

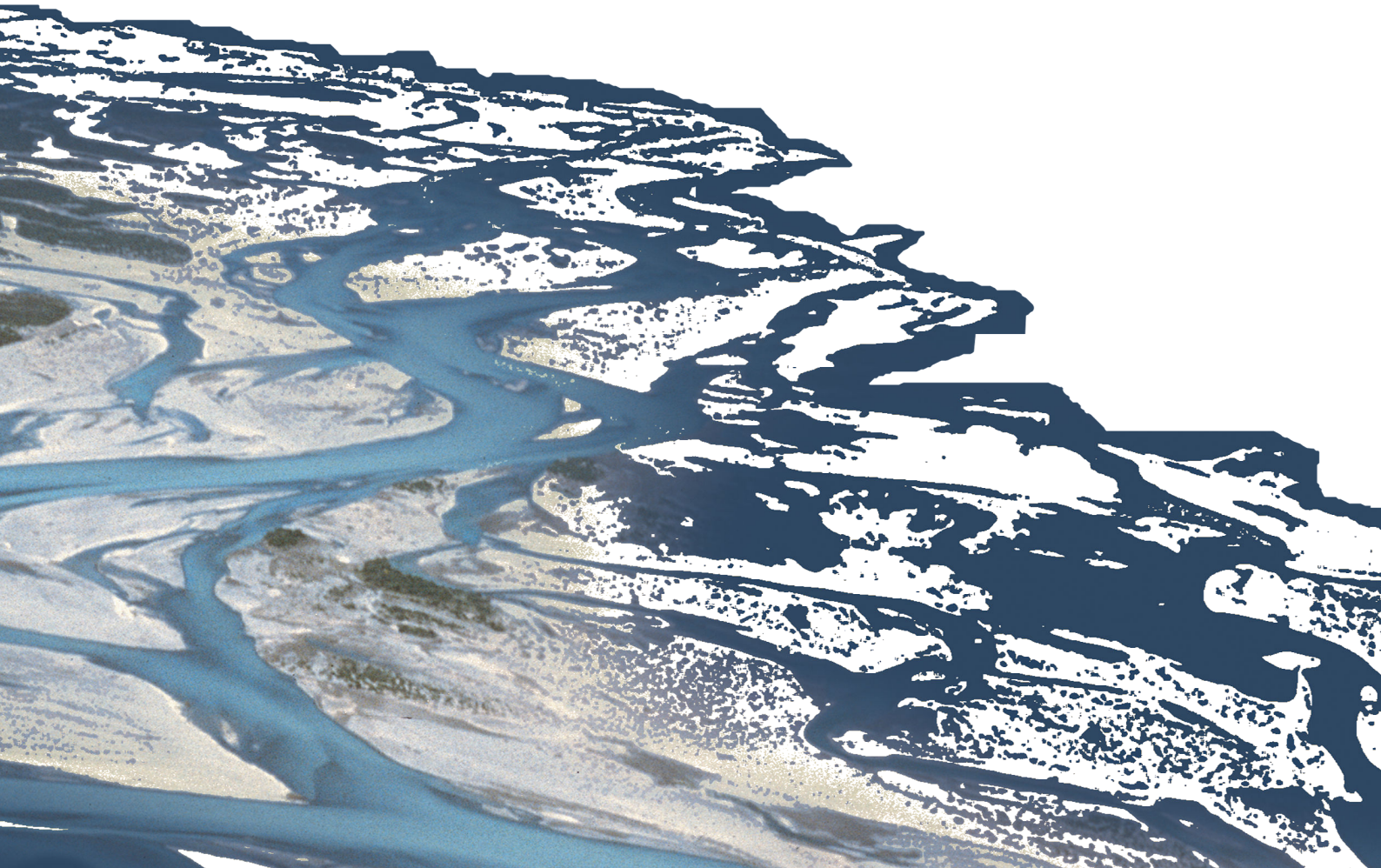


BASEMENT

**BASIC SIMULATION ENVIRONMENT
FOR MODELLING OF ENVIRONMENTAL
FLOWS AND NATURAL HAZARDS**

SYSTEM MANUALS

**VERSION 4.0
FEBRUARY 2023**



Preamble

VERSION 4.0.0

February 2023

Credits

Contributors

Over the years, many enthusiastic engineers and developers have contributed to the development, testing and documentation of BASEMENT. An up-to-date overview of the current development team, along with current and former contributors, can be found on our website:

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**BASIC SIMULATION ENVIRONMENT
FOR MODELLING OF ENVIRONMENTAL
FLOWS AND NATURAL HAZARDS**

INTRODUCTION & INSTALLATION

**VERSION 4.0
FEBRUARY 2023**



BASEMENT

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Summary of Contents

1.1 Introduction

BASEMENT version 4 is a freeware simulation tool for hydro- and morphodynamic modelling developed at the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of ETH Zurich. The software provides a powerful tool for the simulation of river hydro- and morphodynamics. BASEMENT system manual provides information about BASEMENT software and guides the user through the process of using BASEMENT version 4.

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 4 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 modules BASEMD and BASEHPC are described in the migration guide for the users already familiar with BASEMENT. The release notes summarize the changes introduced by BASEMENT version 4 and the summary of features provides an overview of the available functionalities of the new version.

1.2.2 User Manual

The user manual provides information about the simulation environment of BASEMENT version 4. 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 4.

1.2.4 Tutorials and Test Cases

This part is composed of three tutorials and two test cases. The tutorials guide the user throughout the pre-processing, the numerical simulation and post-processing stages of BASEMENT version 4 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 4 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 Operating System Requirements

2.1.1.1 Microsoft Windows

BASEMENT version 4 has been tested for MS Windows 10 and 11. 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 version 4 is available for the following Linux (x86-64) systems:

- Ubuntu 18.04 (LTS), alias “Bionic Beaver”:
 - Kernel version 5.4
 - 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)
- Ubuntu 20.04 (LTS), alias “Focal Fossa”:
 - Kernel version 5.13
 - GNU C Library (glibc) version 2.31
 - VTK-version: 9

- 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 22.04 (LTS), alias “Jammy Jellyfish”:
 - Kernel version 5.15
 - GNU C Library (glibc) version 2.35
 - 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 4 is **only** possible for CUDA-enabled (Compute Unified Device Architecture) GPUs produced by NVIDIA. BASEMENT version 4 has been specifically tested with GPUs listed in [2.1](#).

Table 2.1 GPU hardware used for the numerical simulations

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

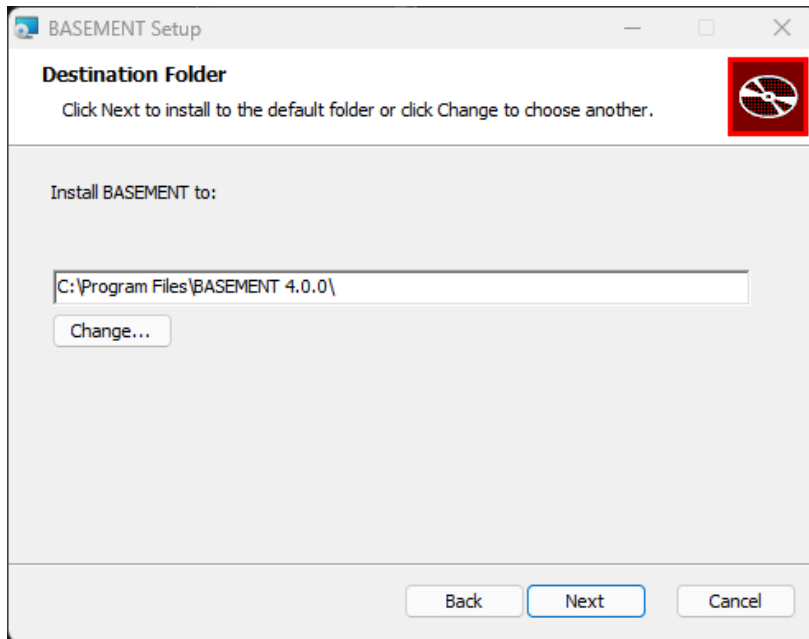


Figure 2.1 Select the installation folder.

2.1.2 Installing under Windows

BASEMENT version 4 is available for Microsoft Windows Windows 10 and 11 operating system.

2.1.2.1 Getting the binaries

First of all, you need to get a copy of the latest software package. Therefore go to the project webpage <https://basement.ethz.ch> and download the latest version (BASEMENT version 4.x) free of charge.

2.1.2.2 Installation procedure under Windows 10 and 11

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

Step 1: Accepting the license agreement

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

Step 2: Select the installation folder

After accepting the License agreement, you can choose where to install the binaries. The recommended location is "C:\Program Files\BASEMENT 4.0" (Figure 2.1). You are free to choose any other directory.

Step 3 and 4: Confirming and finishing the installation

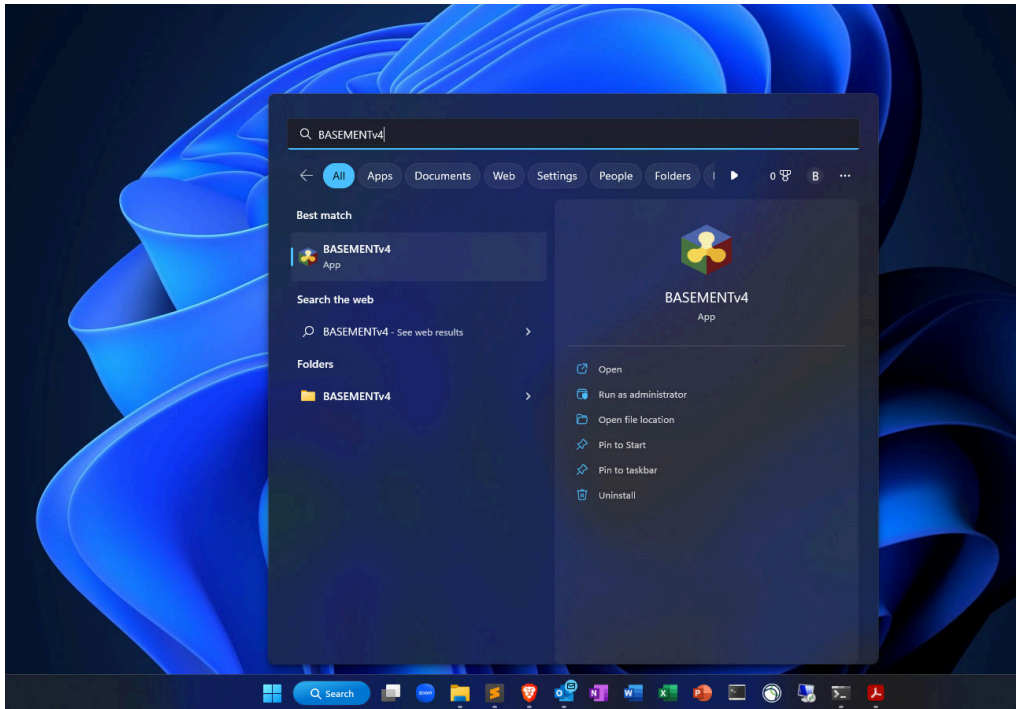


Figure 2.2 Start BASEMENT over the icon in the Start Menu folder.

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

Step 5: Start BASEMENT

You can start the program by opening the Start Menu, navigating to the Start Menu folder of BASEMENT and clicking on the program icon of BASEMENT version 4 (Figure 2.2). To create a Desktop shortcut, simply drag the program icon to your Desktop. Clicking on the BASEMENT icon runs the program as a standalone application including a simple graphical user interface (to run BASEMENT in batch mode see the section Run the programm in the User Manual documentation part).

The graphical user interface should appear as in Figure 2.3.

2.1.3 Installing under Linux

2.1.3.1 Getting the binaries

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

2.1.3.2 Installation procedure

Step 1: Preparation of the installation

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

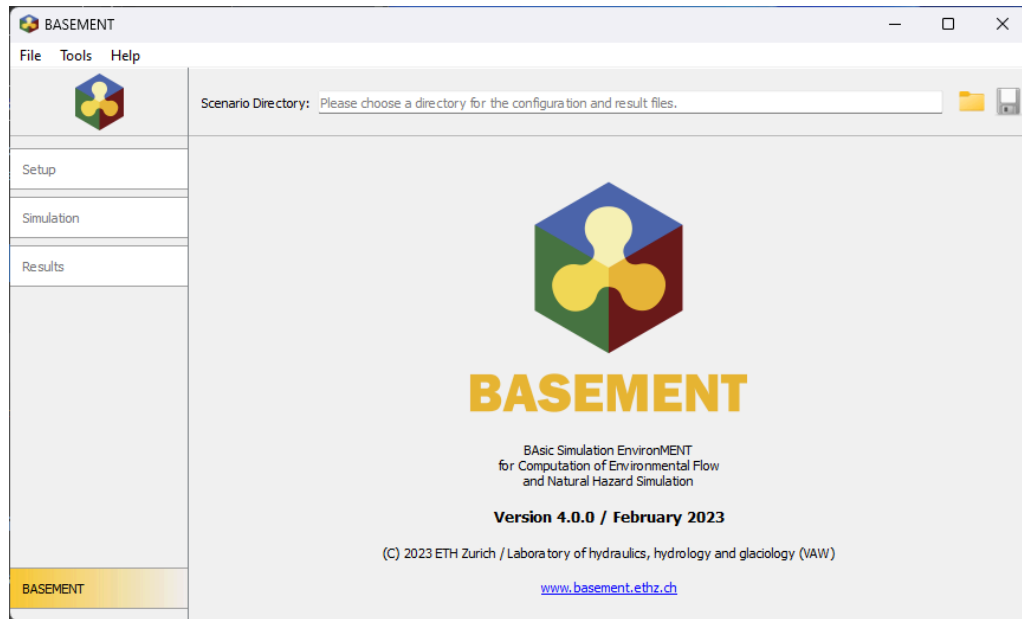


Figure 2.3 The graphical user interface.

```
$ 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, then 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 and 11

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

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

2.2.2 Linux

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

```
$ basement
```

to start the program (if no environment variables have been set, change into your 'bin' directory of the installation path). The GUI starting page is appearing. You have now to select or create the scenario directory in the scenario directory field. The configuration

of the .json files (3 steps) is the same as for Microsoft Windows (see Section 2.2.1) and information about the use of the GUI is given in the section ‘BASEMENT Graphical User Interface’ of the User Manual. Selecting the executables and running a simulation on Linux or using batch mode works the same way as it does on Windows explained in the User Manual. *Notice:* **The command filename must not contain any spaces or special characters like ä, ö, ü, è, etc.**

3

Migration Guide

3.1 General

BASEMENT version 4 consists of two main modules, namely BASEMD (MD stands for Multi Domain) and BASEHPC (HPC stands for High Performance Computing, based on the possibility to use GPGPUs). The BASEMD module refers to the former version 2.8.2 and the BASEHPC module to the version 3.2. Version 4 combines all the functionality of the previous versions, providing an unified GUI and workflow. The migration of existing model setups for versions 2.8.2 and 3.2 will be explained in the following.

3.2 Migration from version 2.8.2

3.2.1 Convertor for command (BMC) files

Running simulations with BASEMENT version 4 requires the model setup to be defined in files with the JSON format (model.json), while for version 2.8.2, model definitions were done in command (BMC) files. In order to migrate an existing model from version 2.8.2, the command file must first be converted into the JSON format. The conversion of a BMC file to a JSON file can be done either with the graphical user interface (GUI) of BASEMENT version 4, or with the standalone executable `BMv4_BASEMD_converter`.

3.2.1.1 Conversion in the GUI

A BMC file can be converted into a model.json file with the following steps:

1. Select the scenarion directory in the GUI, that contains the command (BMC) file.
2. Convert the BMC file via the “Import BMC file” function in the File-Menu.
3. Follow the simulation workflow as described in the User Manual.

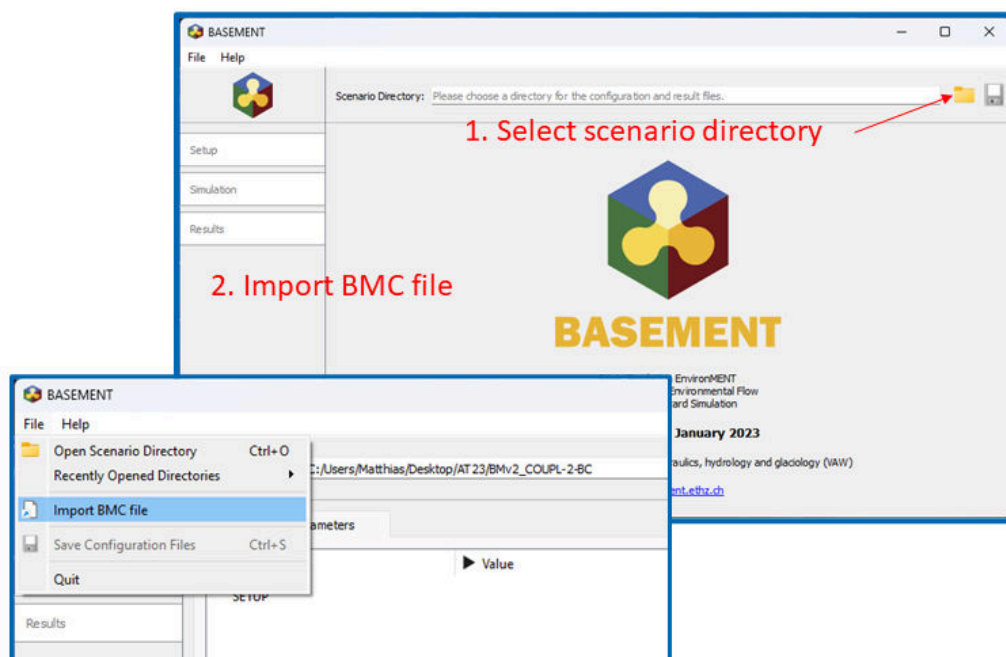


Figure 3.1 Migration from version 2.8.2 by selection of a scenario directory and importing a BMC file.

3.2.1.2 Conversion with BMv4_BASEMD_converter

Alternatively, a BMC file can be converted into a model.json file with the executable BMv4_BASEMD_converter via the command line.

On linux, run the command:

```
$ BMv4_BASEMD_converter myModel.bmc -o model.json
```

On Windows, run the command (assuming you added the installation location of BASEMENT to the Path environment variable)

```
> BMv4_BASEMD_converter.exe myModel.bmc -o model.json
```

3.2.2 Restart simulation from result (h5) file

The output format CGNS became deprecated with BASEMENT version 4 and was replaced by the h5 format. In order to restart a simulation with a restart file in CGNS format, the file must be converted to h5 format. Therefore, the python script cgns_to_h5.py is provided on the BASEMENT website <https://basement.ethz.ch/download/tools/python-scripts.html>.

The script requires python 3 and the module h5py, which can be installed, e.g. with 'pip install h5py'. To convert a CGNS file into an h5 file run the following command:

```
$ python cgns_to_h5.py restart.cgns
```




```
{
  "SETUP":{
    "simulation_name":"Flaz_A_run",
    "DOMAIN": {
      "PHYSICAL_PROPERTIES": {
        "gravity": 9.81
      },
      "BASEPLANE_2D": {
        "GEOMETRY": {
          "mesh_file": "Flaz_mesh.2dm",
          "INTERPOLATION": {
            "method": "weighted"
          }
        }
      }
    }
  }
}
```

```
{
  "SETUP":{
    "simulation_name":"Flaz_A_run",
    "BASEHPC": {
      "PHYSICAL_PROPERTIES": {
        "gravity": 9.81
      },
      "BASEPLANE_2D": {
        "GEOMETRY": {
          "mesh_file": "Flaz_mesh.2dm",
          "INTERPOLATION": {
            "method": "weighted"
          }
        }
      }
    }
  }
}
```

Figure 3.2 Migration from version 3.2 by replacing the keyword “DOMAIN” with “BASEHPC” the setup file.

Then follow the simulation workflow as described in the User Manual. # Migration from version 3.2

3.2.3 Adapt setup file

The combination of all the functionalities of the previous versions required a minor modification in the structure of the setup file (model.json). Therefore, the migration of an existing simulation from version 3.2 requires to adapt the setup file (model.json) in a text editor of choice and replace the keyword “DOMAIN” to “BASEHPC” as illustrated in (Figure 3.2).

4

Release Notes

4.1 Version 4.0

4.1.1 General

BASEMENT version 4 consists of two modules, BASEMD and BASEHPC; MD stands for “Multi-Domain” and corresponds to the previous version 2.8.2, HPC stands for “High-Performance Computing” and corresponds to the previous version 3.2. Thus, all features from the two previous versions are retained and integrated into a common simulation workflow. The selection of the modules occurs via the keywords “BASEHPC” or “BASEMD” in the model definition file.

- BASEMENT now provides an installer package for Ubuntu 22.04, while the version for Ubuntu 16.04 was discontinued. Also, BASEMENT now requires CUDA 11.7.0.
- Keys in JSON configuration files were sorted by the GUI. This problem has been fixed.
- The trees representing the JSON files in the GUI are now expanded by default.
- Items in JSON objects can now be reordered using the GUI via drag and drop.
- The 1-D Grid Editor previously contained in version 2.8.2 is now integrated into the GUI of version 4.
- The migration of existing simulations from version 2.8.2 and 3.2 to version 4 are described in the migration guide (Section [3.1](#))

4.1.2 Known Issues

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

- Aborting a simulation using Ctrl+C can corrupt the HDF5 result file.
- Currently, there is a known, but not yet resolved issue in the sediment transport solver. More specifically, the flux calculation exhibits an asymmetrical behavior depending on the orientation of the flux vector with respect to the edge normal. Up to now, we have not observed a significant impact of this on the simulation of sediment transport. We will fix this issue as soon as possible and recommend to examine the plausibility of morphodynamic simulation results critically as always.
- Tool tip text is too long to be displayed completely.
- Abort bottom may no work as intended, i.e. simulation does not stop.

4.1.3 Module BASEHPC

4.1.3.1 Bug fixes

- A bug causing a segmentation fault when using the MORPHOLOGY and TRACER block has been fixed.

4.1.4 Module BASEMD

4.1.4.1 General

BASEplane

- Implementation of time range for controller. Within the time range, the controller will be active (manipulated variable is based on PID/HID control). Outside of the time range, a default value for the manipulated variable must be specified.
- The CGNS format for saving simulation states was discontinued and replaced by the .h5 format. Existing CGNS files may be

4.1.4.2 Bug fixes

BASEchain

- A bug in the gravitational transport feature for mixed size sediment transport has been fixed.
- A bug in the implementation of the hiding_exponent (mpm_h and parker formulation) in mixed size sediment transport has been fixed.

4.1.4.3 Known Issues

BASEplane

- The upstream and downstream stringdefs of the inner boundary weir must be of the same length, otherwise mass might not be conserved.

BASEchain

- Fixed bed starts eroding if both suspended load and bed load transport are activated if the suspended load is below transport capacity.
- Van Rijn formula does not result in any sediment being transported (1D-model).

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

4.2 Notes on older releases

Release notes of previous version can be found on the webpage: <https://basement.ethz.ch/download/software-download/release-notes>

Summary of Features Version 4.0

5.1 Features of module BASEMD

5.1.1 Submodule BASEchain

5.1.1.1 Numerics

Spatial Discretization	Finite Volumes
Time Integration	explicit Euler
Riemann Solvers	Roe, HLL, upwind

5.1.1.2 Geometry

Type	Cross sections : simple, composite (flood plains, main channel)
Slices	Friction and soil description, no flow consideration
Mobile bed	Fixed bed consideration, uniform distribution of deposition and erosion over wetted part of cross section, partially wetted soils (suspended load)
Input Formats	BASEMENT (*.bmg)

5.1.1.3 Hydrodynamics

Model	1D Saint-Venant equations
Conservative Variables	A (continuity), Q (momentum)
Source Terms	Friction (semi-implicite), bed slope, lateral source/sink
Friction	Strickler (kstr), Manning (n), grain size friction
Determination of $z(A)$	Interpolation from table or iteration or consideration of levees

Boundary Conditions	Wall, hydrographs, hQ-relation, in/out, zhydrograph, weir, gate, multiple boundary, zero_gradient
Initial Conditions	Sub-critical backwater calculation, dry, from input file
Inner boundary	Weir/Gate

5.1.1.4 Sediment Transport: Bed load

Model	Hirano-Exner equation, sorting equation for sediment mixtures
Transport Formula	MPM, MPM-multi, power law, MPM-H, Parker, Rickenmann, Smart-Jaeggi, Smart-Jaeggi-multi, Wu, Van Rijn, parametrized shear stress, abrasion-law of Sternberg, Wilcock and Crowe, Engelund and Hansen, Ashida and Michiue
Boundary Conditions	Hydrograph, IOUp and IODown, transport capacity, fractionated hydrograph
Active Layer	Constant, variable thickness
Source Terms	Local source/sink, dredge source, bed-load function

5.1.1.5 Sediment transport : Suspended load

Transport Equation	Advection-Diffusion Equation
Discretization	QUICK, QUICKEST, Holly-Preissmann, MDPM, Upwind
Exchange Terms	Concentration: Van Rijn, Zyserman et al., constant factor Shear stresses: Xu
Source Terms	Local source/sink

5.1.1.6 Sediment transport : Gravitational induced transport

Approach	Geometrical modelling in longitudinal direction (1D) based on critical failure angles
Features	Single and multiple grain classes

5.1.1.7 Output Variables/Formats

- Variables

General Information	Geometry and characteristics of cross sections
Bed load	Total and for each grain class
Grain mixtures	For each cross section, slice and layer

- Format

Standard output	Talweg: z_{dam} (left/right), z_{bottom} (mean), friction, Q_b^{cap} , C_{tot} Cross section: Water surface elevation WSE, energy level EL, velocity v , wetted area A , discharge Q , Froude number Fr , friction
Special output	Edge: continuity flux, momentum flux, $Q_{b,i}$, Q_s^{adv} , Q_s^{diff} Tecplot Format: Bed level, water surface elevation, energy level, discharge, wetted area, dike levels, bed load, grain class concentrations and suspended sediment concentration in active layer Monitoring Output: Q , Q_b , A , WSE, v , geometry, C , b (=mean bottom level), energy_line (EL), Fr , h (=mean flow depth) Restart files: Hydrodynamics, bedload, suspended load Volume files: Variation of water volume, variation of sediment volume, suspended sediment volume, transport capacity volume

5.1.2 Submodule BASEplane

5.1.2.1 Numerics

Spatial Discretization	Finite Volumes
Time Integration	explicit Euler
Riemann Solvers	exact, HLL, HLLC

5.1.2.2 Geometry

Cell/Grid Type	Triangular, quadrilateral, hybrid
Mobile bed	Fixed bed consideration, bed armor consideration, uniform distribution of deposition and erosion over wet elements
Input Formats	Grid-file *.2dm (SMS, QGIS)
Moving bed	User enforced vertical movement of selected nodes

5.1.2.3 Hydrodynamics

Model	Shallow Water Equations
Conservative Variables	h , $u \cdot h$, $v \cdot h$
Source Terms	Friction, bed slope, local discharge source/sink, diffusive fluxes (kinematic and turbulent viscosity)
Friction	Strickler (roughness k_{str}), Manning (roughness n), Chézy, Darcy-Weissbach, Log. friction law, Yalin, Bezzola
Boundary Conditions	Wall, inlet (hydrograph), outlet (weir, gate, zero gradient, h - Q relation, z Hydrograph), inner boundaries (inner weir, inner gate)
Initial Conditions	Dry, user defined condition (based on material index), continuing old simulation

5.1.2.4 Sediment Transport: Bed load

Model	Hirano-Exner equation, sorting equation for sediment mixtures
Transport Formula	MPM, MPM-multi, power law, MPM-H, Parker, Rickenmann, Smart-Jaeggi, Wu, Van Rijn, Wilcock and Crowe, Engelund and Hansen, Ashida and Michiue
Direction	lateral bed slope effect (Ikeda), curvature effect (Engelund)
Boundary Conditions	Wall, inlet (hydrograph, transport capacity), outlet (outflow = inflow), inner boundaries (open, weir)
Active Layer	Constant, variable thickness
External source Terms	Local source/sink, dredge source

5.1.2.5 Sediment transport : Suspended load

Transport Equation	Advection-Diffusion Equation
Discretization	Upwind-Scheme
Exchange Terms	Van Rijn of Zyserman et al./Lin
Source Terms	Local source/sink

5.1.2.6 Sediment transport : Gravitational induced transport

Approach	Geometrical modelling based on critical failure angles
Features	Unstructured mesh, single and multiple grain classes

5.1.2.7 Output Variables/Formats

- Variables

General Information	Input file, element data (water depth, velocities, bed shear stress, etc), node data (bed elevation, etc), balances
Bed load	Element data (theta_critical, etc.), node data (bedload, delta_z, etc.)
Grain mixtures	Grain size distribution for selected elements

- Format

Standard output	SMS Format and ASCII tables
Monitoring Output	String discharge, Boundaries, Balances, Debug-output
Time History	Time history of selected elements, nodes or edges
Additional Formats	Tecplot, Shape (GIS), AVS-UCD, VTK (Paraview)
Restart file	Binary format (CGNS), hydraulic computation, bed load computation, suspended load computation

5.1.3 Submodule BASEsub

5.1.3.1 Numerics

Spatial Discretization	LBM (Lattice-Boltzmann Method)
Time Integration	explicit Euler

5.1.3.2 Geometry

Cell/Grid Types	Structured mesh, cubic cells
Input Formats	Self-generated block mesh, parts can be de-activated

5.1.3.3 Hydrodynamics

Model	3-D Richards equations, Saturation-formulation, mixed Saturation-Pressure formulation
Primary Variables	Effective water saturation, Pore-water pressure
Source Terms	Water source (infiltration)
Constitutive Models, Material properties	Van Genuchten-Mualem, Brooks-Corey, kf-conductivity value of soil
Boundary Conditions	Bounce-back boundary, Pressure boundary, Effective water saturation boundary, Seepage boundary
Initial Conditions	Constant values: Pores-water pressure, effective water saturation Hydrostatic pressure distribution Hot-start from old simulation file

5.1.3.4 Output Variables/Formats

- Variables:
 - Primary variables: Effective water saturation, pore-water pressure
 - Secondary variables: Darcy velocities

General Information Cut-plane or cul-lines through 3-D mesh, seepage line

- Format

Standard output	ASCII (Gnuplot)
Additional Formats	Tecplot, SMS/QGIS
Restart file	Binary file containing values of probability distribution functions

5.2 Features of module BASEHPC

5.2.1 Hydrodynamics

Riemann Solver

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

Hydraulic Initial Conditions

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

Parameters

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

Boundary Conditions

- WALL : inviscid, default
- STANDARD (in parenthesis user-required data):
 - INFLOW: uniform (discharge; slope), froude (discharge, froude number), hq_relation (H-Q relation), zhydrograph (water surface elevation, inflowPossible)
 - OUTFLOW: uniform (slope), zero_gradient (-), weir (weir height, constant or dynamic poleni factor), hq_relation (H-Q relation), dynamic wall (collapse time), zhydrograph (water surface elevation, inflowPossible)
- INTERNAL: dynamic wall (collapse time), internal wall (-), hq_relation (H-Q relation)
- LINKED: hq_relation (H-Q relation), 2 way hq_relation (2 H-Q relations, time lag, water surface elevation upstream and downstream), weir (weir height, constant or dynamic poleni factor), zhydrograph (water surface elevation) zhydrograph with kinetic energy (water surface elevation)

Friction

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

- Strickler
- Chezy
- Bezzola

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

Turbulence

- Parameters:
 - Turbulence start time
 - On/off switch for diffusion of turbulent species (tke, epsilon)
 - Relaxation parameter for turbulent diffusion
 - On/off switch for friction generated turbulence
- Closure model for Reynolds stress:
 - Constant viscosity (default)
 - k-epsilon model
 - Mixing length model
- Initial conditions:
 - Zero, i.e. no turbulence (default)
 - Uniform values for tke and epsilon
 - Region defined values for tke and epsilon
 - Continue
- Boundary conditions (k-epsilon model)
 - STANDARD: k_eps_in, zero_gradient_out
- Source:
 - Type: k_eps (force k-epsilon values directly)
 - Sink behaviours: exact (as prescribed), available (as prescribed or less), infinity (as much as possible)

Flood

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

Source (water volume)

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

5.2.2 Morphodynamics

5.2.2.1 Bed load transport

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

Parameters

- Morphodynamic start time
- Sediment porosity
- Sediment density

Initial conditions

- Mesh file
- Continue

Incipient motion

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

Closure formula

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

Direction

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

Bedload boundary conditions

- WALL: inviscid, default
- STANDARD:
 - INFLOW: equilibrium (reference_bed_elevation), sedimentograph (sediment_discharge), transport capacity (boudary_factor)
 - OUTFLOW: equilibrium (reference_bed_elevation)

- Weighting scheme for transport capacity and sedimentograph: geometrical (default), wetted area, conveyance
- LINKED: equilibrium (reference_bed_elevation at upstream boundary)

Bed material

- Grain class
- Fixed bed

Gravitational Transport

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

Source (sediment volume)

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

5.2.2.2 Suspended load transport

Parameters

- Relaxation parameter
- Diffusivity coefficient (isotropic, longitudinal/transversal)
- Turbulent diffusivity coefficient (isotropic, longitudinal/transversal)
- Scaling (beta) factor for the suspended source terms

Settling Velocity

- Closure model for the grain settling velocity:
 - Van Rijn
 - Wu and Wang
 - Zhang
- Shape factor parameter (

Shear partition

- Skin friction parameter for suspended load computations
- Default value or region defined

Erosion rate

- Closure model for the erosion rate:
 - Van Rijn
 - Zyserman and Fredsoe
- Critical shields parameter (both)

Deposition rate

- Closure model for the deposition rate:
 - Lin
 - Xu
- Critical shields parameter (Xu)

Initial conditions

- Zero, i.e. no suspended load concentration (default)
- Uniform initial concentration
- Region defined values for concentration
- Continue

Boundary conditions

- STANDARD:
 - INFLOW: concentration_in, discharge_in, discharge_in_warea
 - OUTFLOW: zero_gradient_out

Source (suspended sediment volume)

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

5.2.3 Tracers

Parameters

- Tracer start time
- Number of tracers (max. 5)
- Molecular diffusivity coefficient (isotropic, longitudinal/transversal)
- Turbulent diffusivity coefficient (isotropic, longitudinal/transversal)

Initial conditions

- Zero, i.e. no tracer concentration (default)
- Uniform initial concentration
- Region defined values for concentration
- Continue

Boundary conditions

- STANDARD:
 - INFLOW: concentration_in, discharge_in, discharge_in_warea
 - OUTFLOW: zero_gradient_out

Source (tracer volume)

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

5.2.4 Vegetation

Parameters:

- Flow resistance modification (Strickler approach)
- Shear stress partitioning
- Critical Shields parameter modification (with MPM formula)
- Vegetation uprooting
- Plant burial

Initial conditions:

- Continue
- Region defined (regiondef)

Output variables:

- Aboveground biomass [-]
- Belowground biomass [-]
- Rooting depth [m]

5.2.5 Output Variables Summary

The output are generated on the mesh elements (cell centered) or at nodestrings and are stored in a binary file format (.h5).

The output type available are summarized in Table 5.22.

Table 5.22 Output types and description.

Output	Description
Cell-centered	
water_surface	Water surface elevation [m]
water_depth	Water depth [m]
bottom_elevation	Bottom elevation [m]
friction_chezy	Dimensionless squared chezy friction coefficient [-]
delta_z	Change in bottom elevation of during the course of the simulation [m]
spec_discharge	Specific hydraulic discharge (q_x, q_y) [m ² /s]
flow_velocity	Flow velocity (u_x, u_y) [m/s]
turb_k	Turbulent kinetic energy (κ) [m ² /s ²]
turb_reynolds	Turbulent Reynolds stresses [Nm/m ²]
flow_velocity	Flow velocity (u_x, u_y) [m/s]
flow_curvature	Flow curvature (inverse of flow radius) [m ⁻¹]
flow_radius	Flow radius [m]
theta	Non-dimensional effective bed shear stress for bedload transport [-]
theta_critical	Non-dimensional critical bed shear stress [-]

Output	Description
trsp_capacity	Bedload transport capacity ($q_{b,x}$, $q_{b,y}$) [m^2/s] as compact volume, no porosity
trsp_capacity_abs	Bedload transport capacity magnitude q_b [m^2/s] as compact volume, no porosity
suspended_conc	Suspended sediment concentration [-]
suspended_theta	Non-dimensional effective bed shear stress for suspended sediment transport [-]
bed_gradient	Local bed gradient ($\partial z/\partial x$, $\partial z/\partial y$) [-]
flood_tracking	Water front arrival time [s] Max. water depth [m] Max. flow velocity [m/s] Max. specific discharge [m^2/s] Max. bed shear stress [Pa]
tracer1-5	Concentration of tracer specie 1 [-] ... Concentration of tracer specie 5 [-]
aboveground_biomass	Above ground biomass of vegetation [-]
belowground_biomass	Above ground biomass of vegetation [-]
rooting_depth	Rooting depth of vegetation [m]
Nodestring	
ns_hyd_discharge	Hydraulic output variables on the Nodestrings
ns_mor_discharge	Morphologic output variables on the Nodestrings

6

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**BASIC SIMULATION ENVIRONMENT
FOR MODELLING OF ENVIRONMENTAL
FLOWS AND NATURAL HAZARDS**

APPENDIX

**VERSION 4.0
FEBRUARY 2023**



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Julian Seward, jseward@acm.org
 bzip2/libbzip2 version 1.0.8 of 13 July 2019

Curl

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Mesa 3-D graphics library
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Google double-conversion

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File: aclocal.m4 (only for ICU4C)
Section: pkg.m4 - Macros to locate and utilise pkg-config.

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```

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=====

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Version 1.0, January 1, 2003

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You must give prominent notice with each copy of the work that the Library is used in it and that the Library and its use are covered by this License. You must supply a copy of this License. If the work during execution displays copyright notices, you must include the copyright notice for the Library among them, as well as a reference directing the user to the copy of this License. Also, you must do one of these things:

- a) Accompany the work with the complete corresponding machine-readable source code for the Library including whatever changes were used in the work (which must be distributed under Sections 1 and 2 above); and, if the work is an executable linked with the Library, with the complete machine-readable "work that uses the Library", as object code and/or source code, so that the user can modify the Library and then relink to produce a modified executable containing the modified Library. (It is understood that the user who changes the contents of definitions files in the Library will not necessarily be able to recompile the application to use the modified definitions.)
- b) Use a suitable shared library mechanism for linking with the Library. A suitable mechanism is one that (1) uses at run time a copy of the library already present on the user's computer system, rather than copying library functions into the executable, and (2) will operate properly with a modified version of the library, if the user installs one, as long as the modified version is interface-compatible with the version that the work was made with.
- c) Accompany the work with a written offer, valid for at least three years, to give the same user the materials specified in Subsection 6a, above, for a charge no more than the cost of performing this distribution.
- d) If distribution of the work is made by offering access to copy from a designated place, offer equivalent access to copy the above specified materials from the same place.
- e) Verify that the user has already received a copy of these materials or that you have already sent this user a copy.

For an executable, the required form of the "work that uses the Library" must include any data and utility programs needed for reproducing the executable from it. However, as a special exception, the materials to be distributed need not include anything that is normally distributed (in either source or binary form) with the major components (compiler, kernel, and so on) of the operating system on which the executable runs, unless that component itself accompanies the executable.

It may happen that this requirement contradicts the license restrictions of other proprietary libraries that do not normally accompany the operating system. Such a contradiction means you cannot use both them and the Library together in an executable that you distribute.

7. 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 not covered by this License, and distribute such a combined library, provided that the separate distribution of the work based on the Library and of the other library facilities is otherwise permitted, and provided that you do these two things:

- a) Accompany the combined library with a copy of the same work based on the Library, uncombined with any other library facilities. This must be distributed under the terms of the Sections above.
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If you develop a new library, and you want it to be of the greatest possible use to the public, we recommend making it free software that everyone can redistribute and change. You can do so by permitting redistribution under these terms (or, alternatively, under the terms of the ordinary General Public License).

To apply these terms, attach the following notices to the library. It is safest to attach them to the start of each source file to most effectively convey 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 library's name and a brief idea of what it does.>
Copyright (C) <year> <name of author>
```

```
This 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.
```

```
This 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 this library; if not, write to the Free Software
Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA 02111-1307 USA
```

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

You should also get your employer (if you work as a programmer) or your school, if any, to sign a "copyright disclaimer" for the library, if necessary. Here is a sample; alter the names:

```
Yoyodyne, Inc., hereby disclaims all copyright interest in the
library `Frob' (a library for tweaking knobs) written by James Random Hacker.
```

```
<signature of Ty Coon>, 1 April 1990
Ty Coon, President of Vice
```

That's all there is to it!

ShapelibGNU LIBRARY GENERAL PUBLIC LICENSE
Version 2, June 1991

```
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        675 Mass Ave, Cambridge, MA 02139, USA
Everyone is permitted to copy and distribute verbatim copies
of this license document, but changing it is not allowed.
```

[This is the first released version of the library GPL. It is numbered 2 because it goes with version 2 of the ordinary GPL.]

Preamble

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The reason we have a separate public license for some libraries is that they blur the distinction we usually make between modifying or adding to a program and simply using it. Linking a program with a library, without changing the library, is in some sense simply using the library, and is analogous to running a utility program or application program. However, in a textual and legal sense, the linked executable is a combined work, a derivative of the original library, and the ordinary General Public License treats it as such.

Because of this blurred distinction, using the ordinary General Public License for libraries did not effectively promote software sharing, because most developers did not use the libraries. We concluded that weaker conditions might promote sharing better.

However, unrestricted linking of non-free programs would deprive the users of those programs of all benefit from the free status of the libraries themselves. This Library General Public License is intended to permit developers of non-free programs to use free libraries, while preserving your freedom as a user of such programs to change the free libraries that are incorporated in them. (We have not seen how to achieve this as regards changes in header files, but we have achieved it as regards changes in the actual functions of the Library.) The hope is that this will lead to faster development of free libraries.

The precise terms and conditions for copying, distribution and modification follow. Pay close attention to the difference between a "work based on the library" and a "work that uses the library". The former contains code derived from the library, while the latter only works together with the library.

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"Source code" for a work means the preferred form of the work for making modifications to it. For a library, complete source code means all the source code for all modules it contains, plus any associated interface definition files, plus the scripts used to control compilation and installation of the library.

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- c) You must cause the whole of the work to be licensed at no charge to all third parties under the terms of this License.

d) If a facility in the modified Library refers to a function or a table of data to be supplied by an application program that uses the facility, other than as an argument passed when the facility is invoked, then you must make a good faith effort to ensure that, in the event an application does not supply such function or table, the facility still operates, and performs whatever part of its purpose remains meaningful.

(For example, a function in a library to compute square roots has a purpose that is entirely well-defined independent of the application. Therefore, Subsection 2d requires that any application-supplied function or table used by this function must be optional: if the application does not supply it, the square root function must still compute square roots.)

These requirements apply to the modified work as a whole. If identifiable sections of that work are not derived from the Library, and can be reasonably considered independent and separate works in themselves, then this License, and its terms, do not apply to those sections when you distribute them as separate works. But when you distribute the same sections as part of a whole which is a work based on the Library, the distribution of the whole must be on the terms of this License, whose permissions for other licensees extend to the entire whole, and thus to each and every part regardless of who wrote it.

Thus, it is not the intent of this section to claim rights or contest your rights to work written entirely by you; rather, the intent is to exercise the right to control the distribution of derivative or collective works based on the Library.

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This option is useful when you wish to copy part of the code of the Library into a program that is not a library.

4. You may copy and distribute the Library (or a portion or derivative of it, under Section 2) in object code or executable form under the terms of Sections 1 and 2 above provided that you accompany it with the complete corresponding machine-readable source code, which must be distributed under the terms of Sections 1 and 2 above on a medium customarily used for software interchange.

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5. A program that contains no derivative of any portion of the Library, but is designed to work with the Library by being compiled or linked with it, is called a "work that uses the Library". Such a work, in isolation, is not a derivative work of the Library, and therefore falls outside the scope of this License.

However, linking a "work that uses the Library" with the Library creates an executable that is a derivative of the Library (because it contains portions of the Library), rather than a "work that uses the library". The executable is therefore covered by this License. Section 6 states terms for distribution of such executables.

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- b) Accompany the work with a written offer, valid for at least three years, to give the same user the materials specified in Subsection 6a, above, for a charge no more than the cost of performing this distribution.
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Appendix: How to Apply These Terms to Your New Libraries

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To apply these terms, attach the following notices to the library. It is safest to attach them to the start of each source file to most effectively convey 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 library's name and a brief idea of what it does.>
Copyright (C) <year> <name of author>
```

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This library is free software; you can redistribute it and/or
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```

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```
Yoyodyne, Inc., hereby disclaims all copyright interest in the
library `Frob' (a library for tweaking knobs) written by James Random Hacker.
```

```
<signature of Ty Coon>, 1 April 1990
Ty Coon, President of Vice
```

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Vtk

/*=====

Program: Visualization Toolkit
Module: Copyright.txt

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Zlib

ZLIB DATA COMPRESSION LIBRARY

zlib 1.2.12 is a general purpose data compression library. All the code is thread safe. The data format used by the zlib library is described by RFCs (Request for Comments) 1950 to 1952 in the files <http://tools.ietf.org/html/rfc1950> (zlib format), [rfc1951](http://tools.ietf.org/html/rfc1951) (deflate format) and [rfc1952](http://tools.ietf.org/html/rfc1952) (gzip format).

All functions of the compression library are documented in the file `zlib.h` (volunteer to write man pages welcome, contact zlib@gzip.org). A usage example of the library is given in the file `test/example.c` which also tests that the library is working correctly. Another example is given in the file `test/minigzip.c`. The compression library itself is composed of all source files in the root directory.

To compile all files and run the test program, follow the instructions given at the top of `Makefile.in`. In short `./configure; make test`, and if that goes well, `make install` should work for most flavors of Unix. For Windows, use one of the special makefiles in `win32/` or `contrib/vstudio/`. For VMS, use `make_vms.com`.

Questions about zlib should be sent to zlib@gzip.org, or to Gilles Vollant info@winimage.com for the Windows DLL version. The zlib home page is <http://zlib.net/>. Before reporting a problem, please check this site to verify that you have the latest version of zlib; otherwise get the latest version and check whether the problem still exists or not.

PLEASE read the zlib FAQ http://zlib.net/zlib_faq.html before asking for help.

Mark Nelson markn@ieee.org wrote an article about zlib for the Jan. 1997 issue of Dr. Dobb's Journal; a copy of the article is available at <http://marknelson.us/1997/01/01/zlib-engine/>.

The changes made in version 1.2.12 are documented in the file `ChangeLog`.

Unsupported third party contributions are provided in directory `contrib/`.

zlib is available in Java using the `java.util.zip` package, documented at <http://java.sun.com/developer/technicalArticles/Programming/compression/> .

A Perl interface to zlib written by Paul Marquess <pmqs@cpan.org> is available at CPAN (Comprehensive Perl Archive Network) sites, including <http://search.cpan.org/~pmqs/IO-Compress-Zlib/> .

A Python interface to zlib written by A.M. Kuchling <amk@amk.ca> is available in Python 1.5 and later versions, see <http://docs.python.org/library/zlib.html> .

zlib is built into tcl: <http://wiki.tcl.tk/4610> .

An experimental package to read and write files in .zip format, written on top of zlib by Gilles Vollant <info@winimage.com>, is available in the `contrib/minizip` directory of zlib.

Notes for some targets:

- For Windows DLL versions, please see `win32/DLL_FAQ.txt`
- For 64-bit Irix, `deflate.c` must be compiled without any optimization. With `-O`, one `libpng` test fails. The test works in 32 bit mode (with the `-n32` compiler flag). The compiler bug has been reported to SGI.
- zlib doesn't work with `gcc 2.6.3` on a DEC 3000/300LX under OSF/1 2.1 it works when compiled with `cc`.
- On Digital Unix 4.0D (formerly OSF/1) on AlphaServer, the `cc` option `-std1` is necessary to get `gzprintf` working correctly. This is done by `configure`.
- zlib doesn't work on HP-UX 9.05 with some versions of `/bin/cc`. It works with other compilers. Use "make test" to check your compiler.
- `gzdopen` is not supported on RISCOS or BEOS.
- For PalmOs, see <http://palmzlib.sourceforge.net/>

Acknowledgments:

The deflate format used by zlib was defined by Phil Katz. The deflate and zlib specifications were written by L. Peter Deutsch. Thanks to all the people who reported problems and suggested various improvements in zlib; they are too numerous to cite here.

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