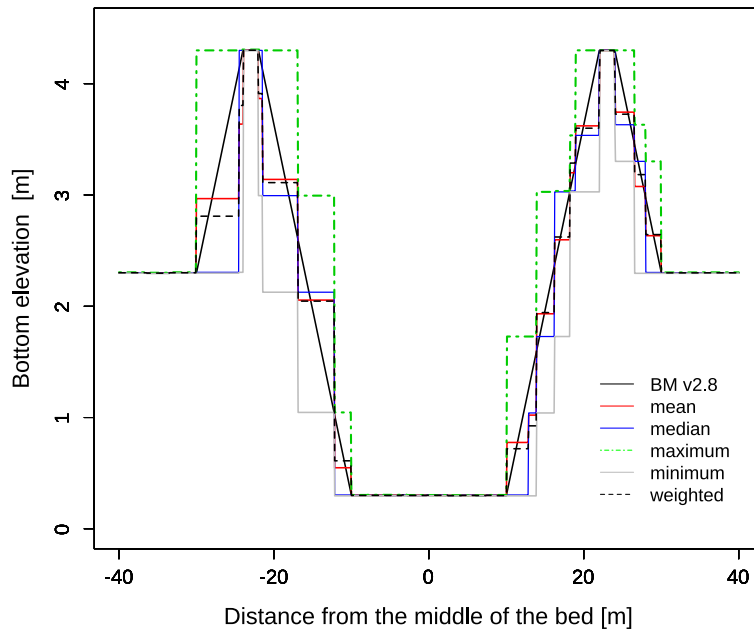


Figure 3.8 Comparison of interpolation methods with the mesh of BASEMENT version 2.8 (BM v2.8) on a cross section at $x=150$ m of the trapezoidal channel with breaklines and for a coarser mesh resolution

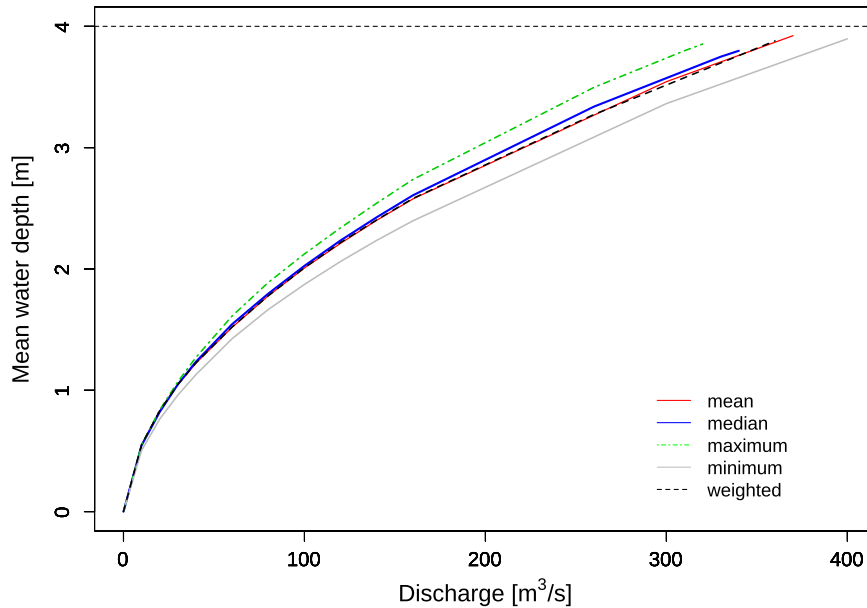


Figure 3.9 Comparison of H - Q relations between the simulations of BASEMENT v3.0 for different interpolation types on the trapezoidal channel at $x = 150$ m.

their attributes. As described 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 (`stringsdefs`). 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

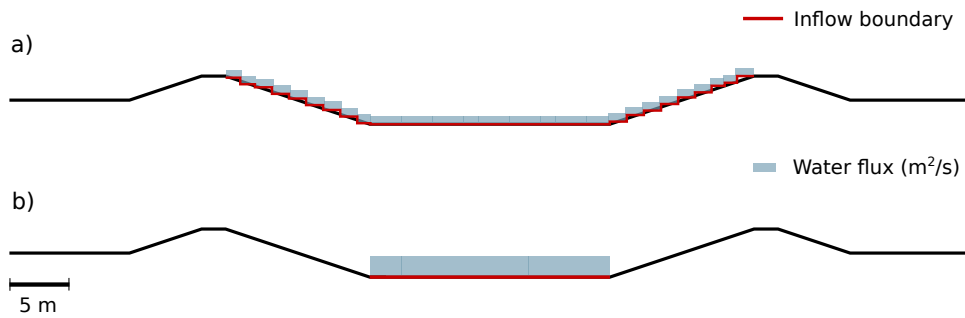


Figure 3.10 Channel cross section and inflow boundary limit in BASEMENT version 3.0
 a) Inflow boundary limit set at levee's highest point b) Reduced inflow boundary limit

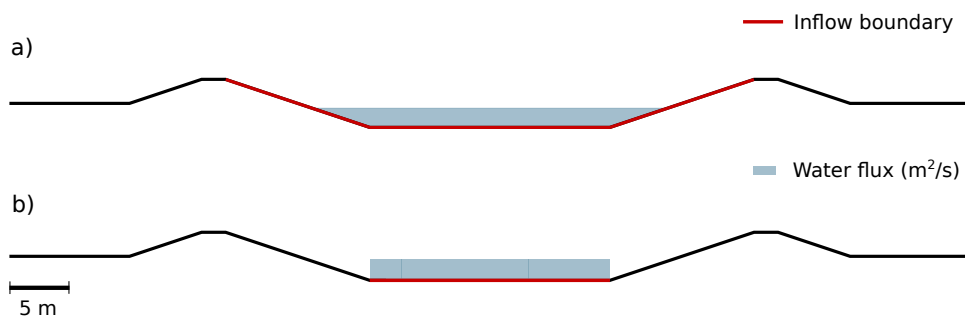


Figure 3.11 Channel cross section and inflow boundary limit in BASEMENT version 2.8
 a) Inflow boundary limit set at levee's highest point b) Reduced inflow boundary limit

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 ($Q = 60 \text{ m}^3/\text{s}$) and small flux towards the floodplains as represented on Figure 3.12 for a discharge value $Q = 200 \text{ m}^3/\text{s}$. 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.

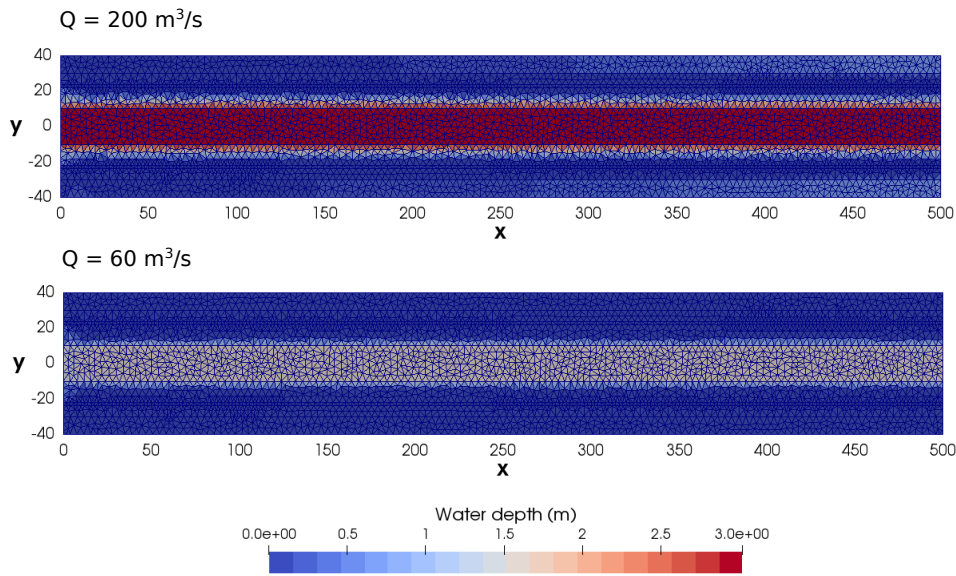


Figure 3.12 Planar view of the simulation results using BASEMENT v3.0 of the trapezoidal channel with breaklines and for two discharge stages. Inflow boundary ($x=0.0$ m) defined between the top elevation of the levees (Figure 3.10, a), inducing a converging flow from the levee towards the channel center and small fluxes towards the floodplains for higher discharge $Q=200\text{ m}^3/\text{s}$

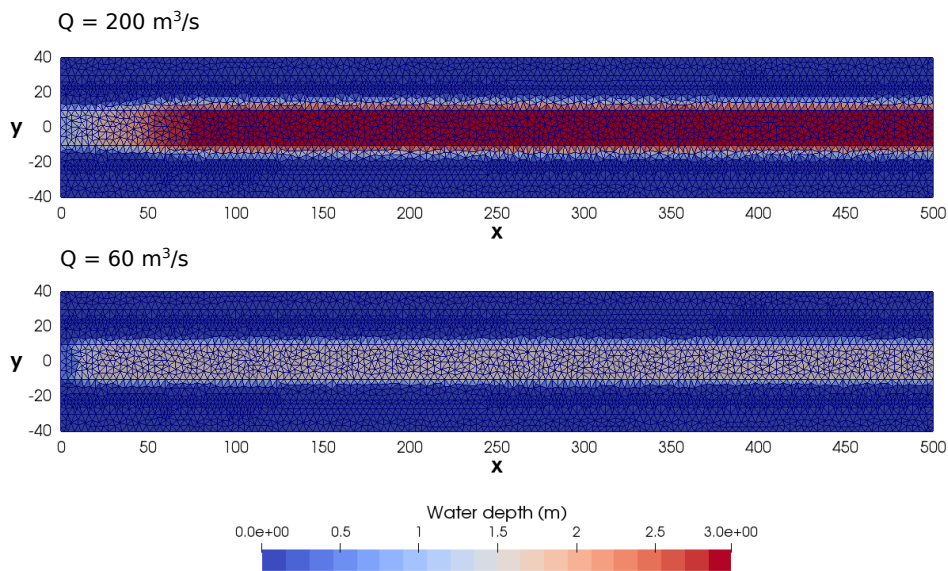


Figure 3.13 Planar view of the simulation results using BASEMENT v3.0 of the trapezoidal channel with breaklines and for two discharge stages. Inflow boundary ($x=0.0$ m) restricted to the channel bed (Figure 3.10, b), inducing an increase of the flow velocity.

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 single GPU processors.

The speedup $S = \frac{T_1}{T_N}$ 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 N th 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.

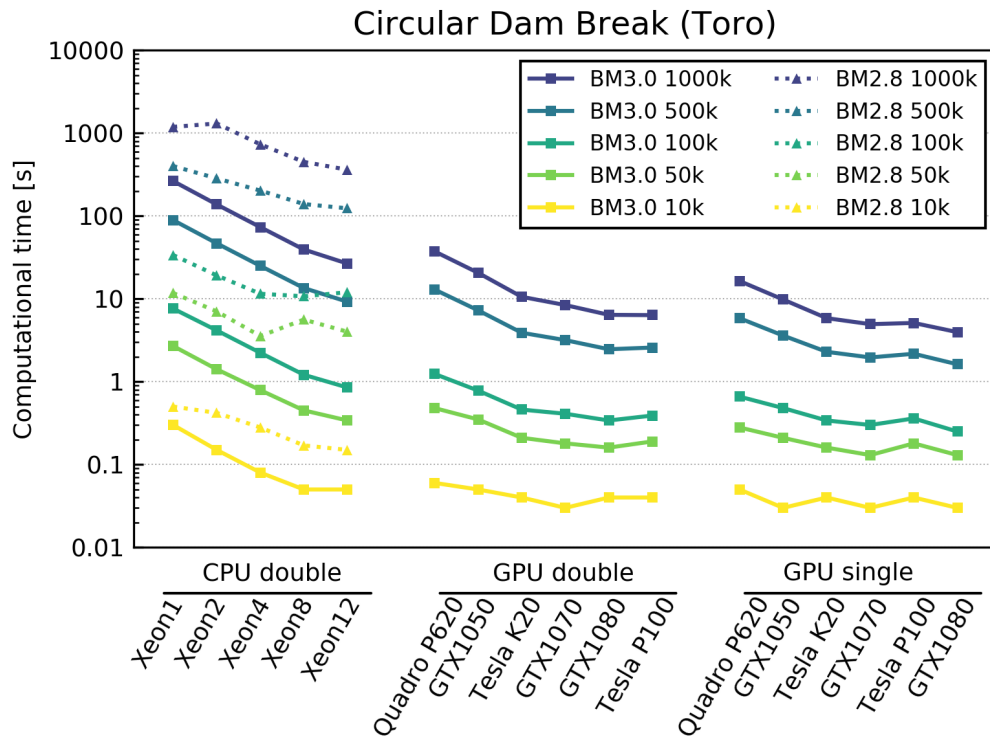


Figure 3.14 Execution time of the circular dam break test case for different backends and mesh sizes

The increasing number of threads for simulations performed with BASEMENT version 2.8 does not increase the speedup significantly 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.

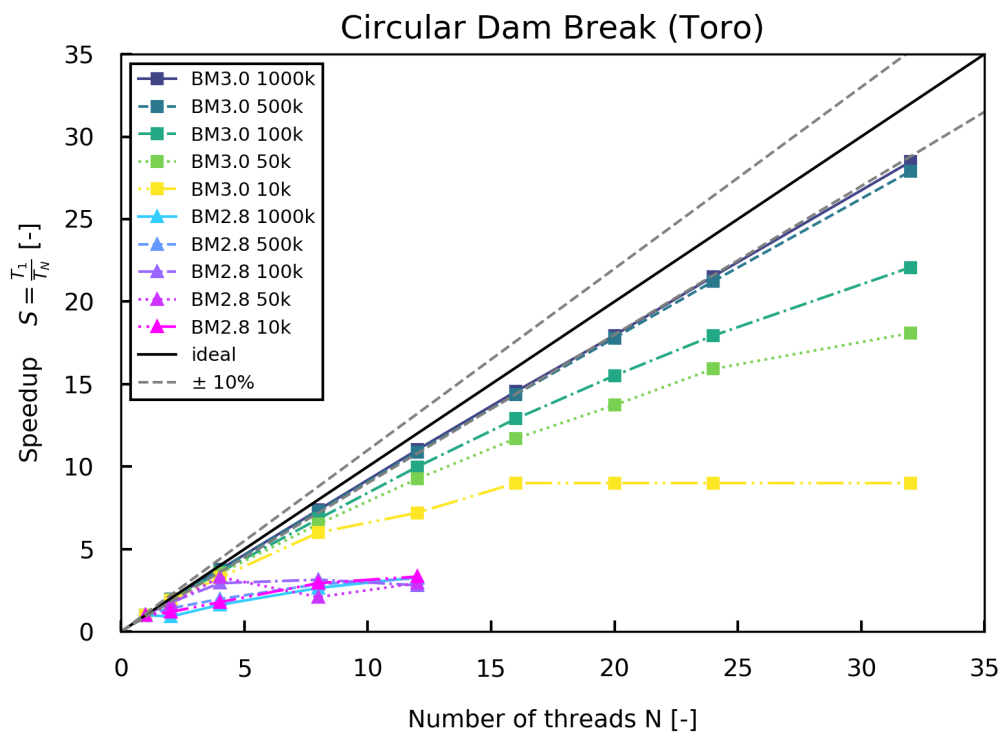


Figure 3.15 Speedup compared to the sequential time (T_1) of the circular dam break test case performed on CPU for an increasing number of threads and different mesh sizes

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)

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 (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

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 (boundary 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

- Chen, X., Ma, J. and Dey, S. (2010). Sediment transport on arbitrary slopes: Simplified model. *Journal of Hydraulic Engineering-ASCE*, 136(5): 311–317.
- Duran, A., Liang, Q. and Marche, F. (2013). On the well-balanced numerical discretization of shallow water equations on unstructured meshes. *Journal of Computational Physics*, 235: 565–586.
- Ikeda, S. (1982). Lateral Bed-Load Transport on Side Slopes. *Journal of the Hydraulics Division-Asce*, 108(11): 1369–1373.
- Soares-Frazão, S. and Zech, Y. (2011). HLLC scheme with novel wave-speed estimators appropriate for two-dimensional shallow-water flow on erodible bed. *International Journal for Numerical Methods in Fluids*, 66.
- Toro, E.F. (2001). Shock-Capturing Methods for Free-Surface Shallow Flows. *John Wiley*, Chichester, New York.
- van Rijn, L.C. (1989). Handbook Sediment Transport by Current and Waves. *Delft Hydraulics Laboratory*, Delft, The Netherlands.

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

APPENDIX

**VERSION 3.0
September 2019**



BASEMENT

Third Party Software

1.1 Third party software copyright notices

Abseil

Copyright Google Inc.

License: Apache 2.0

glibc-queue

Copyright (C) 1991-2015 Free Software Foundation, Inc.

The GNU C Library is free software; you can redistribute it and/or modify it under the terms of the GNU Lesser General Public License as published by the Free Software Foundation; either version 2.1 of the License, or (at your option) any later version.

The GNU C Library is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for more details.

You should have received a copy of the GNU Lesser General Public License along with the GNU C Library; if not, write to the Free Software Foundation, Inc., 51 Franklin St, Fifth Floor, Boston, MA 02110-1301 USA

* All code incorporated from 4.4 BSD is distributed under the following license:

Copyright (C) 1991 Regents of the University of California.
All rights reserved.

Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:

1. Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
2. Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the

documentation and/or other materials provided with the distribution.

3. [This condition was removed.]
4. Neither the name of the University nor the names of its contributors may be used to endorse or promote products derived from this software without specific prior written permission.

THIS SOFTWARE IS PROVIDED BY THE REGENTS AND CONTRIBUTORS ``AS IS'' AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE REGENTS OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

Google Test

Copyright 2008, Google Inc.

All rights reserved.

License: BSD 2.0

HDF5

HDF5 (Hierarchical Data Format 5) Software Library and Utilities
Copyright (c) 2006-2018, The HDF Group.

NCSA HDF5 (Hierarchical Data Format 5) Software Library and Utilities
Copyright (c) 1998-2006, The Board of Trustees of the University of Illinois.

All rights reserved.

Redistribution and use in source and binary forms, with or without modification, are permitted for any purpose (including commercial purposes) provided that the following conditions are met:

1. Redistributions of source code must retain the above copyright notice, this list of conditions, and the following disclaimer.
2. Redistributions in binary form must reproduce the above copyright notice, this list of conditions, and the following disclaimer in the documentation and/or materials provided with the distribution.
3. Neither the name of The HDF Group, the name of the University, nor the name of any Contributor may be used to endorse or promote products derived from this software without specific prior written permission from The HDF Group, the University, or the Contributor, respectively.

DISCLAIMER:

THIS SOFTWARE IS PROVIDED BY THE HDF GROUP AND THE CONTRIBUTORS "AS IS" WITH NO WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED. IN NO EVENT SHALL THE HDF GROUP OR THE CONTRIBUTORS BE LIABLE FOR ANY DAMAGES SUFFERED BY THE USERS ARISING OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

You are under no obligation whatsoever to provide any bug fixes, patches, or upgrades to the features, functionality or performance of the source code ("Enhancements") to anyone; however, if you choose to make your Enhancements available either publicly, or directly to The HDF Group, without imposing a separate written license agreement for such Enhancements, then you hereby grant the following license: a non-exclusive, royalty-free perpetual license to install, use, modify, prepare derivative works, incorporate into other computer software, distribute, and sublicense such enhancements or derivative works thereof, in binary and source code form.

Limited portions of HDF5 were developed by Lawrence Berkeley National Laboratory (LBNL). LBNL's Copyright Notice and Licensing Terms can be found here: COPYING_LBNL_HDF5 file in this directory or at http://support.hdfgroup.org/ftp/HDF5/releases/COPYING_LBNL_HDF5.

Contributors: National Center for Supercomputing Applications (NCSA) at the University of Illinois, Fortner Software, Unidata Program Center (netCDF), The Independent JPEG Group (JPEG), Jean-loup Gailly and Mark Adler (gzip), and Digital Equipment Corporation (DEC).

Portions of HDF5 were developed with support from the Lawrence Berkeley National Laboratory (LBNL) and the United States Department of Energy under Prime Contract No. DE-AC02-05CH11231.

Portions of HDF5 were developed with support from the University of California, Lawrence Livermore National Laboratory (UC LLNL). The following statement applies to those portions of the product and must be retained in any redistribution of source code, binaries, documentation, and/or accompanying materials:

This work was partially produced at the University of California, Lawrence Livermore National Laboratory (UC LLNL) under contract no. W-7405-ENG-48 (Contract 48) between the U.S. Department of Energy (DOE) and The Regents of the University of California (University) for the operation of UC LLNL.

DISCLAIMER:

This work was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

HDF5 is available with the SZIP compression library but SZIP is not part of HDF5 and has separate copyright and license terms. See SZIP Compression in HDF Products (www.hdfgroup.org/doc_resource/SZIP/) for further details.

HighFive

License: BSL 1.0

JSON for Modern C++

Copyright (c) 2013-2018 Niels Lohmann

License: MIT

libgcc, libstdc++, libgomp

Copyright (C) 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014 Free Software Foundation, Inc.

License: GPLv3 with GCC Runtime Library Exception 3.1

mingw-w64-winpthreads

Copyright (c) 2011 mingw-w64 project

Permission is hereby granted, free of charge, to any person obtaining a copy of this software and associated documentation files (the "Software"), to deal in the Software without restriction, including without limitation the rights to use, copy, modify, merge, publish, distribute, sublicense, and/or sell copies of the Software, and to permit persons to whom the Software is furnished to do so, subject to the following conditions:

The above copyright notice and this permission notice shall be included in all copies or substantial portions of the Software.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.

```

/*
 * Parts of this library are derived by:
 *
 * Posix Threads library for Microsoft Windows
 *
 * Use at own risk, there is no implied warranty to this code.
 * It uses undocumented features of Microsoft Windows that can change
 * at any time in the future.
 *
 * (C) 2010 Lockless Inc.
 * All rights reserved.
 *
 * Redistribution and use in source and binary forms, with or without modification,
 * are permitted provided that the following conditions are met:
 *
 * * Redistributions of source code must retain the above copyright notice,
 *   this list of conditions and the following disclaimer.
 * * Redistributions in binary form must reproduce the above copyright notice,
 *   this list of conditions and the following disclaimer in the documentation
 *   and/or other materials provided with the distribution.
 * * Neither the name of Lockless Inc. nor the names of its contributors may be
 *   used to endorse or promote products derived from this software without
 *   specific prior written permission.
 *
 * THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS "AS IS" AN
 * ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED
 * WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED.
 * IN NO EVENT SHALL THE COPYRIGHT HOLDER OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT,
 * INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING,
 * BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE,
 * DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF
 * LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE
 * OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED
 * OF THE POSSIBILITY OF SUCH DAMAGE.
 */

```

OP2

Copyright (c) 2011, Gihan Mudalige, Istvan Reguly, Mike Giles, and others.
Please see the AUTHORS file in the main source directory for details.
All rights reserved.

License: BSD 2.0

OpenMesh

Copyright (c) 2001-2015, RWTH-Aachen University

Department of Computer Graphics and Multimedia

All rights reserved.

www.openmesh.org

License: BSD 2.0

Qt

Copyright (C) 2018 The Qt Company Ltd and other contributors

License: LGPL 3.0

SimpleXdmf

Copyright (c) 2017 hsimyu

License: MIT

TCLAP

Copyright (c) 2003 Michael E. Smoot

License: MIT

1.2 Third party software licenses

LGPL 3.0

GNU LESSER GENERAL PUBLIC LICENSE
Version 3, 29 June 2007

Copyright (C) 2007 Free Software Foundation, Inc. <<https://fsf.org/>>
Everyone is permitted to copy and distribute verbatim copies
of this license document, but changing it is not allowed.

This version of the GNU Lesser General Public License incorporates
the terms and conditions of version 3 of the GNU General Public
License, supplemented by the additional permissions listed below.

0. Additional Definitions.

As used herein, "this License" refers to version 3 of the GNU Lesser
General Public License, and the "GNU GPL" refers to version 3 of the GNU
General Public License.

"The Library" refers to a covered work governed by this License,
other than an Application or a Combined Work as defined below.

An "Application" is any work that makes use of an interface provided
by the Library, but which is not otherwise based on the Library.
Defining a subclass of a class defined by the Library is deemed a mode
of using an interface provided by the Library.

A "Combined Work" is a work produced by combining or linking an
Application with the Library. The particular version of the Library
with which the Combined Work was made is also called the "Linked
Version".

The "Minimal Corresponding Source" for a Combined Work means the Corresponding Source for the Combined Work, excluding any source code for portions of the Combined Work that, considered in isolation, are based on the Application, and not on the Linked Version.

The "Corresponding Application Code" for a Combined Work means the object code and/or source code for the Application, including any data and utility programs needed for reproducing the Combined Work from the Application, but excluding the System Libraries of the Combined Work.

1. Exception to Section 3 of the GNU GPL.

You may convey a covered work under sections 3 and 4 of this License without being bound by section 3 of the GNU GPL.

2. Conveying Modified Versions.

If you modify a copy of the Library, and, in your modifications, a facility refers to a function or data to be supplied by an Application that uses the facility (other than as an argument passed when the facility is invoked), then you may convey a copy of the modified version:

- a) under this License, provided that you make a good faith effort to ensure that, in the event an Application does not supply the function or data, the facility still operates, and performs whatever part of its purpose remains meaningful, or
- b) under the GNU GPL, with none of the additional permissions of this License applicable to that copy.

3. Object Code Incorporating Material from Library Header Files.

The object code form of an Application may incorporate material from a header file that is part of the Library. You may convey such object code under terms of your choice, provided that, if the incorporated material is not limited to numerical parameters, data structure layouts and accessors, or small macros, inline functions and templates (ten or fewer lines in length), you do both of the following:

- a) Give prominent notice with each copy of the object code that the Library is used in it and that the Library and its use are covered by this License.
- b) Accompany the object code with a copy of the GNU GPL and this license document.

4. Combined Works.

You may convey a Combined Work under terms of your choice that, taken together, effectively do not restrict modification of the portions of the Library contained in the Combined Work and reverse engineering for debugging such modifications, if you also do each of the following:

- a) Give prominent notice with each copy of the Combined Work that the Library is used in it and that the Library and its use are covered by this License.
- b) Accompany the Combined Work with a copy of the GNU GPL and this license document.
- c) For a Combined Work that displays copyright notices during execution, include the copyright notice for the Library among these notices, as well as a reference directing the user to the copies of the GNU GPL and this license document.
- d) Do one of the following:

0) Convey the Minimal Corresponding Source under the terms of this License, and the Corresponding Application Code in a form suitable for, and under terms that permit, the user to recombine or relink the Application with a modified version of the Linked Version to produce a modified Combined Work, in the manner specified by section 6 of the GNU GPL for conveying Corresponding Source.

1) Use a suitable shared library mechanism for linking with the Library. A suitable mechanism is one that (a) uses at run time a copy of the Library already present on the user's computer system, and (b) will operate properly with a modified version of the Library that is interface-compatible with the Linked Version.

e) Provide Installation Information, but only if you would otherwise be required to provide such information under section 6 of the GNU GPL, and only to the extent that such information is necessary to install and execute a modified version of the Combined Work produced by recombining or relinking the Application with a modified version of the Linked Version. (If you use option 4d0, the Installation Information must accompany the Minimal Corresponding Source and Corresponding Application Code. If you use option 4d1, you must provide the Installation Information in the manner specified by section 6 of the GNU GPL for conveying Corresponding Source.)

5. Combined Libraries.

You may place library facilities that are a work based on the Library side by side in a single library together with other library facilities that are not Applications and are not covered by this License, and convey such a combined library under terms of your choice, if you do both of the following:

- a) Accompany the combined library with a copy of the same work based on the Library, uncombined with any other library facilities, conveyed under the terms of this License.
- b) Give prominent notice with the combined library that part of it is a work based on the Library, and explaining where to find the accompanying uncombined form of the same work.

6. Revised Versions of the GNU Lesser General Public License.

The Free Software Foundation may publish revised and/or new versions of the GNU Lesser General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Library as you received it specifies that a certain numbered version of the GNU Lesser General Public License "or any later version" applies to it, you have the option of following the terms and conditions either of that published version or of any later version published by the Free Software Foundation. If the Library as you received it does not specify a version number of the GNU Lesser General Public License, you may choose any version of the GNU Lesser General Public License ever published by the Free Software Foundation.

If the Library as you received it specifies that a proxy can decide whether future versions of the GNU Lesser General Public License shall apply, that proxy's public statement of acceptance of any version is permanent authorization for you to choose that version for the Library.

GPL 3.0

GNU GENERAL PUBLIC LICENSE

Version 3, 29 June 2007

Copyright (C) 2007 Free Software Foundation, Inc. <<https://fsf.org/>>
Everyone is permitted to copy and distribute verbatim copies
of this license document, but changing it is not allowed.

Preamble

The GNU General Public License is a free, copyleft license for
software and other kinds of works.

The licenses for most software and other practical works are designed
to take away your freedom to share and change the works. By contrast,
the GNU General Public License is intended to guarantee your freedom to
share and change all versions of a program--to make sure it remains free
software for all its users. We, the Free Software Foundation, use the
GNU General Public License for most of our software; it applies also to
any other work released this way by its authors. You can apply it to
your programs, too.

When we speak of free software, we are referring to freedom, not
price. Our General Public Licenses are designed to make sure that you
have the freedom to distribute copies of free software (and charge for
them if you wish), that you receive source code or can get it if you
want it, that you can change the software or use pieces of it in new
free programs, and that you know you can do these things.

To protect your rights, we need to prevent others from denying you
these rights or asking you to surrender the rights. Therefore, you have
certain responsibilities if you distribute copies of the software, or if
you modify it: responsibilities to respect the freedom of others.

For example, if you distribute copies of such a program, whether
gratis or for a fee, you must pass on to the recipients the same
freedoms that you received. You must make sure that they, too, receive
or can get the source code. And you must show them these terms so they
know their rights.

Developers that use the GNU GPL protect your rights with two steps:
(1) assert copyright on the software, and (2) offer you this License
giving you legal permission to copy, distribute and/or modify it.

For the developers' and authors' protection, the GPL clearly explains
that there is no warranty for this free software. For both users' and
authors' sake, the GPL requires that modified versions be marked as
changed, so that their problems will not be attributed erroneously to
authors of previous versions.

Some devices are designed to deny users access to install or run
modified versions of the software inside them, although the manufacturer
can do so. This is fundamentally incompatible with the aim of
protecting users' freedom to change the software. The systematic
pattern of such abuse occurs in the area of products for individuals to
use, which is precisely where it is most unacceptable. Therefore, we
have designed this version of the GPL to prohibit the practice for those
products. If such problems arise substantially in other domains, we
stand ready to extend this provision to those domains in future versions
of the GPL, as needed to protect the freedom of users.

Finally, every program is threatened constantly by software patents.
States should not allow patents to restrict development and use of
software on general-purpose computers, but in those that do, we wish to
avoid the special danger that patents applied to a free program could
make it effectively proprietary. To prevent this, the GPL assures that
patents cannot be used to render the program non-free.

The precise terms and conditions for copying, distribution and
modification follow.

TERMS AND CONDITIONS

0. Definitions.

"This License" refers to version 3 of the GNU General Public License.

"Copyright" also means copyright-like laws that apply to other kinds of works, such as semiconductor masks.

"The Program" refers to any copyrightable work licensed under this License. Each licensee is addressed as "you". "Licensees" and "recipients" may be individuals or organizations.

To "modify" a work means to copy from or adapt all or part of the work in a fashion requiring copyright permission, other than the making of an exact copy. The resulting work is called a "modified version" of the earlier work or a work "based on" the earlier work.

A "covered work" means either the unmodified Program or a work based on the Program.

To "propagate" a work means to do anything with it that, without permission, would make you directly or secondarily liable for infringement under applicable copyright law, except executing it on a computer or modifying a private copy. Propagation includes copying, distribution (with or without modification), making available to the public, and in some countries other activities as well.

To "convey" a work means any kind of propagation that enables other parties to make or receive copies. Mere interaction with a user through a computer network, with no transfer of a copy, is not conveying.

An interactive user interface displays "Appropriate Legal Notices" to the extent that it includes a convenient and prominently visible feature that (1) displays an appropriate copyright notice, and (2) tells the user that there is no warranty for the work (except to the extent that warranties are provided), that licensees may convey the work under this License, and how to view a copy of this License. If the interface presents a list of user commands or options, such as a menu, a prominent item in the list meets this criterion.

1. Source Code.

The "source code" for a work means the preferred form of the work for making modifications to it. "Object code" means any non-source form of a work.

A "Standard Interface" means an interface that either is an official standard defined by a recognized standards body, or, in the case of interfaces specified for a particular programming language, one that is widely used among developers working in that language.

The "System Libraries" of an executable work include anything, other than the work as a whole, that (a) is included in the normal form of packaging a Major Component, but which is not part of that Major Component, and (b) serves only to enable use of the work with that Major Component, or to implement a Standard Interface for which an implementation is available to the public in source code form. A "Major Component", in this context, means a major essential component (kernel, window system, and so on) of the specific operating system (if any) on which the executable work runs, or a compiler used to produce the work, or an object code interpreter used to run it.

The "Corresponding Source" for a work in object code form means all the source code needed to generate, install, and (for an executable work) run the object code and to modify the work, including scripts to control those activities. However, it does not include the work's System Libraries, or general-purpose tools or generally available free programs which are used unmodified in performing those activities but which are not part of the work. For example, Corresponding Source includes interface definition files associated with source files for

the work, and the source code for shared libraries and dynamically linked subprograms that the work is specifically designed to require, such as by intimate data communication or control flow between those subprograms and other parts of the work.

The Corresponding Source need not include anything that users can regenerate automatically from other parts of the Corresponding Source.

The Corresponding Source for a work in source code form is that same work.

2. Basic Permissions.

All rights granted under this License are granted for the term of copyright on the Program, and are irrevocable provided the stated conditions are met. This License explicitly affirms your unlimited permission to run the unmodified Program. The output from running a covered work is covered by this License only if the output, given its content, constitutes a covered work. This License acknowledges your rights of fair use or other equivalent, as provided by copyright law.

You may make, run and propagate covered works that you do not convey, without conditions so long as your license otherwise remains in force. You may convey covered works to others for the sole purpose of having them make modifications exclusively for you, or provide you with facilities for running those works, provided that you comply with the terms of this License in conveying all material for which you do not control copyright. Those thus making or running the covered works for you must do so exclusively on your behalf, under your direction and control, on terms that prohibit them from making any copies of your copyrighted material outside their relationship with you.

Conveying under any other circumstances is permitted solely under the conditions stated below. Sublicensing is not allowed; section 10 makes it unnecessary.

3. Protecting Users' Legal Rights From Anti-Circumvention Law.

No covered work shall be deemed part of an effective technological measure under any applicable law fulfilling obligations under article 11 of the WIPO copyright treaty adopted on 20 December 1996, or similar laws prohibiting or restricting circumvention of such measures.

When you convey a covered work, you waive any legal power to forbid circumvention of technological measures to the extent such circumvention is effected by exercising rights under this License with respect to the covered work, and you disclaim any intention to limit operation or modification of the work as a means of enforcing, against the work's users, your or third parties' legal rights to forbid circumvention of technological measures.

4. Conveying Verbatim Copies.

You may convey verbatim copies of the Program's source code as you receive it, in any medium, provided that you conspicuously and appropriately publish on each copy an appropriate copyright notice; keep intact all notices stating that this License and any non-permissive terms added in accord with section 7 apply to the code; keep intact all notices of the absence of any warranty; and give all recipients a copy of this License along with the Program.

You may charge any price or no price for each copy that you convey, and you may offer support or warranty protection for a fee.

5. Conveying Modified Source Versions.

You may convey a work based on the Program, or the modifications to produce it from the Program, in the form of source code under the

terms of section 4, provided that you also meet all of these conditions:

- a) The work must carry prominent notices stating that you modified it, and giving a relevant date.
- b) The work must carry prominent notices stating that it is released under this License and any conditions added under section 7. This requirement modifies the requirement in section 4 to "keep intact all notices".
- c) You must license the entire work, as a whole, under this License to anyone who comes into possession of a copy. This License will therefore apply, along with any applicable section 7 additional terms, to the whole of the work, and all its parts, regardless of how they are packaged. This License gives no permission to license the work in any other way, but it does not invalidate such permission if you have separately received it.
- d) If the work has interactive user interfaces, each must display Appropriate Legal Notices; however, if the Program has interactive interfaces that do not display Appropriate Legal Notices, your work need not make them do so.

A compilation of a covered work with other separate and independent works, which are not by their nature extensions of the covered work, and which are not combined with it such as to form a larger program, in or on a volume of a storage or distribution medium, is called an "aggregate" if the compilation and its resulting copyright are not used to limit the access or legal rights of the compilation's users beyond what the individual works permit. Inclusion of a covered work in an aggregate does not cause this License to apply to the other parts of the aggregate.

6. Conveying Non-Source Forms.

You may convey a covered work in object code form under the terms of sections 4 and 5, provided that you also convey the machine-readable Corresponding Source under the terms of this License, in one of these ways:

- a) Convey the object code in, or embodied in, a physical product (including a physical distribution medium), accompanied by the 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 copy of the Corresponding Source for all the software in the product that is covered by this License, on a durable physical medium customarily used for software interchange, for a price no more than your reasonable cost of physically performing this conveying of source, or (2) access to copy the Corresponding Source from a network server at no charge.
- c) Convey individual copies of the object code with a copy of the written offer to provide the Corresponding Source. This alternative is allowed only occasionally and noncommercially, and only if you received the object code with such an offer, in accord with subsection 6b.
- d) Convey the object code by offering access from a designated place (gratis or for a charge), and offer equivalent access to the Corresponding Source in the same way through the same place at no further charge. You need not require recipients to copy the Corresponding Source along with the object code. If the place to copy the object code is a network server, the Corresponding Source may be on a different server (operated by you or a third party)

that supports equivalent copying facilities, provided you maintain clear directions next to the object code saying where to find the Corresponding Source. Regardless of what server hosts the Corresponding Source, you remain obligated to ensure that it is available for as long as needed to satisfy these requirements.

e) Convey the object code using peer-to-peer transmission, provided you inform other peers where the object code and Corresponding Source of the work are being offered to the general public at no charge under subsection 6d.

A separable portion of the object code, whose source code is excluded from the Corresponding Source as a System Library, need not be included in conveying the object code work.

A "User Product" is either (1) a "consumer product", which means any tangible personal property which is normally used for personal, family, or household purposes, or (2) anything designed or sold for incorporation into a dwelling. In determining whether a product is a consumer product, doubtful cases shall be resolved in favor of coverage. For a particular product received by a particular user, "normally used" refers to a typical or common use of that class of product, regardless of the status of the particular user or of the way in which the particular user actually uses, or expects or is expected to use, the product. A product is a consumer product regardless of whether the product has substantial commercial, industrial or non-consumer uses, unless such uses represent the only significant mode of use of the product.

"Installation Information" for a User Product means any methods, procedures, authorization keys, or other information required to install and execute modified versions of a covered work in that User Product from a modified version of its Corresponding Source. The information must suffice to ensure that the continued functioning of the modified object code is in no case prevented or interfered with solely because modification has been made.

If you convey an object code work under this section in, or with, or specifically for use in, a User Product, and the conveying occurs as part of a transaction in which the right of possession and use of the User Product is transferred to the recipient in perpetuity or for a fixed term (regardless of how the transaction is characterized), the Corresponding Source conveyed under this section must be accompanied by the Installation Information. But this requirement does not apply if neither you nor any third party retains the ability to install modified object code on the User Product (for example, the work has been installed in ROM).

The requirement to provide Installation Information does not include a requirement to continue to provide support service, warranty, or updates for a work that has been modified or installed by the recipient, or for the User Product in which it has been modified or installed. Access to a network may be denied when the modification itself materially and adversely affects the operation of the network or violates the rules and protocols for communication across the network.

Corresponding Source conveyed, and Installation Information provided, in accord with this section must be in a format that is publicly documented (and with an implementation available to the public in source code form), and must require no special password or key for unpacking, reading or copying.

7. Additional Terms.

"Additional permissions" are terms that supplement the terms of this License by making exceptions from one or more of its conditions. Additional permissions that are applicable to the entire Program shall be treated as though they were included in this License, to the extent that they are valid under applicable law. If additional permissions apply only to part of the Program, that part may be used separately under those permissions, but the entire Program remains governed by

this License without regard to the additional permissions.

When you convey a copy of a covered work, you may at your option remove any additional permissions from that copy, or from any part of it. (Additional permissions may be written to require their own removal in certain cases when you modify the work.) You may place additional permissions on material, added by you to a covered work, for which you have or can give appropriate copyright permission.

Notwithstanding any other provision of this License, for material you add to a covered work, you may (if authorized by the copyright holders of that material) supplement the terms of this License with terms:

- a) Disclaiming warranty or limiting liability differently from the terms of sections 15 and 16 of this License; or
- b) Requiring preservation of specified reasonable legal notices or author attributions in that material or in the Appropriate Legal Notices displayed by works containing it; or
- c) Prohibiting misrepresentation of the origin of that material, or requiring that modified versions of such material be marked in reasonable ways as different from the original version; or
- d) Limiting the use for publicity purposes of names of licensors or authors of the material; or
- e) Declining to grant rights under trademark law for use of some trade names, trademarks, or service marks; or
- f) Requiring indemnification of licensors and authors of that material by anyone who conveys the material (or modified versions of it) with contractual assumptions of liability to the recipient, for any liability that these contractual assumptions directly impose on those licensors and authors.

All other non-permissive additional terms are considered "further restrictions" within the meaning of section 10. If the Program as you received it, or any part of it, contains a notice stating that it is governed by this License along with a term that is a further restriction, you may remove that term. If a license document contains a further restriction but permits relicensing or conveying under this License, you may add to a covered work material governed by the terms of that license document, provided that the further restriction does not survive such relicensing or conveying.

If you add terms to a covered work in accord with this section, you must place, in the relevant source files, a statement of the additional terms that apply to those files, or a notice indicating where to find the applicable terms.

Additional terms, permissive or non-permissive, may be stated in the form of a separately written license, or stated as exceptions; the above requirements apply either way.

8. Termination.

You may not propagate or modify a covered work except as expressly provided under this License. Any attempt otherwise to propagate or modify it is void, and will automatically terminate your rights under this License (including any patent licenses granted under the third paragraph of section 11).

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, you do not qualify to receive new licenses for the same material under section 10.

9. Acceptance Not Required for Having Copies.

You are not required to accept this License in order to receive or run a copy of the Program. Ancillary propagation of a covered work occurring solely as a consequence of using peer-to-peer transmission to receive a copy likewise does not require acceptance. However, nothing other than this License grants you permission to propagate or modify any covered work. These actions infringe copyright if you do not accept this License. Therefore, by modifying or propagating a covered work, you indicate your acceptance of this License to do so.

10. Automatic Licensing of Downstream Recipients.

Each time you convey a covered work, the recipient automatically receives a license from the original licensors, to run, modify and propagate that work, subject to this License. You are not responsible for enforcing compliance by third parties with this License.

An "entity transaction" is a transaction transferring control of an organization, or substantially all assets of one, or subdividing an organization, or merging organizations. If propagation of a covered work results from an entity transaction, each party to that transaction who receives a copy of the work also receives whatever licenses to the work the party's predecessor in interest had or could give under the previous paragraph, plus a right to possession of the Corresponding Source of the work from the predecessor in interest, if the predecessor has it or can get it with reasonable efforts.

You may not impose any further restrictions on the exercise of the rights granted or affirmed under this License. For example, you may not impose a license fee, royalty, or other charge for exercise of rights granted under this License, and you may not initiate litigation (including a cross-claim or counterclaim in a lawsuit) alleging that any patent claim is infringed by making, using, selling, offering for sale, or importing the Program or any portion of it.

11. Patents.

A "contributor" is a copyright holder who authorizes use under this License of the Program or a work on which the Program is based. The work thus licensed is called the contributor's "contributor version".

A contributor's "essential patent claims" are all patent claims owned or controlled by the contributor, whether already acquired or hereafter acquired, that would be infringed by some manner, permitted by this License, of making, using, or selling its contributor version, but do not include claims that would be infringed only as a consequence of further modification of the contributor version. For purposes of this definition, "control" includes the right to grant patent sublicenses in a manner consistent with the requirements of this License.

Each contributor grants you a non-exclusive, worldwide, royalty-free patent license under the contributor's essential patent claims, to make, use, sell, offer for sale, import and otherwise run, modify and propagate the contents of its contributor version.

In the following three paragraphs, a "patent license" is any express agreement or commitment, however denominated, not to enforce a patent (such as an express permission to practice a patent or covenant not to sue for patent infringement). To "grant" such a patent license to a party means to make such an agreement or commitment not to enforce a patent against the party.

If you convey a covered work, knowingly relying on a patent license, and the Corresponding Source of the work is not available for anyone to copy, free of charge and under the terms of this License, through a publicly available network server or other readily accessible means, then you must either (1) cause the Corresponding Source to be so available, or (2) arrange to deprive yourself of the benefit of the patent license for this particular work, or (3) arrange, in a manner consistent with the requirements of this License, to extend the patent license to downstream recipients. "Knowingly relying" means you have actual knowledge that, but for the patent license, your conveying the covered work in a country, or your recipient's use of the covered work in a country, would infringe one or more identifiable patents in that country that you have reason to believe are valid.

If, pursuant to or in connection with a single transaction or arrangement, you convey, or propagate by procuring conveyance of, a covered work, and grant a patent license to some of the parties receiving the covered work authorizing them to use, propagate, modify or convey a specific copy of the covered work, then the patent license you grant is automatically extended to all recipients of the covered work and works based on it.

A patent license is "discriminatory" if it does not include within the scope of its coverage, prohibits the exercise of, or is conditioned on the non-exercise of one or more of the rights that are specifically granted under this License. You may not convey a covered work if you are a party to an arrangement with a third party that is in the business of distributing software, under which you make payment to the third party based on the extent of your activity of conveying the work, and under which the third party grants, to any of the parties who would receive the covered work from you, a discriminatory patent license (a) in connection with copies of the covered work conveyed by you (or copies made from those copies), or (b) primarily for and in connection with specific products or compilations that contain the covered work, unless you entered into that arrangement, or that patent license was granted, prior to 28 March 2007.

Nothing in this License shall be construed as excluding or limiting any implied license or other defenses to infringement that may otherwise be available to you under applicable patent law.

12. No Surrender of Others' Freedom.

If conditions are imposed on you (whether by court order, agreement or otherwise) that contradict the conditions of this License, they do not excuse you from the conditions of this License. If you cannot convey a covered work so as to satisfy simultaneously your obligations under this License and any other pertinent obligations, then as a consequence you may not convey it at all. For example, if you agree to terms that obligate you to collect a royalty for further conveying from those to whom you convey the Program, the only way you could satisfy both those terms and this License would be to refrain entirely from conveying the Program.

13. Use with the GNU Affero General Public License.

Notwithstanding any other provision of this License, you have permission to link or combine any covered work with a work licensed under version 3 of the GNU Affero General Public License into a single combined work, and to convey the resulting work. The terms of this License will continue to apply to the part which is the covered work, but the special requirements of the GNU Affero General Public License, section 13, concerning interaction through a network will apply to the combination as such.

14. Revised Versions of this License.

The Free Software Foundation may publish revised and/or new versions of the GNU General Public License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns.

Each version is given a distinguishing version number. If the Program specifies that a certain numbered version of the GNU General Public License "or any later version" applies to it, you have the option of following the terms and conditions either of that numbered version or of any later version published by the Free Software Foundation. If the Program does not specify a version number of the GNU General Public License, you may choose any version ever published by the Free Software Foundation.

If the Program specifies that a proxy can decide which future versions of the GNU General Public License can be used, that proxy's public statement of acceptance of a version permanently authorizes you to choose that version for the Program.

Later license versions may give you additional or different permissions. However, no additional obligations are imposed on any author or copyright holder as a result of your choosing to follow a later version.

15. Disclaimer of Warranty.

THERE IS NO WARRANTY FOR THE PROGRAM, TO THE EXTENT PERMITTED BY APPLICABLE LAW. EXCEPT WHEN OTHERWISE STATED IN WRITING THE COPYRIGHT HOLDERS AND/OR OTHER PARTIES PROVIDE THE PROGRAM "AS IS" WITHOUT WARRANTY OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. THE ENTIRE RISK AS TO THE QUALITY AND PERFORMANCE OF THE PROGRAM IS WITH YOU. SHOULD THE PROGRAM PROVE DEFECTIVE, YOU ASSUME THE COST OF ALL NECESSARY SERVICING, REPAIR OR CORRECTION.

16. Limitation of Liability.

IN NO EVENT UNLESS REQUIRED BY APPLICABLE LAW OR AGREED TO IN WRITING WILL ANY COPYRIGHT HOLDER, OR ANY OTHER PARTY WHO MODIFIES AND/OR CONVEYS THE PROGRAM AS PERMITTED ABOVE, BE LIABLE TO YOU FOR DAMAGES, INCLUDING ANY GENERAL, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR INABILITY TO USE THE PROGRAM (INCLUDING BUT NOT LIMITED TO LOSS OF DATA OR DATA BEING RENDERED INACCURATE OR LOSSES SUSTAINED BY YOU OR THIRD PARTIES OR A FAILURE OF THE PROGRAM TO OPERATE WITH ANY OTHER PROGRAMS), EVEN IF SUCH HOLDER OR OTHER PARTY HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

17. Interpretation of Sections 15 and 16.

If the disclaimer of warranty and limitation of liability provided above cannot be given local legal effect according to their terms, reviewing courts shall apply local law that most closely approximates an absolute waiver of all civil liability in connection with the Program, unless a warranty or assumption of liability accompanies a copy of the Program in return for a fee.

END OF TERMS AND CONDITIONS

How to Apply These Terms to Your New Programs

If you develop a new program, and you want it to be of the greatest possible use to the public, the best way to achieve this is to make it free software which everyone can redistribute and change under these terms.

To do so, attach the following notices to the program. It is safest to attach them to the start of each source file to most effectively state the exclusion of warranty; and each file should have at least

the "copyright" line and a pointer to where the full notice is found.

```
<one line to give the program's name and a brief idea of what it does.>
Copyright (C) <year> <name of author>
```

This program is free software: you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation, either version 3 of the License, or (at your option) any later version.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License along with this program. If not, see [<https://www.gnu.org/licenses/>](https://www.gnu.org/licenses/).

Also add information on how to contact you by electronic and paper mail.

If the program does terminal interaction, make it output a short notice like this when it starts in an interactive mode:

```
<program> Copyright (C) <year> <name of author>
This program comes with ABSOLUTELY NO WARRANTY; for details type `show w'.
This is free software, and you are welcome to redistribute it
under certain conditions; type `show c' for details.
```

The hypothetical commands `show w' and `show c' should show the appropriate parts of the General Public License. Of course, your program's commands might be different; for a GUI interface, you would use an "about box".

You should also get your employer (if you work as a programmer) or school, if any, to sign a "copyright disclaimer" for the program, if necessary. For more information on this, and how to apply and follow the GNU GPL, see [<https://www.gnu.org/licenses/>](https://www.gnu.org/licenses/).

The GNU General Public License does not permit incorporating your program into proprietary programs. If your program is a subroutine library, you may consider it more useful to permit linking proprietary applications with the library. If this is what you want to do, use the GNU Lesser General Public License instead of this License. But first, please read [<https://www.gnu.org/licenses/why-not-lgpl.html>](https://www.gnu.org/licenses/why-not-lgpl.html).

GCC Runtime Library Exception

Version 3.1, 31 March 2009

Copyright (C) 2009 Free Software Foundation, Inc. [<http://fsf.org/>](http://fsf.org/)

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

This GCC Runtime Library Exception ("Exception") is an additional permission under section 7 of the GNU General Public License, version 3 ("GPLv3"). It applies to a given file (the "Runtime Library") that bears a notice placed by the copyright holder of the file stating that the file is governed by GPLv3 along with this Exception.

When you use GCC to compile a program, GCC may combine portions of certain GCC header files and runtime libraries with the compiled program. The purpose of this Exception is to allow compilation of non-GPL (including proprietary) programs to use, in this way, the header files and runtime libraries covered by this Exception.

0. Definitions.

A file is an "Independent Module" if it either requires the Runtime Library for execution after a Compilation Process, or makes use of an

interface provided by the Runtime Library, but is not otherwise based on the Runtime Library.

"GCC" means a version of the GNU Compiler Collection, with or without modifications, governed by version 3 (or a specified later version) of the GNU General Public License (GPL) with the option of using any subsequent versions published by the FSF.

"GPL-compatible Software" is software whose conditions of propagation, modification and use would permit combination with GCC in accord with the license of GCC.

"Target Code" refers to output from any compiler for a real or virtual target processor architecture, in executable form or suitable for input to an assembler, loader, linker and/or execution phase. Notwithstanding that, Target Code does not include data in any format that is used as a compiler intermediate representation, or used for producing a compiler intermediate representation.

The "Compilation Process" transforms code entirely represented in non-intermediate languages designed for human-written code, and/or in Java Virtual Machine byte code, into Target Code. Thus, for example, use of source code generators and preprocessors need not be considered part of the Compilation Process, since the Compilation Process can be understood as starting with the output of the generators or preprocessors.

A Compilation Process is "Eligible" if it is done using GCC, alone or with other GPL-compatible software, or if it is done without using any work based on GCC. For example, using non-GPL-compatible Software to optimize any GCC intermediate representations would not qualify as an Eligible Compilation Process.

1. Grant of Additional Permission.

You have permission to propagate a work of Target Code formed by combining the Runtime Library with Independent Modules, even if such propagation would otherwise violate the terms of GPLv3, provided that all Target Code was generated by Eligible Compilation Processes. You may then convey such a combination under terms of your choice, consistent with the licensing of the Independent Modules.

2. No Weakening of GCC Copyleft.

The availability of this Exception does not imply any general presumption that third-party software is unaffected by the copyleft requirements of the license of GCC.

Apache 2.0

Apache License
Version 2.0, January 2004
<http://www.apache.org/licenses/>

TERMS AND CONDITIONS FOR USE, REPRODUCTION, AND DISTRIBUTION

1. Definitions.

"License" shall mean the terms and conditions for use, reproduction, and distribution as defined by Sections 1 through 9 of this document.

"Licensor" shall mean the copyright owner or entity authorized by the copyright owner that is granting the License.

"Legal Entity" shall mean the union of the acting entity and all other entities that control, are controlled by, or are under common control with that entity. For the purposes of this definition, "control" means (i) the power, direct or indirect, to cause the direction or management of such entity, whether by contract or

otherwise, or (ii) ownership of fifty percent (50%) or more of the outstanding shares, or (iii) beneficial ownership of such entity.

"You" (or "Your") shall mean an individual or Legal Entity exercising permissions granted by this License.

"Source" form shall mean the preferred form for making modifications, including but not limited to software source code, documentation source, and configuration files.

"Object" form shall mean any form resulting from mechanical transformation or translation of a Source form, including but not limited to compiled object code, generated documentation, and conversions to other media types.

"Work" shall mean the work of authorship, whether in Source or Object form, made available under the License, as indicated by a copyright notice that is included in or attached to the work (an example is provided in the Appendix below).

"Derivative Works" shall mean any work, whether in Source or Object form, that is based on (or derived from) the Work and for which the editorial revisions, annotations, elaborations, or other modifications represent, as a whole, an original work of authorship. For the purposes of this License, Derivative Works shall not include works that remain separable from, or merely link (or bind by name) to the interfaces of, the Work and Derivative Works thereof.

"Contribution" shall mean any work of authorship, including the original version of the Work and any modifications or additions to that Work or Derivative Works thereof, that is intentionally submitted to Licensor for inclusion in the Work by the copyright owner or by an individual or Legal Entity authorized to submit on behalf of the copyright owner. For the purposes of this definition, "submitted" means any form of electronic, verbal, or written communication sent to the Licensor or its representatives, including but not limited to communication on electronic mailing lists, source code control systems, and issue tracking systems that are managed by, or on behalf of, the Licensor for the purpose of discussing and improving the Work, but excluding communication that is conspicuously marked or otherwise designated in writing by the copyright owner as "Not a Contribution."

"Contributor" shall mean Licensor and any individual or Legal Entity on behalf of whom a Contribution has been received by Licensor and subsequently incorporated within the Work.

2. Grant of Copyright License. Subject to the terms and conditions of this License, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable copyright license to reproduce, prepare Derivative Works of, publicly display, publicly perform, sublicense, and distribute the Work and such Derivative Works in Source or Object form.
3. Grant of Patent License. Subject to the terms and conditions of this License, each Contributor hereby grants to You a perpetual, worldwide, non-exclusive, no-charge, royalty-free, irrevocable (except as stated in this section) patent license to make, have made, use, offer to sell, sell, import, and otherwise transfer the Work, where such license applies only to those patent claims licensable by such Contributor that are necessarily infringed by their Contribution(s) alone or by combination of their Contribution(s) with the Work to which such Contribution(s) was submitted. If You institute patent litigation against any entity (including a cross-claim or counterclaim in a lawsuit) alleging that the Work or a Contribution incorporated within the Work constitutes direct or contributory patent infringement, then any patent licenses granted to You under this License for that Work shall terminate as of the date such litigation is filed.
4. Redistribution. You may reproduce and distribute copies of the

Work or Derivative Works thereof in any medium, with or without modifications, and in Source or Object form, provided that You meet the following conditions:

- (a) You must give any other recipients of the Work or Derivative Works a copy of this License; and
- (b) You must cause any modified files to carry prominent notices stating that You changed the files; and
- (c) You must retain, in the Source form of any Derivative Works that You distribute, all copyright, patent, trademark, and attribution notices from the Source form of the Work, excluding those notices that do not pertain to any part of the Derivative Works; and
- (d) If the Work includes a "NOTICE" text file as part of its distribution, then any Derivative Works that You distribute must include a readable copy of the attribution notices contained within such NOTICE file, excluding those notices that do not pertain to any part of the Derivative Works, in at least one of the following places: within a NOTICE text file distributed as part of the Derivative Works; within the Source form or documentation, if provided along with the Derivative Works; or, within a display generated by the Derivative Works, if and wherever such third-party notices normally appear. The contents of the NOTICE file are for informational purposes only and do not modify the License. You may add Your own attribution notices within Derivative Works that You distribute, alongside or as an addendum to the NOTICE text from the Work, provided that such additional attribution notices cannot be construed as modifying the License.

You may add Your own copyright statement to Your modifications and may provide additional or different license terms and conditions for use, reproduction, or distribution of Your modifications, or for any such Derivative Works as a whole, provided Your use, reproduction, and distribution of the Work otherwise complies with the conditions stated in this License.

5. **Submission of Contributions.** Unless You explicitly state otherwise, any Contribution intentionally submitted for inclusion in the Work by You to the Licensor shall be under the terms and conditions of this License, without any additional terms or conditions. Notwithstanding the above, nothing herein shall supersede or modify the terms of any separate license agreement you may have executed with Licensor regarding such Contributions.
6. **Trademarks.** This License does not grant permission to use the trade names, trademarks, service marks, or product names of the Licensor, except as required for reasonable and customary use in describing the origin of the Work and reproducing the content of the NOTICE file.
7. **Disclaimer of Warranty.** Unless required by applicable law or agreed to in writing, Licensor provides the Work (and each Contributor provides its Contributions) on an "AS IS" BASIS, WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied, including, without limitation, any warranties or conditions of TITLE, NON-INFRINGEMENT, MERCHANTABILITY, or FITNESS FOR A PARTICULAR PURPOSE. You are solely responsible for determining the appropriateness of using or redistributing the Work and assume any risks associated with Your exercise of permissions under this License.
8. **Limitation of Liability.** In no event and under no legal theory, whether in tort (including negligence), contract, or otherwise, unless required by applicable law (such as deliberate and grossly negligent acts) or agreed to in writing, shall any Contributor be liable to You for damages, including any direct, indirect, special, incidental, or consequential damages of any character arising as a result of this License or out of the use or inability to use the

Work (including but not limited to damages for loss of goodwill, work stoppage, computer failure or malfunction, or any and all other commercial damages or losses), even if such Contributor has been advised of the possibility of such damages.

9. Accepting Warranty or Additional Liability. While redistributing the Work or Derivative Works thereof, You may choose to offer, and charge a fee for, acceptance of support, warranty, indemnity, or other liability obligations and/or rights consistent with this License. However, in accepting such obligations, You may act only on Your own behalf and on Your sole responsibility, not on behalf of any other Contributor, and only if You agree to indemnify, defend, and hold each Contributor harmless for any liability incurred by, or claims asserted against, such Contributor by reason of your accepting any such warranty or additional liability.

END OF TERMS AND CONDITIONS

APPENDIX: How to apply the Apache License to your work.

To apply the Apache License to your work, attach the following boilerplate notice, with the fields enclosed by brackets "[]" replaced with your own identifying information. (Don't include the brackets!) The text should be enclosed in the appropriate comment syntax for the file format. We also recommend that a file or class name and description of purpose be included on the same "printed page" as the copyright notice for easier identification within third-party archives.

Copyright [yyyy] [name of copyright owner]

Licensed under the Apache License, Version 2.0 (the "License");
you may not use this file except in compliance with the License.
You may obtain a copy of the License at

<http://www.apache.org/licenses/LICENSE-2.0>

Unless required by applicable law or agreed to in writing, software distributed under the License is distributed on an "AS IS" BASIS, WITHOUT WARRANTIES OR CONDITIONS OF ANY KIND, either express or implied. See the License for the specific language governing permissions and limitations under the License.

BSL 1.0

Boost Software License - Version 1.0 - August 17th, 2003

Permission is hereby granted, free of charge, to any person or organization obtaining a copy of the software and accompanying documentation covered by this license (the "Software") to use, reproduce, display, distribute, execute, and transmit the Software, and to prepare derivative works of the Software, and to permit third-parties to whom the Software is furnished to do so, all subject to the following:

The copyright notices in the Software and this entire statement, including the above license grant, this restriction and the following disclaimer, must be included in all copies of the Software, in whole or in part, and all derivative works of the Software, unless such copies or derivative works are solely in the form of machine-executable object code generated by a source language processor.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, TITLE AND NON-INFRINGEMENT. IN NO EVENT SHALL THE COPYRIGHT HOLDERS OR ANYONE DISTRIBUTING THE SOFTWARE BE LIABLE FOR ANY DAMAGES OR OTHER LIABILITY, WHETHER IN CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.

BSD 2.0

Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:

- * Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
- * Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.
- * Neither the name of the <organization> nor the names of its contributors may be used to endorse or promote products derived from this software without specific prior written permission.

THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS "AS IS" AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL <COPYRIGHT HOLDER> BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

MIT

Permission is hereby granted, free of charge, to any person obtaining a copy of this software and associated documentation files (the "Software"), to deal in the Software without restriction, including without limitation the rights to use, copy, modify, merge, publish, distribute, sublicense, and/or sell copies of the Software, and to permit persons to whom the Software is furnished to do so, subject to the following conditions:

The above copyright notice and this permission notice shall be included in all copies or substantial portions of the Software.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.