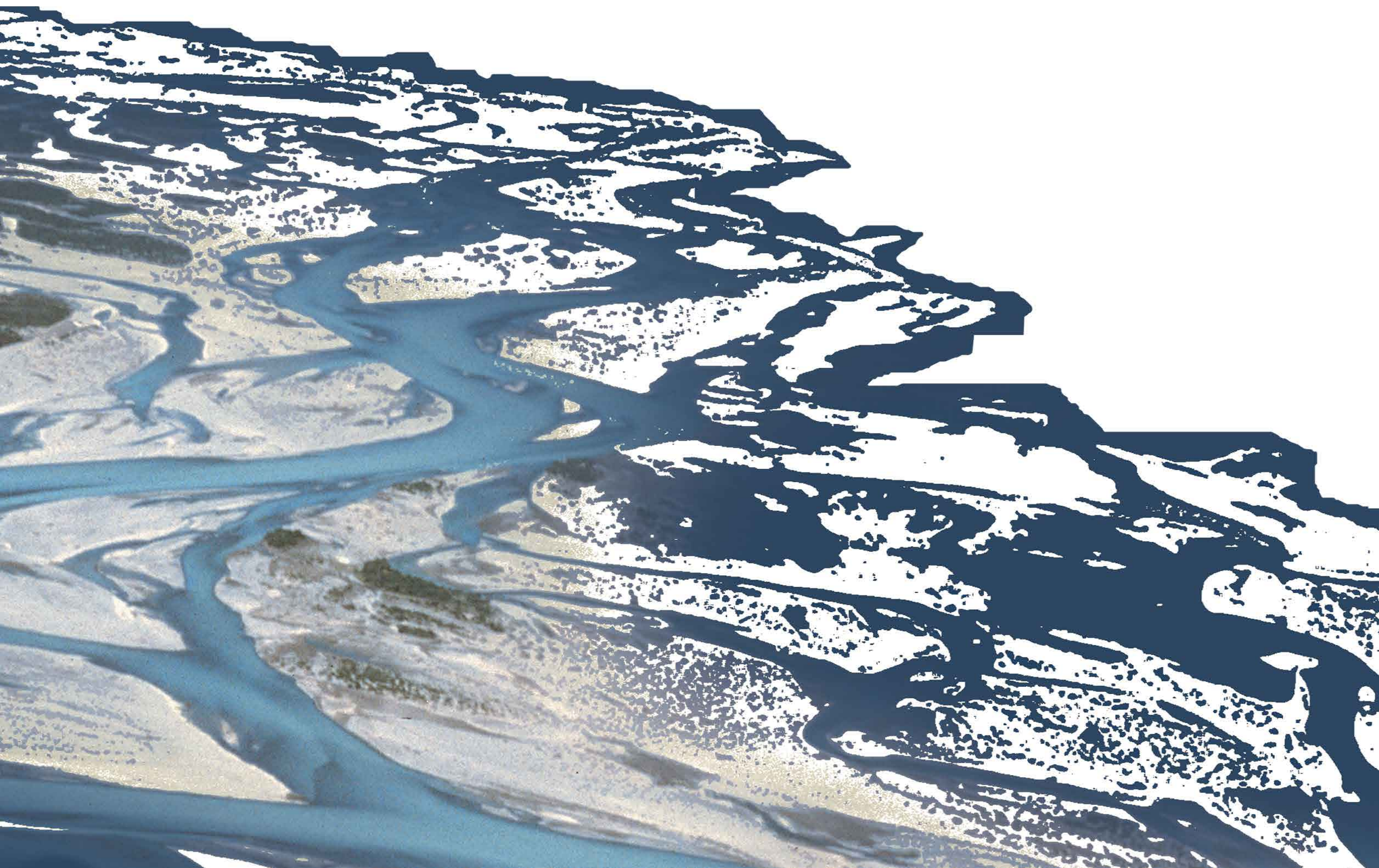
BASEMENT

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

SYSTEM MANUALS

VERSION 3.1
November 2020



Preamble

VERSION 3.1

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For Website:

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For Software:

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

USER MANUAL

VERSION 3.1
November 2020

Contents

1

Basic Simulation Environment

1.1 Introduction

The software system BASEMENT (BAsic-Simulation-EnvironMENT) provides a functional environment for numerical simulation of river flows with sediment transport in alpine and sub-alpine regions.

The continual development of the software system has lead to BASEMENT version 3.0, a newly developed version motivated by an increase of efficiency, while guaranteeing the stability of the numerical models. Compared to the former versions of BASEMENT, version 3.0 has a simpler spatial discretization and improved performance. In addition, the software provides a new simulation workflow and graphic user interface (GUI).

The development process is at an early stage and focuses primarily on efficient two dimensional flows modelling with bedload transport. Further development of the software system BASEMENT is expected in the future with the implementation of a 1D model and the increase of available features and application domains.

1.2 General Use

1.2.1 Problem Description

In connection with watercourses and river areas, increasingly complex problems have to be addressed. The estimation of floods, the more frequent occurrence of restoration projects or the study of naturally shaped watercourses implicate the examination of larger regions - also outside of the actual waterway - and a more manifold shape of the channels. The simple formulas for the calculation of flow behaviour used in the past showed in several cases to be insufficient to obtain the desired information. The extent of the considered areas makes the application of hydraulic models in a laboratory - usually employed for difficult cases - impossible or too expensive. So, the numerical simulation of flow behaviour is in many cases the most obvious solution. However, existing programs have still some weak points. Some are limited in their capabilities (e.g. only steady flow and no sediment transport) or may lack in user support caused in incompleteness of documentation or training of users. Furthermore, inherent numerical problems request certain expertise to be overcome. In addition, the preparation of the input data and the processing of the results to a shape, which facilitates the interpretation, are often very laborious.

The aim of the software system BASEMENT, in terms of its free availability and its accompanying scholar programs, is to enable a broader range of people to skilfully process river modelling projects in a justifiable amount of time.

1.2.2 Product Delineation and Employment Domains

1.2.2.1 Product Delineation

BASEMENT is a river engineering tool, which supports the engineer in the solution of tasks in the domain of river area modelling. The program permits reliable computations based on state of the art numerical tools, constant onward development and successive realisation of case studies.

Unlike currently used programs for the simulation of a specific flow behaviour, BASEMENT intends the arrangement of many different problem types with one single tool to gain an integrated understanding for the initial position, the solution process and its results.

1.2.2.2 Employment Domains

The aim of BASEMENT is to permit the solution of as many problems as possible in the domain of river engineering, especially in cases for which the traditional dimensioning tools are insufficient and studies including physical hydraulic models are not possible or too expensive. Typical employment domains are:

- Several problems in relation with the sediment transport of water courses, for instance the future development of deltas and alluvial fans, the long term evolution of the bottom of channels, or the aggradation of storage spaces and the consequences of their scavenging;
- River engineering enterprises, which imply the modification of the channel geometry, as this can be the case for example for revitalisations or protection measures, where the consequences of the interventions have to be evaluated;
- Identification and quantification of dangers for the development of danger maps or of protection and emergency measures, considering the flow behaviour and sediment deposition both inside and outside of the main channel, as well as erosion danger, and consequences of debris flows and dam breaks.

1.2.3 Capabilities

BASEMENT has the following fundamental capabilities:

- Simulation of flow behaviour under steady and unsteady conditions in a channel as well as its transition;

- Simulation of sediment transport (bed load) under steady and unsteady conditions in a channel with arbitrary geometry;
- Simulation of erosion and deposition;

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Modelling procedure

2.1 General

The modelling procedure involves three stages: the pre-processing, the numerical simulation and the post-processing (Figure 2.1). A numerical project is based on a topographical region on which one or more scenarios are studied by running appropriate numerical simulations. Each scenario and all representative parameters with the required type of data should be defined in advance. The pre-processing stage consists of gathering the necessary external data in order to obtain the required input file format for the numerical simulation. The simulation generates output files that can be visualized and modified by external softwares (e.g. ParaView) in order to represent and interpret the results of the numerical simulation. The scenario directory contains all the files (input files, configuration files, output files,. . .) required to execute a numerical simulation with BASEMENT.

This section will present in details the pre- and post-processing parts, while the numerical simulation will be explained in Section 4.

Figure 2.1 *Overview of the modelling procedure with BASEMENT*

2.2 Preprocessing

2.2.1 General

Three main types of external data need to be provided for the numerical simulation: topography, hydrology and sediment data. The pre-processing stage involves the conversion of external data into appropriate input files that are used in the numerical simulation. The topography of the investigated region has to be transformed into a computational mesh. The topographical data types are manifold and may come from a cluster of point with (x,y,z)-coordinates, cross sections, height contour lines or raster data like a digital elevation model (DEM). Beside the computational mesh, hydrological and morphological data have to be determined for the numerical simulation and therefore converted into series data, constant or dynamic value (e.g. weir activation). The hydrology is characterised by inflow discharge, friction, water level or local sources and sink. The soil parameters include the mean grain size, the porosity, sediment density, the roughness, the angle of rest and the sediment flow.

2.2.2 Computational Mesh

2.2.2.1 Concept

The numerical methods used in BASEMENT are based on a discretization of the domain topography into unstructured triangular elements. These elements are the control volumes (finite volume of 1st order) for the computation of flow equations and the complex of these elements forms the computational mesh. Once the domain has been discretise into unstructured triangular elements, thus forming a quality mesh, the topographical elevation information has to be assigned to the quality mesh in order to generate the final computational mesh. The elevation information is attributed to the element center and is equally distributed over the element area. An appropriate definition of the element center coordinates is crucial for the generation of the computational mesh. It exists different methods to define the interpolation point coordinates of a triangular element, in BASEMENT, the average of the triangle node coordinates is used. The element edges define the boundary of the control volume and the connection between the neighboring elements.

One single computational mesh is used for hydro- and morphodynamic simulations and has to be of type "MyMesh.2dm" (Figure 2.1). The plugin BASEmesh for the free and open source geographic information system software Quantum GIS (QGIS) provides automated routines for mesh generation in case of a small or large meshes. The breaklines, the definition of boundaries and the generation of the quality mesh are steps of the mesh generation process using BASEmesh.

2.2.2.2 Breaklines

Breaklines affect the quality mesh outcome by preventing the meshing of elements over them during the meshing process. Breaklines enable to delineate the limits of the quality mesh as well as relevant regions like buildings or zones of local mesh refinement. These regions are characterized by marker points (Regiondefs) that allow the user to divide the computational mesh into areas of common features for the numerical simulation, e.g setting different initial friction values or definition of an external source over a specific region of the mesh.

Breaklines are important and should be carefully defined due to the computational mesh specificity of attributing one elevation information to the cell center. The risk encountered is the loss of geometrical accuracy at locations of distinct change of slope (e.g. levee crests or river side walls) or where the cells are required to have a determined and fixed elevation (riverbed, bank crest,. . .). In order to overcome this issue, areas of fixed or known elevation need to be delimited by breaklines as regions to ensure that the right elevation is assigned to the cell.

2.2.2.3 Boundary Conditions

Boundary conditions control the water and sediment flow into and out of the domain. Boundary conditions are defined on STRINGDEFs, i.e. on a selected sequence of successive vertices (with direction) located either inside or at the boundary of the computational mesh. The sequence of vertices along the stringdef gives the stringdef's direction with a left and right side. The upstream flow direction must be defined by the user during the setup stage of the numerical simulation and has to be set according to the stringdef definition, i.e. direction.

There exists three types of boundary conditions, the external (standard), internal and linked boundaries. The external boundaries are defined on the domain boundary, while the internal boundary is defined inside the domain. Linked boundary conditions connect two stringdefs inside or on the boundary of the domain. More informations about the type of boundaries and their features can be found in the Reference Manual. The "upstream_direction" is determined by placing yourself on the first node of the stringdef and looking into the direction of the second node of the nodestring. Then, determine whether "upstream" is on your left or right side.

STRINGDEFs can be defined on nodestrings, which are listed at the end of the computational mesh file "MyMesh.2dm".

Please Note: In BASEMENT version 3.x, the number of nodes per nodestring is limited to 40, i.e. larger nodestrings must be split up.

2.2.2.4 Mesh Quality

The quality of the mesh is defined by the size and number of mesh elements that compose the computational mesh. Regions of high interest need some mesh refinement to get higher accuracy and regions of lower interest often have a coarser mesh. Two parameters are characterizing the mesh quality: the maximum element area and the minimum element angle.

The maximum element area is assigned to cluster of elements, i.e. specific region surrounded by breaklines and can vary among the zones. The minimum element angle is a parameter defined over the entire mesh. Smaller angles lead to less elements, while larger angles lead to more elements.

2.2.3 Hydrological, sediment and tracer data

2.2.3.1 Hydrology

The hydrology of the domain can be specified at boundary conditions in case of water fluxes or over a defined region of the computational mesh if an external source (mass) like rainfall, local source or sink is considered. The water flux can be implemented as discharge (m^3/s), h-q relation or as water surface elevation and the external source can be implemented as discharge or as rainfall precipitation (mm/h).

The type of data can be assigned as a single constant value (lake level, constant discharge,. . .) or as a time series like a hydrograph or series variable (e.g. h-q relation) or as dynamic in case of weir activation or dam collapse. In case of variable water flux (e.g. discharge hydrograph or rating curve), the hydrological data is stored in a time series data file (MyData.txt, see Figure 2.1). The simulation module will then interpolate the desired values to the actual computational time. The source data is either defined as constant or in a time series.

Initial hydraulic conditions can be defined as dry or defined by setting the values of the water surface elevation (wse), the velocity in x direction (u) and y direction (v) over the regions.

2.2.3.2 Sediment Transport

The river bed is characterized by a porosity and a mean grain size diameter (m) determined from sediment or line samples. In BASEMENT version 3, the simulation works only for uniform sediments.

The sediment flow is defined as a specific bedload flux, which is averaged and evenly distributed over the stringdef length (sediment flow boundary). The sediment boundaries are of type standard (external boundaries). The type of data for the specific bed load flux is either set constant or defined in a time series as sedimentograph [m^3/s] or in a transport capacity formula, without porosity. The reference bed elevation has to be provided at inflow and outflow boundary conditions of type equilibrium.

2.2.3.3 Tracer Transport

The presence of dissolved species in the flow can be defined as either boundary conditions, local sources or sinks and also as initial conditions. At present, the maximum number of transported species is 5. The fluxes of each specie can be defined as discharges (m^3/s) or, alternatively, the concentration [-] of each specie can be set according to user specified values.

Similarly to the hydrological and sediment data, the tracer discharges or target concentrations can either be set as constant or defined as a time series. For the case of fluxes prescribed as boundary discharges, these are distributed evenly along the boundary length or weighted according to the wet area of the boundary section. In the case of region-defined local sources, the total discharge is distributed evenly across the region's area. In the case of a prescribed target concentration at boundaries or sources this value is uniformly applied to the entirety of the boundary length or region area, respectively.

2.3 Simulation Workflow

The software system BASEMENT encompasses the numerical simulation, composed of numerical subsystems, executables binary files and interfaces to the infrastructural software like the pre- and post-processors. More details concerning the simulation workflow are described in Section 4.

2.4 Postprocessing

2.4.1 Output Files

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 2.1.

Table 2.1 *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]
flow_curvature	Flow curvature (inverse of flow radius) [m^{-1}]
flow_radius	Flow radius [m]
theta	Non-dimensional effective bed shear stress [-]
theta_critical	Non-dimensional critical bed shear stress [-]
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
bed_gradient	Local bed gradient ($\partial z/\partial x$, $\partial z/\partial y$) [-]

Output	Description
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 tracer2 tracer3 tracer4 tracer5	Mass of specie 1 [-] … … … Mass of specie 5 [-]
Nodestring	
ns_hyd_discharge	Hydraulic output variables on the Nodestrings
ns_mor_discharge	Morphologic output variables on the Nodestrings

2.4.2 Result Visualization

The visualization of results is separated from the software system BASEMENT and can be done with independent products using a well-defined common interface. The output are available as an extensible data model format “results.xdmf” (see Figure 2.1) for the cell centered outputs or in a text format (.csv) for the nodestring output. The software ParaView and QGIS enables to visualize the results stored in “results.xdmf”.

3

Grid Generation with BASEmesh

3.1 General

In order to provide a free and open source solution for the creation of computational meshes, the plugin BASEmesh for the open source geographic information (GIS) software QGIS was developed. The plugin utilises Jonathan R. Shewchuk's advanced mesh generator Triangle (Shewchuk, 1996) as its meshing algorithm.

BASEmesh version 2.x is compatible with BASEMENT v2.8 and v3.x, but requires QGIS version 3.10 or higher. For versions of BASEmesh compatible with QGIS v2.18 or versions lower than v3.10, please refer to the compatibility section on the BASEmesh Website.

3.2 Installation

BASEmesh is available for installation through a custom plugin repository which is not included in QGIS upon installation. The BASEmesh plugin repository must be added to the QGIS plugin manager by the user prior to installation.

To install BASEmesh, follow these steps:

1. Start QGIS
2. Load the QGIS plugin manager by choosing *Manage and Install Plugins...* in the *Plugins* category of the QGIS toolbar
3. Select *Settings* from the left panel
4. Click on *Add...* and provide a descriptive name, e.g. 'BASEmesh Plugin Repository'
5. Specify the repository address: https://people.ee.ethz.ch/~basement/qgis_plugins/qgis_plugins.xml
6. Press OK to confirm; a new entry has been added to the list of plugin repositories (make sure the *Status* reports as *connected* before continuing)

7. Select *All* from the left panel of the plugin manager and search for 'BASEmesh'
8. Choose the BASEmesh plugin (if several are available, choose the one with the highest version number) and press *Install Plugin*
9. Close the plugin manager. A new toolbar should have appeared and a *BASEmesh* entry added to the *Plugins* category of the QGIS toolbar

3.3 Mesh generation

The following section covers the basics of mesh generation using version 2.0 of the BASEmesh plugin. For in-depth parameter explanations and advanced use-cases, refer to the BASEmesh Manual.

Mesh generation in BASEmesh v2.x is performed in two steps. First, a 2D quality mesh is generated using Triangle, which is then interpolated using one or more elevation sources. Elevation sources are either existing meshes containing elevation data (TIN), or raster data in the form of a digital elevation model (DEM). This interpolation can be performed for the mesh nodes (BASEMENT v2.8), the mesh elements (BASEMENT v3.x), or both, which allows use of the same computational grid for both environments.

3.3.1 Quality mesh generation

The quality meshing utility provides a QGIS interface to the Triangle advanced mesh generator. As Triangle is two-dimensional, the generated mesh will not contain any elevation information.

The following constraints are available to control the mesh generation process:

- *Break lines*: A map layer containing lines or line strings representing distinct interruptions of the surface slope (e.g. dyke crests, river side walls, ...) which will be preserved in the computational mesh. Note that you do not have to include break lines for node string definitions (see *String definitions* description below).
- *Dividing constraints*: An integer layer attribute used to split a break line before meshing. This is important when using inner boundaries in BASEMENT as the number of mesh elements at the upstream and downstream interface must be equal.
- *Constrained points*: Additional points to enforce during triangulation, such as a known measurement point.
- *Minimum angle constraint:* The minimum angle enforced for any mesh elements generated. This heavily affects the element count of the resulting mesh.
- *Maximum area constraint:* A global maximum area for any mesh elements generated. This will be overridden by any region-specific area constraints defined (see below).

In addition to the global mesh quality constraints, additional constraints may be defined for individual mesh regions. A region is any closed loop of break lines, the constraints are then applied by placing a point marker within a region.

These markers may specify up to three flags:

- *Hole marker*: Regions marked as holes will be carved out of the resulting mesh. This flag is mutually exclusive with the other flags.
- *MATID*: Specify the material ID for any mesh elements generated within this region.
- *Maximum area*: This allows overriding the global maximum area constraint for mesh elements in this region.

In BASEMENT an ordered list of neighbouring node IDs is called a *string definition* (aka. StringDef) or *node string*. In BASEmesh v2.x, their declaration is also part of the quality meshing utility.

They are defined through line strings in a separate map layer and will be preserved in the resulting mesh as break lines are:

- *String definitions layer*: A map layer containing lines defining the node strings.
- *String definition ID field*: The unique name attribute of a given string definition. Required for node string identification.
- *Include in 2DM node strings*: If checked, the node strings will be written into the 2DM mesh file using *NS* tags. Required for BASEMENT v3.x.
- *Write to sidecar file*: If checked, the node strings will be written into a separate text file. Require for BASEMENT v2.8.

Note that BASEMENT v3.x does not allow more than 40 nodes per node string; split your string definition lines if your meshing parameters generate meshes exceeding this limit.

3.3.2 Elevation mesh generation

The elevation meshing utility generates mesh geometries in the SMS 2DM format from existing 3D input geometries. It is provided to allow generation of TIN elevation data from geometries and is not necessary if you already have raster (DEM) elevation data for your quality mesh.

You can use the *BASEmesh/Converters/Convert legacy layer* utilities in the QGIS processing toolbox to create 3D geometries from 2D geometries with elevation attributes as used in previous versions of BASEmesh. Only layers containing elevation information will be displayed for this step.

Key parameters for the elevation meshing utility:

- *Line segments*: A map layer containing 3D lines or line strings constraining the generated output geometry.
- *Fixed points*: A map layer containing 3D points used to further constrain the triangulation.
- *Keep convex hull*: If selected, the convex hull of the input data is kept and used as the mesh boundary.
- *Shrink to segments*: If selected, only closed areas enclosed by break lines are included in the generated mesh.

Note that in BASEmesh v2.x, there is no more differentiation between the mesh domain (aka. mesh boundary polygon) and the mesh break lines layer. For behaviour similar to previous versions of BASEmesh, merge the mesh boundary polygon lines into the break lines layer and select the *Shrink to segments* option as your mesh domain.

3.3.3 Mesh interpolation

The interpolation step converts the flat quality mesh generated by Triangle into a suitable computational mesh for BASEMENT. For v2.8, this means adding elevation information to the mesh nodes, for v3.x, the elevation information is added for the mesh elements instead. This interpolation is done from one or more interpolation sources, i.e. elevation meshes (TIN) or raster data (DEM).

In basic mode, a single elevation source may be selected, though multiple elevation sources are allowed in advanced mode - refer to the Interpolation utility's help panel for details.

Be aware that the interpolation process can be time consuming for large meshes. While it is possible to interpolate both the mesh nodes and elements, this will also double the time required to complete the interpolation process.

4

Simulation workflow

4.1 General

The simulation workflow of the software system BASEMENT (light grey rectangular background on Figure 4.1) is composed of three parts: the pre-simulation, the simulation and the post-simulation. Each part contains an executable (red rectangles) and a command file (.json). The command files are in standardized file format of type JavaScript Object Notation (.json) with an independent language and syntaxe. Binary files (green cylinders) of HDF5 type (Hierarchical Data Format version 5, www.hdfgroup.org) work like containers that can store large amount of data and thus allow the division of the numerical simulation in three parts. The input and output data files are located outside of the simulation environment (Figure 4.1).

The pre-simulation consists on setting up the model for the simulation. The hydro- and morphodynamic parameters are defined inside the command file model.json. The setup executable combines the computational mesh (MyMesh.2dm), external required data (MyData.txt) and the command file (model.json), validates the model and stores it inside the binary setup.h5.

The simulation part runs the simulation on a selected backend type. It combines the

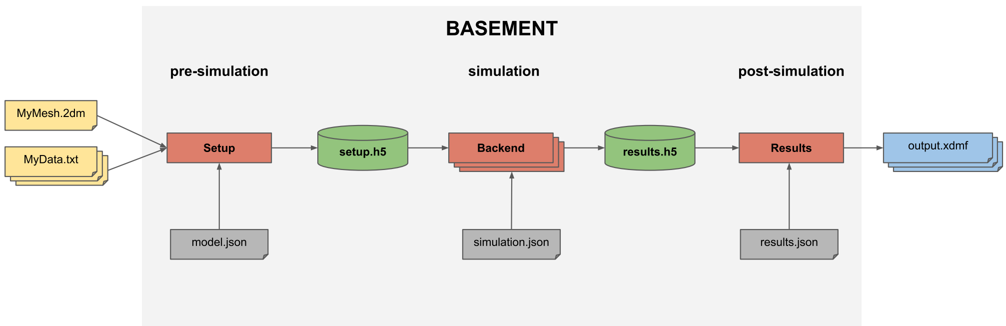

Figure 4.1 *BASEMENT simulation workflow*

model (setup.h5) stored in the first container with the command file simulation.json, where the simulation parameters are defined (e.g. execution time, output). The results of the simulation are stored in the second container (results.h5).

The post-simulation part transforms the simulation result file into output data that can be processed by the user. The type of output format (e.g xdmf) is specified inside the command file results.json. The post-simulation process is based on python scripts.

4.2 Pre-Simulation

4.2.1 Command Files

The first command file model.json defines the parameters required to run a numerical simulation on the generated computational mesh. The domain is available for 2D-simulations only and comprises two main components, the geometry and hydraulics blocks. The morphology block is also available and can be added for simulations with bed load transport.

The geometry block gives information on the computational mesh used for the 2D-simulation. The name of the computational mesh or its path have to be specified. If a computational mesh of BASEMENT version 2.x is used, an elevation interpolation method has to be defined. If no interpolation method is specified, the default interpolation method “mean” is selected. In the STRINGDEF block, the stringdefs must be listed by their name and the upstream flow direction should be indicated as either left or right (see Section 2.2.2.3). The in the REGIONDEF block, regions can be defined by listing a region name and assigning cells to that region via the MatID from the .2dm mesh file. Currently, each MatID should only be assigned to one region. Assigning an already assigned MatID to another region will overwrite the assignment to the previous region.

The hydraulics block contains the information about the initial conditions (dry, continue, region_defined), the parameters (CFL, minimum water depth,. . .), the boundary conditions, friction values, external sources and flood tracking. If the initial conditions are defined via regions, dry initial conditions are assigned for cells which do not belong to any regions from REGIONDEF or whose region is not specifically assigned initial conditions. The boundary conditions are defined by giving the corresponding STRINGDEF name and the required type (standard, linked or internal). The friction value of a cell is set to the default friction value unless specified otherwise via regions. Regions can futher be used to specify external sources. The flood tracking feature will track the maximum values of the water depth, flow velocity, specific discharge, bed shear stress and the flood arrival time.

The morphology block contains all information for setting a morphological simulation with uniform bedload transport. The bed material, the bedload transport formula, initial conditions and parameters like porosity and sediment density are required. Standard bedload boundary conditions characterize sediment inflow and outflow. The curvature and lateral bed slope effects can be activated in order to influence the bedload transport direction. Further, gravitational transport processes can be activated.

The command file model.json does not give any information about the duration of the simulation or the type of output. These are implemented in the next command files.

4.2.2 Model Setup

The setup executable gathers the different input files and generates the run file for the simulation stored in binary format (setup.h5). It validates the model before starting the simulation.

4.3 Simulation

4.3.1 Command File

The command file simulation.json contains information about the simulation time, the type of output (see Table 2.1) and optionally the minimum and maximum time step allowed. The user can define the start time, the output timestep and the end of the numerical simulation. The water surface, the water depth, the flow velocity or the change in bed elevation are examples of specific output that can be defined inside the command file. The output is generally defined on the mesh elements except for the hydraulic and sediment discharge, calculated at flow boundaries (nodestrings).

The command file simulation.json is coupled to the setup file stored inside the first container (setup.h5) in order to run the numerical simulation on a selected backend type. The results are stored as "results.h5" inside the second container.

4.3.2 Model Backend

The backend type can be selected between central processor unit (CPU), graphics processor unit (GPU) or a combination of GPU and CPU. The CPU provides sequential or multi-threading (OpenMP) backends. The backend types that support the numerical simulation are:

- seq: sequential execution on the CPU
- omp: multi-threading using OpenMP technology
- cuda: GPU
- cudaC: GPU with some kernels running sequentially on the CPU
- cudaO: GPU with some kernels running in parallel (OpenMP) on the CPU

All the backends execute the numerical simulations in double precision (default) and can be changed to single precision. For simulation running on CPU, the number of cores has to be given as argument.

4.4 Post-Simulation

The post-simulation converts the simulation results stored in the second container (results.h5) into a defined output format. The name and the output format are specified inside the command file results.json. At the moment, only the .xdmf file type is available

(Figure 4.1). The output.xdmf file can be modified by the user using the software ParaView to present the simulation results in a proper way.

A python script BMv3NodestringResulty.py is available for extracting the stringdefs results (discharge) stored in the results.h5 binary and converts them in a text format (.csv). The available outputs are listed and described in Table 4.1.

Table 4.1 *Output of the post-processing python script BMv3NodestringResulty.py*

Output	**Description**
Mean wse	mean water surface elevation [m]
Discharge	total normal water discharge Q [m^3/s]
Wetted area	total wetted area of the edges belonging to the NS [m^2]
Mean bottom elevation	mean bed elevation of wetted edges [m]
Reference elevation	reference elevation (talweg) [m]
Wetted geometric length	wetted geometric length [m]
Total water volume stored in cells	total water volume stored in the cells belonging to the NS
Total cells conveyance	total conveyance of the cells belonging to the NS
Morphological flux	total normal morphological flux [m3/s] as compact volume, no porosity (output)
Bedload transport	total bed load transport capacity [m3/s] as compact volume, no porosity

4.5 Re-Run Simulation

The concept of rerun is to execute the same setup file (setup.h5) by fetching the initial conditions from the result file (results.h5) without parsing the command file model.json. It allows to continue a simulation from given results, thus obtaining a longer simulation without starting from the beginning. Other parameters can be modified like setting different output time step or adding/removing an output type. The rerun is activated by setting a start time larger than zero and the initial conditions are taken from the result file (results.h5) that should be copied inside the setup file.

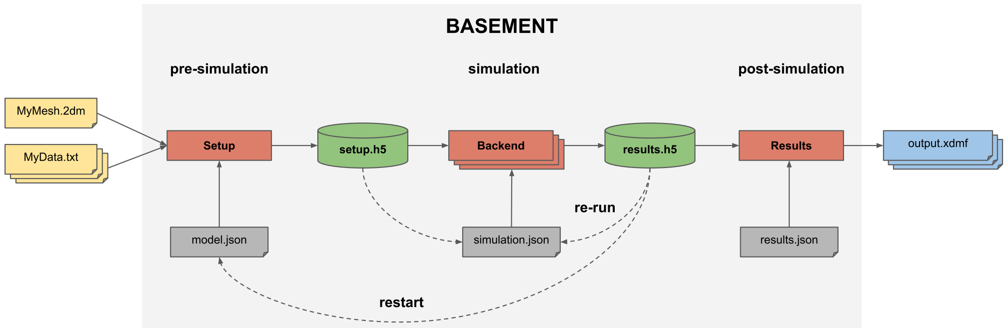

Figure 4.2 *BASEMENT simulation workflow with restart and re-run processes*

4.6 Restart Simulation

Restarting a simulation (Figure 4.2) means to modify the parameters of the command file model.json, while fetching initial conditions from an existing result file (results.h5). It allows, for example to run two different simulations one after the other, e.g. by adding bed load transport after a purely hydraulic simulation that reached steady state.

The block containing the initial conditions (model.json) is set as continue and the existing result file name with the time at which the new simulation start is specified inside the command file. The command file simulation.json indicates the desired end of the simulation and the output time step. The starting time is still required and should be set to 0.0.

5

Graphical User Interface (GUI)

5.1 Graphical user interface

5.1.1 General

The BASEMENT graphical user interface assists the user with model configuration, numerical simulation and result export. For this purpose, the application provides a convenient way to edit the JSON configuration files and to select and run the backend executables.

5.1.2 First Steps

Once started, the BASEMENT user interface application displays the welcome screen (see Figure 5.1). Notice that all the tabs except for 'BASEMENT' are deactivated. The first and most important step when using the application is to select the scenario directory. This directory will contain all the configuration and output files that the application reads and writes. To select a scenario directory, click the button with the "Open" icon and select a folder using the folder selection dialog.

5.1.2.1 Scenario Directory

A scenario directory can only be opened by a single instance of the application at a time. A temporary 'scenario_directory.lock' file is created in the scenario directory to enforce this constraint. This file signals that the directory is locked until the application is closed. If the scenario directory does not exist (this is checked regularly by the application) then an error icon is displayed in the scenario directory text field.

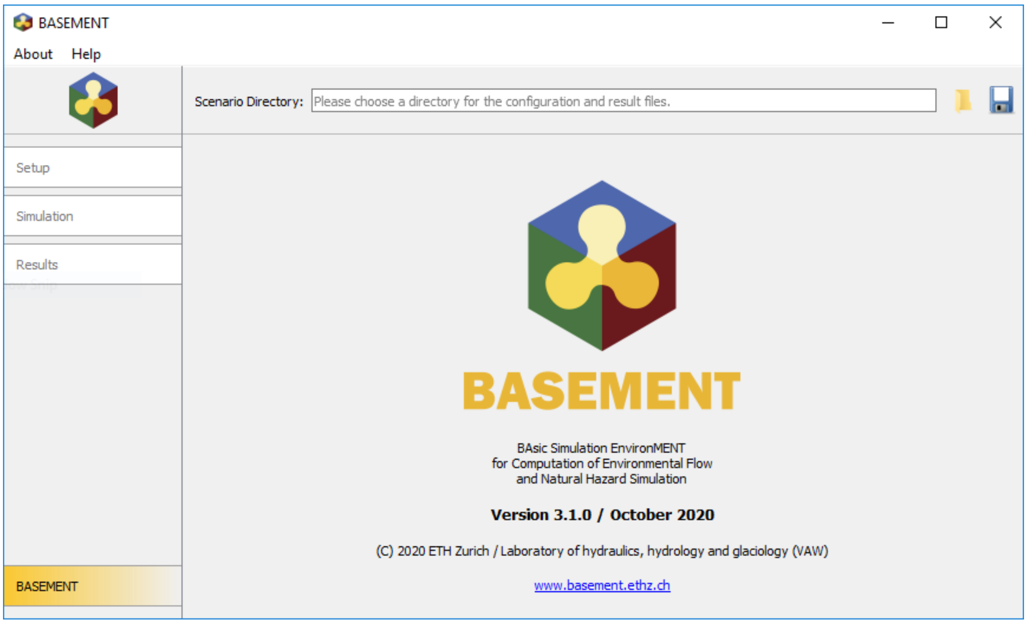

Figure 5.1 *Welcome Screen*

5.1.2.2 Load and Save

The JSON configuration files stored in a directory are loaded when it is selected as a new scenario directory. All currently unsaved changes are discarded after the user accepts the corresponding warning. To save the three JSON configuration files for setup, simulation, and results into the current scenario directory click the button with the "Save" icon.

The tab 'Setup' is activated and selected as soon as a valid scenario directory has been chosen.

5.1.3 Setup

The setup screen (Figure 5.2) is designed for scenario parameter definition. The main part, the JSON editor, contains three columns: 'Parameter', 'Value', and 'Validation'. The name of a JSON item (a parameter or a group of parameters) is displayed in the column 'Parameter', its value is displayed in the column 'Value' and the corresponding validation messages are shown in the 'Validation' column. Note that the button 'Write' is deactivated as long as the validation fails due to invalid parameters. Initially, only the item 'Setup' is present.

5.1.3.1 Adding and Deleting Items

To add a subitem to a parameter group (i.e. a JSON array or a JSON array), right-click on the item to open a context menu as shown in Figure 5.3. Select the item that you want to add for JSON objects or click the generic 'Add item' for JSON arrays. Once selected, the new subitem and all required sub-subitems are created automatically with default values (if available). Press Ctrl+Shift+A to expand all parameter groups quickly.

To delete a JSON item, use the context menu and select 'Delete item'. Deleting parameter groups deletes the group and all contained items (after displaying a warning).

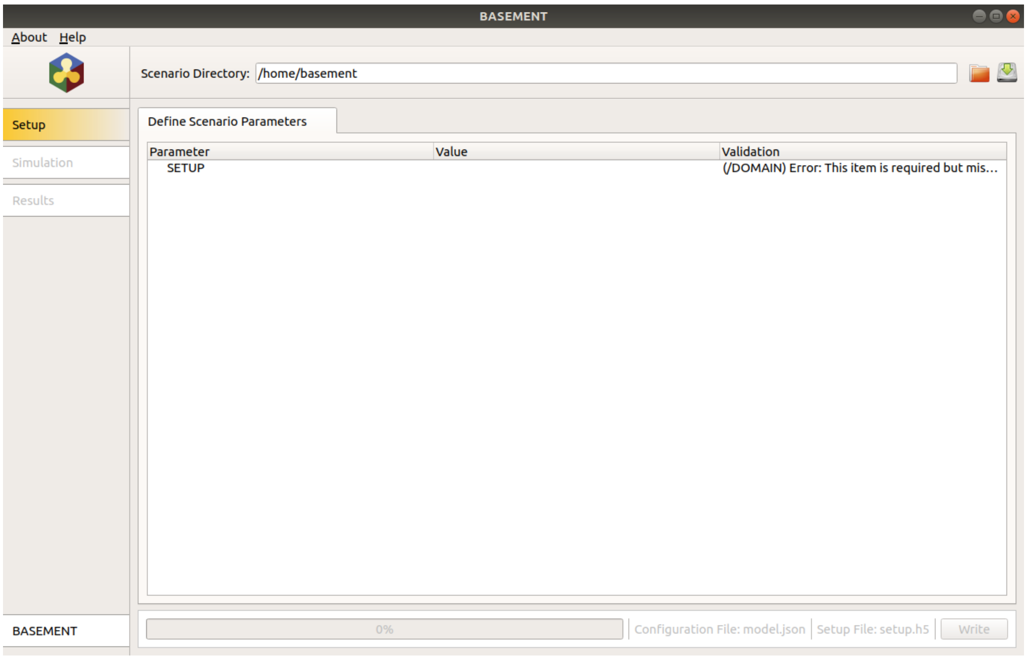

Figure 5.2 *Setup Screen*

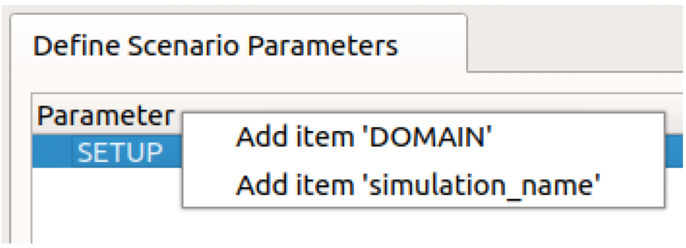

Figure 5.3 *Adding JSON Items*

Figure 5.4 *File Name Editor*

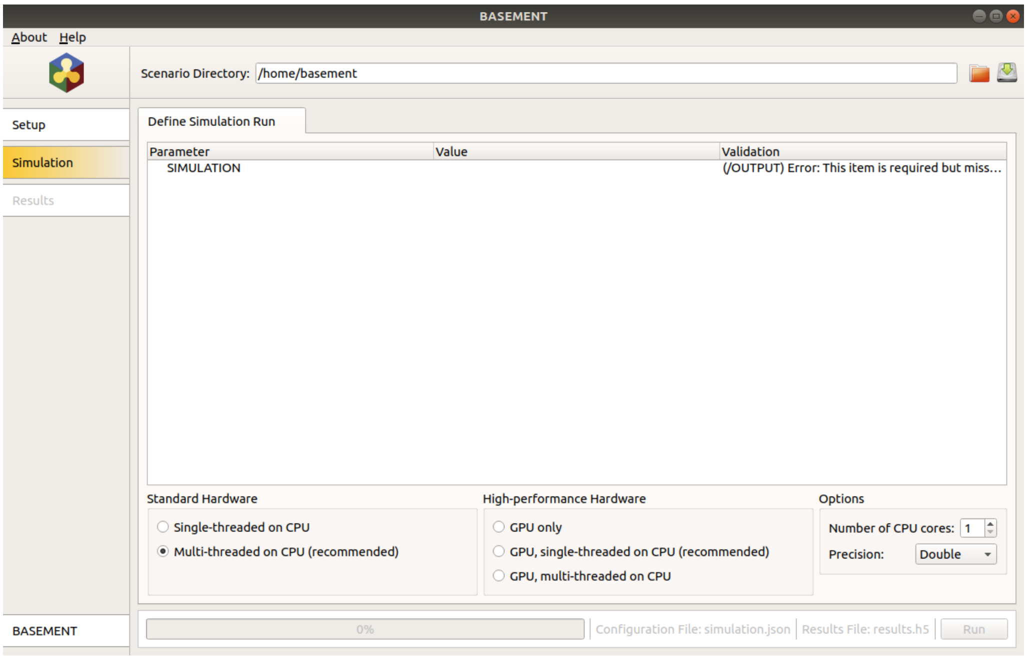

Figure 5.5 *Simulation Screen*

5.1.3.2 Help and Parameter Values

If you want to see the help for a parameter, mouse-over the parameter name and a tooltip with a parameter description appears. Double-clicking a parameter value opens a type-specific editor. In particular, you can click the “Open” icon to select a file for parameters that expect a file name (see Figure 5.4).

5.1.3.3 Run BASEMENT Setup

Click the ‘Write’ button to write the JSON file and to run the setup executable in the background when you are done with configuring the scenario parameters (the names of the written files are displayed next to this button). A closable console tab is opened. This tab contains two views: ‘Console Output’ and ‘Error Output’. The first view contains information about the status from the running BASEMENT setup process. The second view, ‘Error Output’, contains error messages from this process. If everything went well, all the files are successfully written and the ‘Simulation’ tab is activated.

5.1.4 Simulation

The simulation screen (Figure 5.5) is enabled if the file ‘setup.h5’ exists in the scenario directory. Use this screen to edit and review the parameters required to run the numerical simulation. The JSON editor works just like the editor in ‘Setup’, but of course the available parameters are different and only the item ‘Simulation’ is present initially.

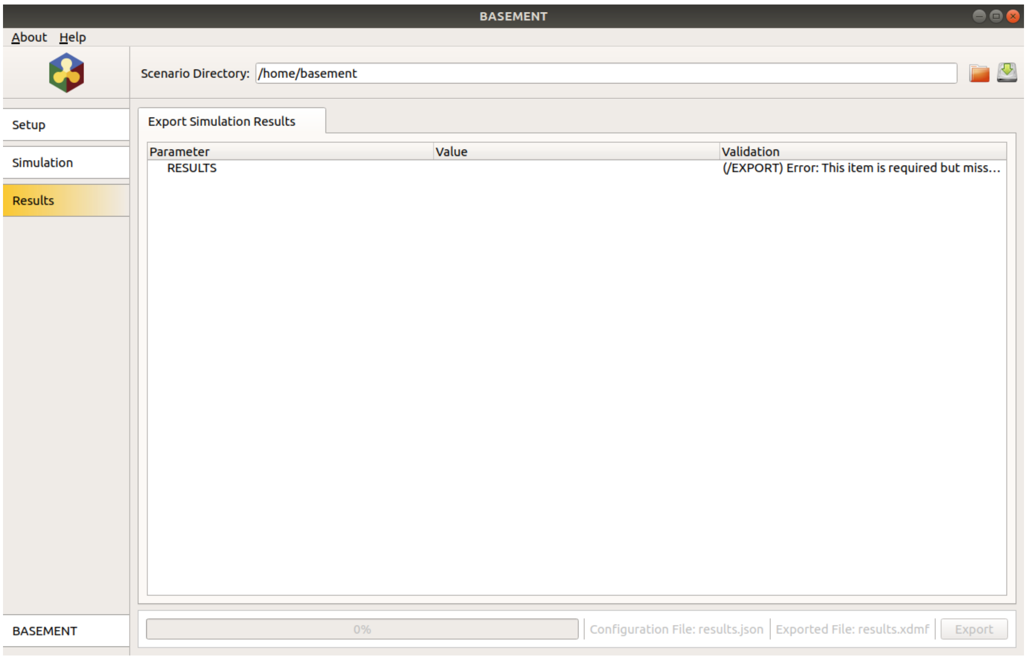

Figure 5.6 *Results Screen*

5.1.4.1 Selecting the Simulation Backend

The simulation screen also provides a way to select the simulation executable and command line flags: Choose the number of CPU cores that shall be used for the simulation, whether you want to compute on the GPU and the precision of the simulation using the controls on the lower end of the screen. Clearly, the number of CPU cores can only be set for multithreaded simulation backends.

5.1.4.2 Run Simulation

When all the parameters are defined and valid, click the button 'Run' to launch the numerical simulation. Again, this will save the JSON configuration file and start the simulation backend in the background (the names of the files that are written are displayed next to the button). Track the progress of the simulation using the progress bar or click 'Abort' to abort. If everything went well, all the files are successfully written and the 'Results' tab is activated.

5.1.5 Results

The results tab (Figure 5.6) is enabled if the file 'results.h5' exists in the scenario directory. It can be used to define the export parameters. Again, the JSON editor works just like the editor in 'Setup'. Initially, only the item 'Results' is present.

When all the parameters are defined and valid, click the button 'Export' to save the JSON configuration file and generate the output. If everything went well, the exported file (and an auxiliary results file in the case of export to 'xdmf') is successfully written to the scenario directory and is available for post-processing.

6

Run the program

6.1 Running BASEMENT

6.1.1 Graphical user interface (GUI)

The installation and executing of the BASEMENT software is described in the part Setup and First Start of the "Introduction and Installation" of this manual. Further details concerning the GUI of BASEMENT are explained in Section 5.1.

6.1.2 Batch mode under Linux

Executing a simulation with BASEMENT normally opens the graphical user interface (GUI) and requires some input from the user, e.g. to select the model data and to confirm warnings generated by the program at the start and during run-time. But BASEMENT can optionally be started without any graphical interaction and without user input. This feature is especially useful if one or several models shall be run automatically via batch or script file. Be aware that executing in batch mode requires special attention, since significant warnings may be suppressed without being noticed! It is recommended to study the generated 'log-file' after the simulation to check the program output for warnings which may have been generated during run time.

Executing in batch mode can be specified at the program start of BASEMENT using command line arguments. The execution of BASEMENT is split in three steps, the setup, the simulation and the results having their own backend and parameters.

6.1.2.1 Setup

The setup parameters of the numerical model are defined in the json file ("model.json"). The setup is executed from the command prompt (console) using the following line:

```
$ ./BMv3_BASEplane_setup -f model.json -o mySim_run.h5
```

The arguments of the setup can be obtained in the command prompt (console) with the help flag '-h'. Table 6.1 shows the setup arguments.

```
$ ./BMv3_BASEplane_setup -h
```

Table 6.1 *Command line flags and arguments for the setup*

Setup flag	Definition and arguments
-h , –help	display help information
-g , –graph	plot the tree as graph
-p , –process	level of processing (int)
-a , –archive	restore the archive (string)
-n , –nthreads	number of threads (int)
-l , –log	level of debug messages (int)
-f , –file	(required) the configuration file name
-o , –output	(required) the output name (.h5)

6.1.2.2 Simulation

The execution of the simulation depends on the backend type. There are five different backend types that can be run with single precision by adding "_single" to the backend name.

Write the following lines to execute the simulation file ("simulation.json") in batch mode using the command line on a sequential backend:

```
$ ./BMv3_BASEplane_seq -f simulation.json -r mySim_run.h5
  -o mySim_run_results.h5 -p
```

And using a single precision:

```
$ ./BMv3_BASEplane_seq_single -f simulation.json -r mySim_run.h5
  -o mySim_run_results.h5 -p
```

Please note: Using single precision can lead to less accurate results!

The available backends are listed below with all having the possiblity of running on single precision:

```
$ ./BMv3_BASEplane_seq
```

```
$ ./BMv3_BASEplane_omp
```

```
$ ./BMv3_BASEplane_cuda
```

```
$ ./BMv3_BASEplane_cudaC
```

```
$ ./BMv3_BASEplane_cudaO
```

The backend "_omp" stands for parallel execution with OpenMP and the number of thread should be specified. The backend "_cuda" stands for GPU simulation. The backend "_cudaC" executes the simulation using a coupled GPU and sequential processor and finally "_cudaO" uses a coupled GPU and parallel processor.

The command line arguments of the simulation are shown in Table 6.2.

***Table 6.2** Command line flags and arguments for the simulation*

Setup flag	Definition and arguments
-h , –help	display help information
-p , –progress	print simulation progress
-r , –runfile	(required) h5 file name with model definition
-a , –archive	restore the archive (string)
-n , –nthreads	number of threads (int)
-l , –log	level of debug messages (int)
-f , –file	(required) the configuration file name
-o , –output	(required) the output name (.h5)

6.1.2.3 Results

The last backend converts the simulation results in output, therefore, the result file ("results.json") is executed as follow:

```
$ ./BMv3_BASEplane_results -f results.json -r mySim_run_results.h5
  -o mySim_output
```

The command line arguments for the output generation are listed in Table 6.3

***Table 6.3** Command line flags and arguments for the results*

Setup flag	Definition and arguments
-r , –results	(required) h5 file name with simulation results
-a , –archive	restore the archive (string)
-n , –nthreads	number of threads (int)
-l , –log	level of debug messages (int)
-f , –file	(required) the configuration file name
-o , –output	(required) the output name

The command line argument can be supported in any order.

Note that the 'xdmf' output file format contains a reference to the simulation results instead of copying the data. Also, an auxiliary results file (named 'output_aux.h5' if the output name is 'output') is generated when exporting this file format. This has the advantage of using less storage space, but it also means that the three files (i.e. the simulation results file, the auxiliary results file, and the generated output file) are required to display the results. When opening such an output file, the file with the simulation results will be read from the path specified using the '–results' command line parameter. Therefore provide a relative path to the simulation results file if you want to be able to move these files to different locations together.

Of particular interest is the possibility to run BASEMENT in the batch mode without the GUI to be started. Under Linux this can be done with a shell script. In a shell script, the three steps as well as several simulations can be run consecutively (for example over the weekend). To generate a shell script just create an empty text file and replace the ending '.txt' by '.sh'. In this file several command lines can be defined as for example:

```
# Project 1
./BMv3_BASEplane_setup -f /home/MyUser/Project_1/model.json
      -o /home/MyUser/Project_1/mySim_run.h5

./BMv3_BASEplane_seq -f /home/MyUser/Project_1/simulation.json
      -r /home/MyUser/Project_1/mySim_run.h5
      -o /home/MyUser/Project_1/mySim_run_results.h5

./BMv3_BASEplane_results -f /home/MyUser/Project_1/results.json
      -r /home/MyUser/Project_1/mySim_run_results.h5
      -o /home/MyUser/Project_1/mySim_output

# Project 2
./BMv3_BASEplane_setup -f /home/MyUser/Project_2/model.json
      -o /home/MyUser/Project_2/mySim_run.h5

./BMv3_BASEplane_cuda -f /home/MyUser/Project_2/simulation.json
      -r /home/MyUser/Project_2/mySim_run.h5
      -o /home/MyUser/Project_2/mySim_run_results.h5

./BMv3_BASEplane_results -f /home/MyUser/Project_2/results.json
      -r /home/MyUser/Project_2/mySim_run_results.h5
      -o /home/MyUser/Project_2/mySim_output
```

To make the shell script executable open to console in the same directory of the shell script and run

```
chmod +x myShellScript.sh
```

Then run the shell script in the console with

```
./myShellScript.sh
```

6.1.3 Batch mode under Windows

Running BASEMENT 3.x in with a graphical user interface under Microsoft Windows can be done with the same work flow as described in Section 6.1.2. The syntax of the PowerShell is slightly different from that of the console. Further, the different backends of the BASEMENT software package have to be called with the full path of the installation folder. Note: Folder paths with whitespaces must be written in quotation marks ("").

For example in the case you installed BASEMENT 3.x in under the path "C:\Program Files (x86)\BASEMENTv3.1.0" and your simulation scenario is stored on drive "F:\" in the folder "Project_1", then you should run the simulation with the following three commands:

```
C:\"Program Files\BASEMENT 3.1.0"\bin\BMv3_BASEplane_setup.exe
      -f F:\Project_1\model.json
      -o F:\Project_1\mySim_run.h5

C:\"Program Files\BASEMENT 3.1.0"\bin\BMv3_BASEplane_seq.exe
      -f F:\Project_1\simulation.json
      -r F:\Project_1\mySim_run.h5
      -o F:\Project_1\mySim_run_results.h5 -p

C:\"Program Files\BASEMENT3.1.0"\bin\BMv3_BASEplane_results.exe
      -f F:\Project_1\results.json
      -r F:\Project_1\mySim_run_results.h5
      -o F:\Project_1\mySim_output
```

Of particular interest is the possibility to run BASEMENT in the batch mode without the GUI to be started. Under Microsoft Windows this can be done with a batch file. In a batch file, the three steps of the simulation workflow as well as several simulations can be run consecutively (for example over the weekend). To generate a batch file file just create an empty text file and replace the ending '.txt' by '.bat'. In this file several command lines can be defined as for example:

```
"C:\"Program Files\BASEMENT3.1.0"\bin\BMv3_BASEplane_setup.exe
      -f F:\Project_1\model.json
      -o F:\Project_1\mySim_run.h5

"C:\"Program Files\BASEMENT3.1.0"\bin\BMv3_BASEplane_seq.exe
      -f F:\Project_1\simulation.json
      -r F:\Project_1\mySim_run.h5
      -o F:\Project_1\mySim_run_results.h5 -p

"C:\"Program Files\BASEMENT3.1.0"\bin\BMv3_BASEplane_results.exe
      -f F:\Project_1\results.json
      -r F:\Project_1\mySim_run_results.h5
      -o F:\Project_1\mySim_output


"C:\"Program Files\BASEMENT3.1.0"\bin\BMv3_BASEplane_setup.exe
      -f F:\Project_2\model.json
      -o F:\Project_2\mySim_run.h5

"C:\"Program Files\BASEMENT3.1.0"\bin\BMv3_BASEplane_omp.exe
      -f F:\Project_2\simulation.json
      -r F:\Project_2\mySim_run.h5
      -o F:\Project_2\mySim_run_results.h5 -p -n 6
```

```
"C:\"Program Files\BASEMENT3.1.0"\bin\BMv3_BASEplane_results.exe
     -f F:\Project_2\results.json
     -r F:\Project_2\mySim_run_results.h5
     -o F:\Project_2\mySim_output
```

Then run the batch file by double clicking on it.

7

References

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

APPENDIX

VERSION 3.1
November 2020

1

Third Party Software

1.1 Third party software copyright notices

Abseil

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Bzip2

```
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Julian Seward, jseward@bzip.org
bzip2/libbzip2 version 1.0.6 of 6 September 2010

Double-conversion

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Egl-registry

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```
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======================

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```

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THE BASIC LIBRARY FUNCTIONS
---------------------------

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  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.

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  you inform other peers where the object code and Corresponding
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  charge under subsection 6d.

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