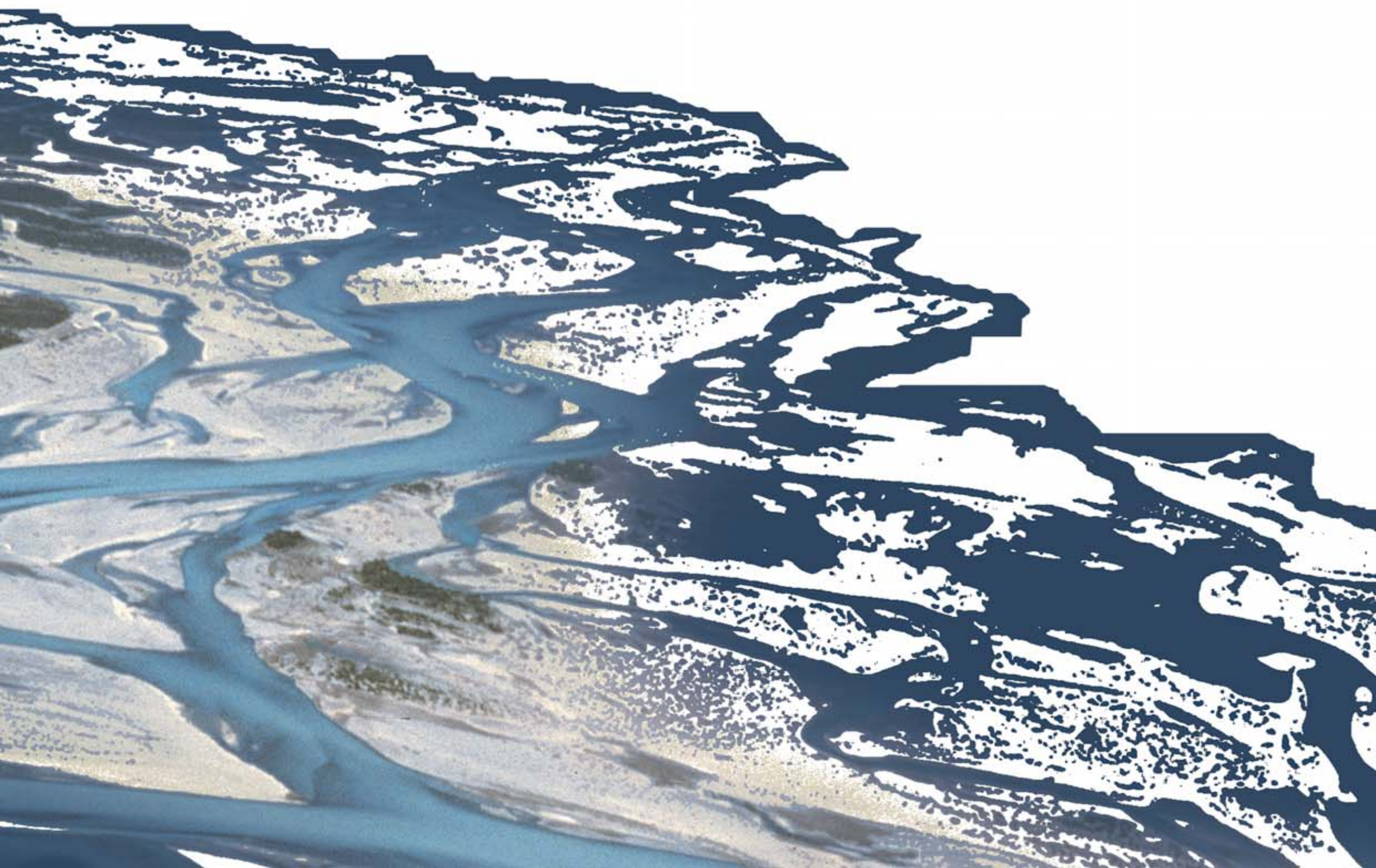
BASEMENT

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

SYSTEM MANUALS

VERSION 3.0
September 2019



Preamble

VERSION 3.0.2

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

USER MANUAL

VERSION 3.0
September 2019

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;

2

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.

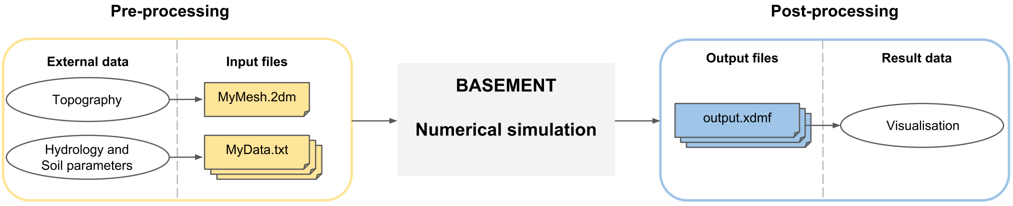

Figure 2.1 *Overview of the modelling procedure with BASEMENT*

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 on the domain. They are defined on the domain as stringdef, i.e. a selected sequence of vertices and element edges of the computational mesh located either at the border or inside the computational mesh. The sequence of vertices along the stringdef gives the stringdef direction with a left and right side. The upstream flow direction is 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.

It exists two types of boundary conditions, the external and internal boundaries. The external boundaries are defined on the domain boundary, while the internal boundary is defined inside the domain. More informations about the type of boundaries and their features can be found in the Reference Manual.

The stringdefs are listed as nodestring 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 and sediment 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 3.0, 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.

2.3 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*

Cell centered	**Nodestring**
Water surface elevation, water depth, bottom elevation, Chézy friction, delta_z, specific discharge, flow velocity, flow curvature, flow radius, flood tracking	Hydraulic and morphodynamic discharge

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 "output.xdmf" (see Figure 2.1) for the cell centered outputs or in a text format (.csv) for the nodestring output. The software ParaView enables to visualize the results stored in "output.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 (Pre-Processing) and to visualize simulation results (Post-Processing) the plugin BASEmesh for the free and open source geographic information system (GIS) software QGIS was developed.

BASEmesh is a QGIS plugin developed to generate triangulated computational grids for BASEMENT based on the advanced mesh generator Triangle by Jonathan R. Shewchuk (Shewchuk, 1996) as meshing algorithm. Currently, there are two versions of BASEmesh available. BASEmesh version 1.4.4 contains all the features including a workflow to generate large meshes for BASEMENT v3.x. This version of BASEmesh is supported up to QGIS version 2.18.28. BASEmesh 1.4.5 contains the same features as version 1.4.4 but is supported and tested for QGIS version 3.10 and newer.

The generation of a computational mesh compatible with BASEMENT version 3.0 is twofold and depends on the domain size and mesh resolution. For small meshes (< 10'000 - 50'000 cells), the procedure to create a computational mesh (2dm) using BASEmesh is the same as for 2D meshes in BASEMENT version 2.8 and the tutorials can be found either in Section 3.3.5 of BASEMENT User Manual version 2.8 or in the Tutorial 1 and 2 of the Pre-Processing section in the Tutorial Manual of version 2.8 available on www.basement.ethz.ch. For larger meshes, the creation of shapefiles during the usual procedure strongly slows down the meshing process. Therefore, the pre-processing for large meshes follows the a new procedure, which avoids the shapefiles generation of of the quality mesh.

3.2 Installation

BASEmesh is at present available on a specific Plugin repository which has to be connected manually in the QGIS plugin manager. In contrast to other plugins, it is not available via the official QGIS plugin repository which is set as default in every QGIS installation.

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

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

Figure 3.1 *Lines to add manually to the 2dm mesh file (orange)*

To install BASEmesh, follow these steps:

(1) Start QGIS

(2) Load the QGIS plugin manager by choosing *Manage and Install Plugins...* in the menu *Plugins* in the QGIS main toolbar

(3) Go to *Settings* (you should now see the connection to the official QGIS-plugin repository)

(4) Click on *Add...* and give a name, e.g. ‘BASEmesh repository’

(5) Enter the repository address: https://people.ee.ethz.ch/~basement/qgis_plugins/qgis_plugins.xml (do not copy paste this address, because it might include line breaks)

(6) Press *OK*

(7) The additional repository should now be visible (make sure that the *Status* is *connected*)

(8) Go to *All* in the menu of the plugin manager and search for ‘BASEmesh’

(9) Choose the BASEmesh plugin (if several are available, choose the one with the highest version number) and press *Install plugin*

3.3 Generation of small meshes

This section illustrates how a small computational mesh (<10’000-50’000 cells) can be generated for simulations in BASEMENT v3.0. The computational mesh is generated using the QGIS plugin BASEmesh in the exact same way as for BASEMENT version 2.8. The mesh generation process is described in detail in Section 3.3.5 of BASEMENT User Manual version 2.8 or in the Tutorial 1 and 2 of the Pre-Processing section in the Tutorial Manual of version 2.8 available on www.basement.ethz.ch. The computational mesh with the elevation information located at the mesh vertices is exported as a 2dm file and a separate stringdefs list is generated during this process. In order to use the 2dm file for simulations with BASEMENT v3.0, the stringdefs list and name have to be added manually at the end of the computational mesh (2dm) and saved under a new name (Figure 3.1). The modified 2dm file is the one used in simulation with BASEMENT v3.0.

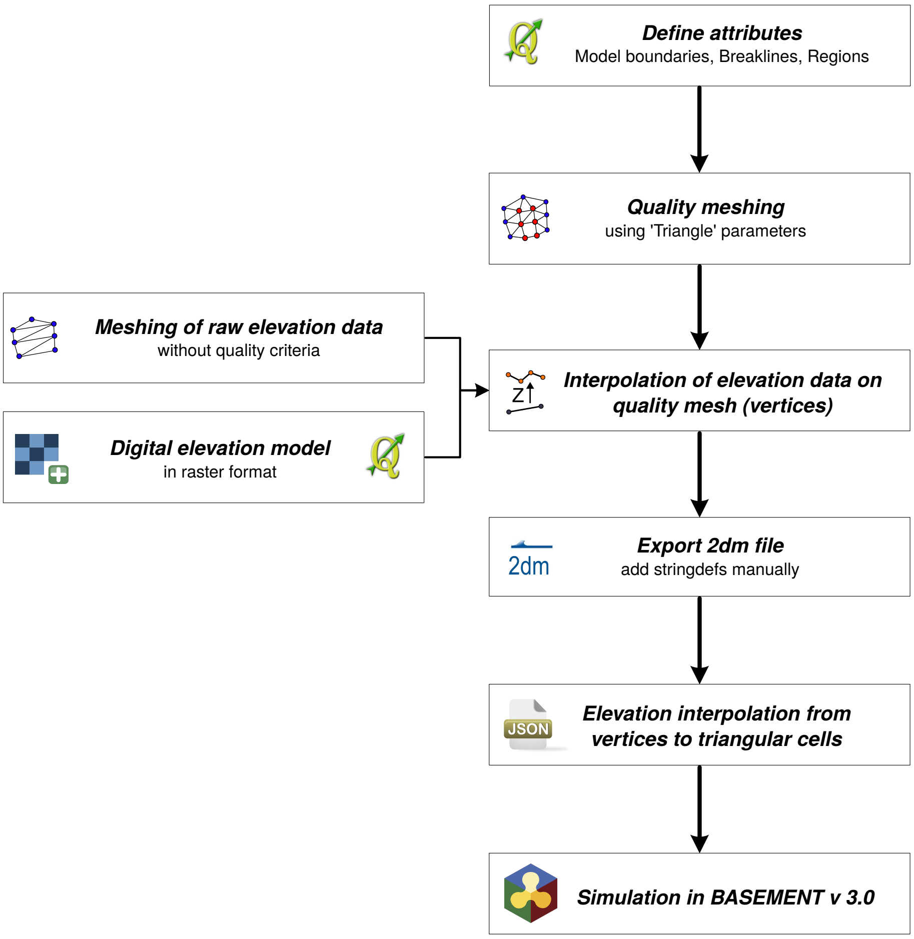

Figure 3.2 *BASEmesh workflow for small meshes and adaptations required in the 2dm and executable (.json) files for the simulation with BASEMENT v3.0*

The elevation information is saved on the mesh vertices and needs to be interpolated to obtain one uniformly distributed elevation information allocated to the corresponding cell. The interpolation method (mean, median, maximum, minimum or weighted) is selected inside the GEOMETRY block of the configuration file model.json.

```
"GEOMETRY": {
    "mesh_file": "Flaz_mesh.2dm",
    "INTERPOLATION": {
        "method": "weighted"
    }
```

More details concerning the elevation interpolation methods are given in the case example of the Migration Guide. Figure 3.2 shows the BASEmesh workflow for small meshes with the transformations required for numerical simulations with BASEMENT v3.0. The procedure for small meshes enables to use existing computational meshes of BASEMENT version 2.x (.2dm) into BASEMENT version 3.x following the two last steps of Figure 3.2.

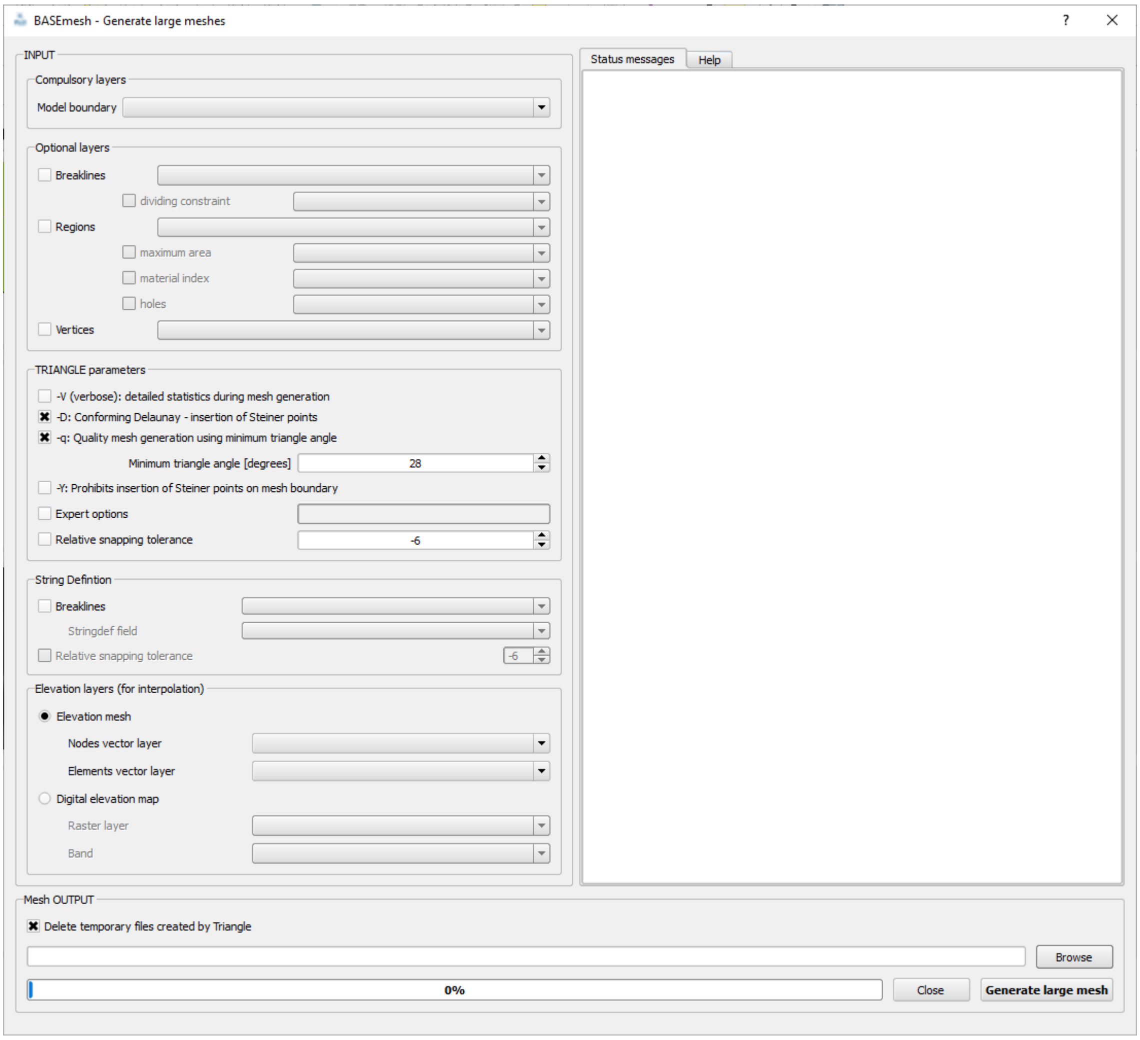

Figure 3.3 *The generation of large meshes can be done with the new procedure in BASEmesh 1.44.*

3.4 Generation of large meshes

During the quality meshing process, the BASEmesh plugin generates shape files that are significantly slowing down the procedure in case of large meshes. Therefore, a new procedure was developed to generate large computational meshes, which skips the generation of shape files. This new procedure for large mesh is available in BASEmesh versions 1.4.4 (up to QGIS version 2.18.28) and 1.4.5 (from QGIS version 3.10 and newer) under the button "XL Mesh" and combines the steps of quality meshing, elevation interpolation, nodestring definition and mesh export. The graphical user interface of the "XL Mesh" procedure is illustrated in Figure 3.3. The resulting meshes are directly compatible with BASEMENT version 3.x.

The general procedure to obtain the .2dm mesh file remains mostly the same. Be aware that all the attributes (elevation data, breaklines, points defining the regions, stringdefs,...) should be defined before starting the large mesh generation.

The computational mesh is generated with Jonathan Richard Shewchuk's excellent unstructured 2D-mesh generator TRIANGLE (Shewchuk, 1996) and requires the specification of all geometric information about the computational domain:

- *Model boundary*: extent of the computational domain.
- *Breaklines*: distinct interruptions of the surface slope (dyke crest, river side walls, ...) which shall be preserved in the computational mesh.
- *Regions*: distinct regions of the mesh surrounded by breaklines, which can be characterized by a material index (matID) and maximum triangle area, or can be specified as a hole in the mesh.
- *Holes*: parts within the mesh which are excluded from modelling (e.g. buildings). These parts are defined by special points (layer region_points) surrounded by breaklines.
- *Vertices*: enforced geometric points in the mesh (e.g. measurement points).

Further, the mesh quality can be influenced by the "TRIANGLE parameters". It is important to keep in mind, that the quality of the computational mesh influences the results of your numerical analysis, e.g. stability, computation time, accuracy, etc. Parameters of major importance are:

- *Maximum area* constraints: definition of the mesh density using *maximum area* contraints for the triangular mesh elements. The *maximum area* is defined as attribut in the layer region_points and holds for a specific *Region* surrounded by breaklines.
- *Dividing constraints*: With this attribut in the layer *Breaklines* one can enforce a certain number of mesh elements along a breakline. This is of major importance for the use of inner boundaries in BASEMENT, where an equal number of mesh elements at the uptream and downstream interface is required.
- *Minimum triangle angle*: no elements with angles smaller than the minimum angle specified are generated (smaller angles lead to less elements, while larger angles lead to more elements).
- *Relative snapping tolerance*: defines, how far two point coordinates may be located apart to still be considered at the same location. The default value is 10E-6. Increasing this tolerance can help to avoid problems due to improper snapping of vertices (line or polygon features) and points in OGIS.

In BASEMENT a list of node IDs is defined as *stringdef* or *nodestring*. They can be defined on the basis of breaklines with a *stringdef* attribute and can be used to define a boundary condition or an output along these nodes. The IDs correspond to the node IDs of the computational mesh. In comparison to the Stringdef tool, the defined stringdefs are added at the end of the .2dm mesh file with the tag "NS" for Nodestring and are **not** written in a separate file. 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.

Finally, topographical information contained in the elevation model be be interpolated on the computational mesh, i.e. an elevation value is assigned to each node of the computational grid. As a result, the final computational mesh is obtained, which is then exported and can be used for simulations. The elevation data serving as input can be provided in two different elevation model types:

1. *Elevation mesh* triangulated from pointwise elevation data (TIN). The routine identifies the coordinates of each quality mesh node and determines any underlying elevation mesh element. Two methods are used for data interpolation:

   a) If an underlying elevation mesh element is found, the elevation of the quality mesh node is interpolated at its x-y-coordinates. This is the normal case, since the elevation mesh usually covers the whole computational domain. Nodes interpolated with this method are marked by a 1 in the element - field of the node attribute table. If the quality mesh node is located at the exact coordinates of an elevation mesh node, its height value is preserved exactly.

   b) If no underlying elevation mesh element is found, the quality node elevation is set to that of the nearest node of the elevation mesh. This is the case if quality mesh nodes lie outside the domain covered by the elevation mesh or when holes are present in the elevation mesh. It may lead to incorrect quality mesh ndoe elevations. Hence, it is recommended to choose a bigger domain for elevation meshing than for quality meshing. Nodes interpolated this way are marked by a 0 in the element - field of the result attribute table and are named 'with special treatment' in the QGIS status messages.

2. *Digital elevation map* as raster data which contains the topography as DTM. The raster elevation data is directly mapped on the computational mesh nodes without interpolation. If no corresponding raster cell is found, the elevation is set to '-9999'.

Be aware that the interpolation process can be time consuming.

The mesh is automatically exported in the .2dm format in the specified directory. During the meshing process temporary files are generated. These can be automatically deleted by checking the box "Delete temprary files created by Triangle".

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

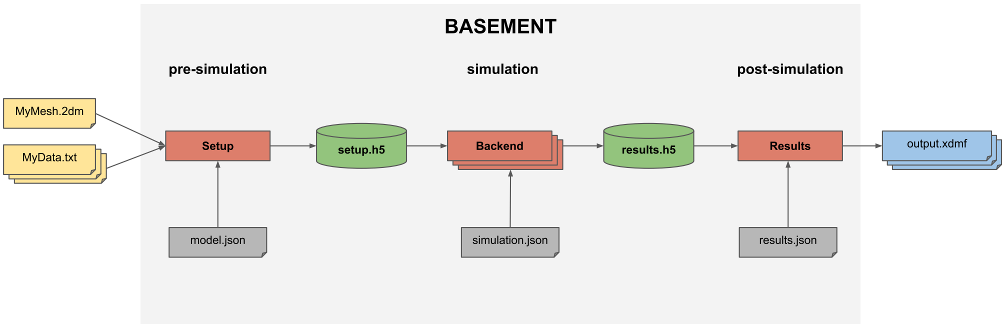

Figure 4.1 *BASEMENT simulation workflow*

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 and its location in the folder have to be specified. If a computational mesh of BASEMENT version 2.x is used, the elevation interpolation method has to be defined. The stringdefs are listed by their name and the upstream flow direction should be indicated as either left or right (see the Numerical Approximation section in the Reference Manual). The regiondefs are also listed by name with the area index as parameter.

The hydraulics block contains the information about the initial conditions (dry, continue, index), the parameters (CFL, minimum water depth,. . .), the boundary conditions, friction values, external sources and flood tracking. The boundary conditions are defined by giving the corresponding stringdef name and the required type (standard, linked or internal). The friction type is assigned to the different domains (regiondef), as for external sources and flood tracking if required.

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 could be activated in order to influence the bedload transport direction.

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 discharge, calculated at flow boundaries.

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 is available for extracting the stringdefs results (discharge) stored in the results.h5 binary and converts them in a text format (.csv).

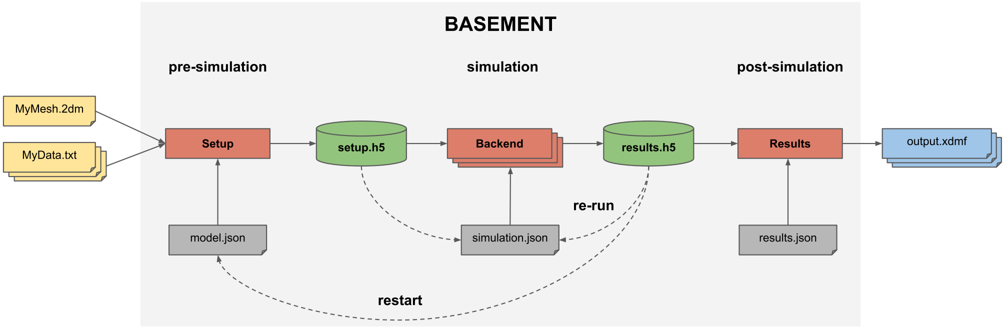

Figure 4.2 *BASEMENT simulation workflow with restart and re-run processes*

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.

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.

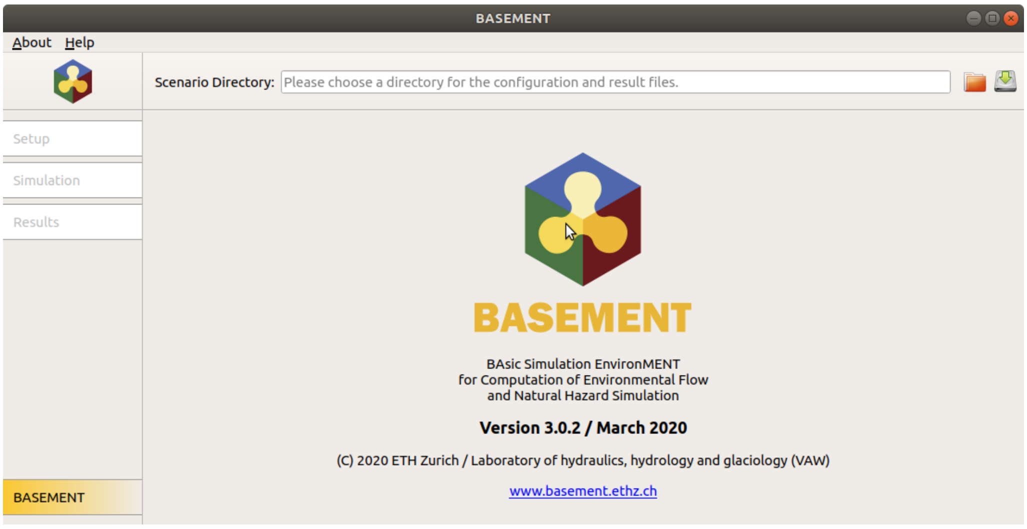

Figure 5.1 *Welcome Screen*

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).

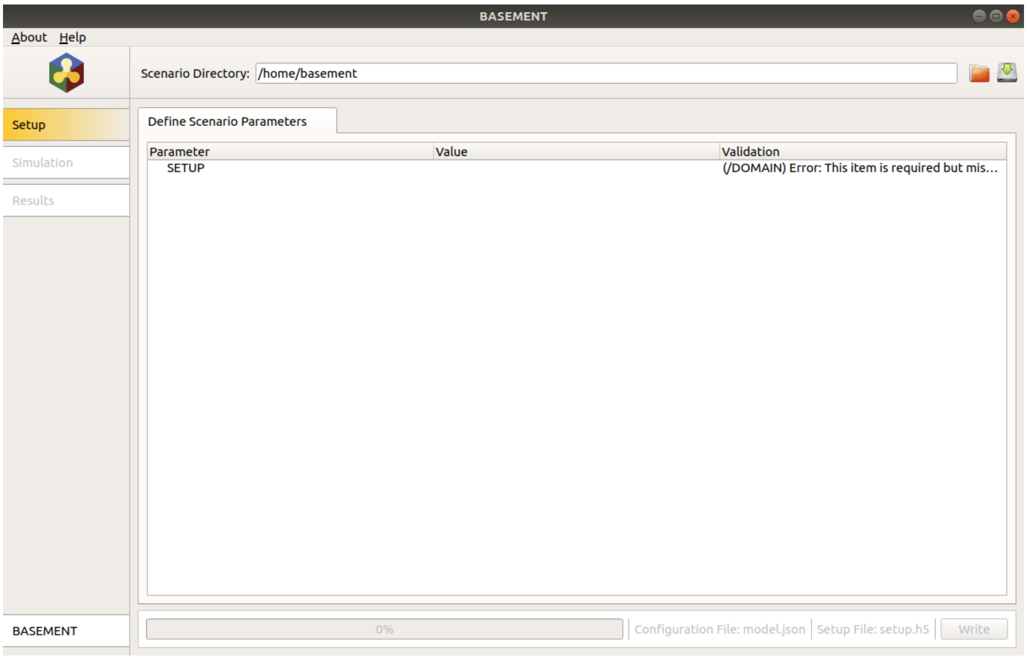

Figure 5.2 *Setup Screen*

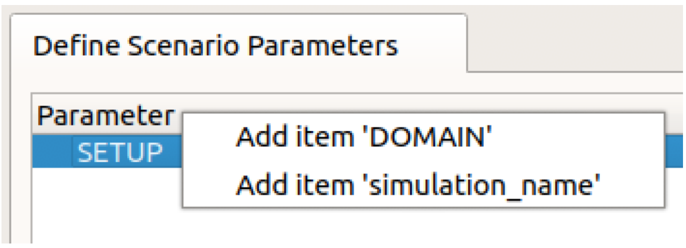

Figure 5.3 *Adding JSON Items*

Figure 5.4 *File Name Editor*

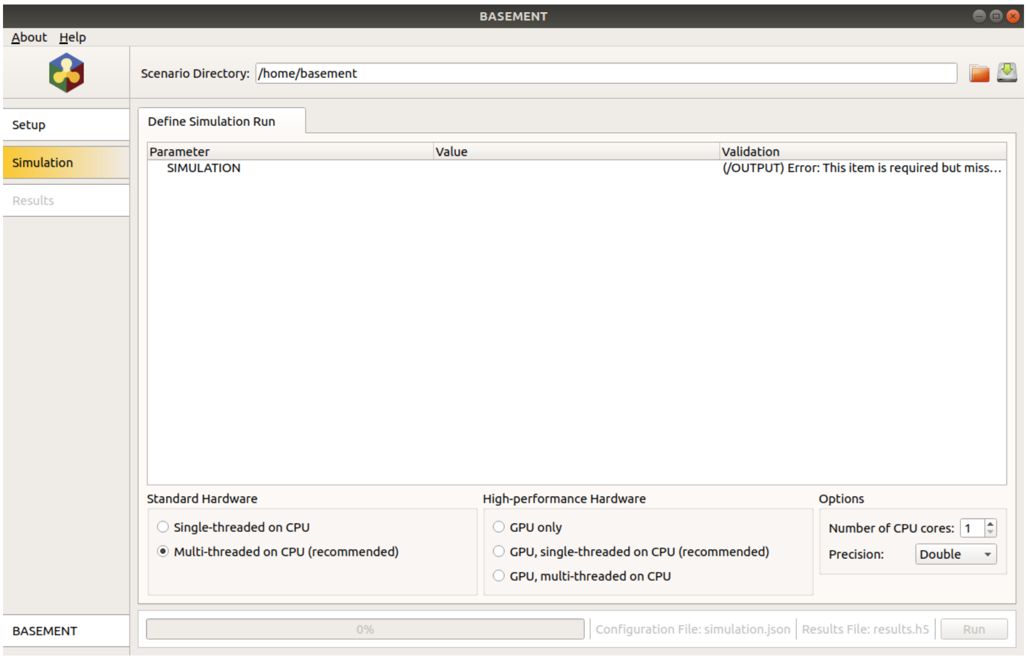

Figure 5.5 *Simulation Screen*

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.

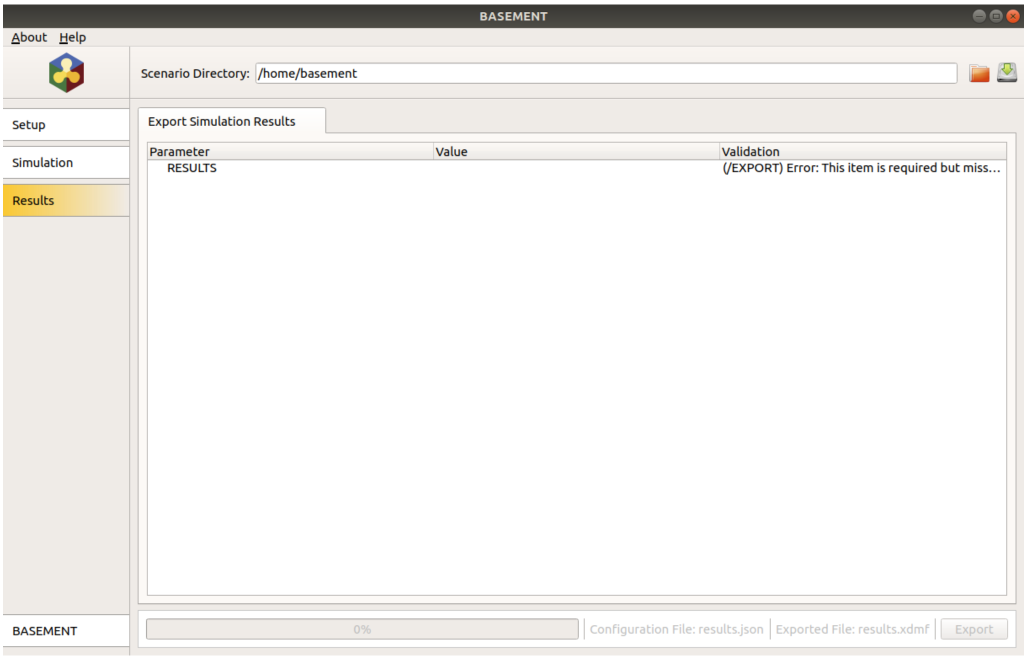

Figure 5.6 *Results Screen*

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)\BASEMENTv3.0" 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 3.0.2"\bin\BMv3_BASEplane_setup.exe
      -f F:\Project_1\model.json
      -o F:\Project_1\mySim_run.h5

C:\"Program Files\BASEMENT 3.0.2"\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\BASEMENT3.0.2"\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\BASEMENT3.0.2"\bin\BMv3_BASEplane_setup.exe
      -f F:\Project_1\model.json
      -o F:\Project_1\mySim_run.h5

"C:\"Program Files\BASEMENT3.0.2"\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\BASEMENT3.0.2"\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\BASEMENT3.0.2"\bin\BMv3_BASEplane_setup.exe
      -f F:\Project_2\model.json
      -o F:\Project_2\mySim_run.h5

"C:\"Program Files\BASEMENT3.0.2"\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\BASEMENT3.0.2"\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

Shewchuk, J.R. (1996). Triangle: Engineering a 2D Quality Mesh Generator and Delaunay Triangulator. *Applied computational geometry: Towards geometric engineering*, *Lecture notes in computer science*, Lin, M.C. and Manocha, D. eds., No. 1148: 203–222. *Springer-Verlag*,

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

APPENDIX

VERSION 3.0
September 2019

1

Third Party Software

1.1 Third party software copyright notices

Abseil

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Bzip2

```
This program, "bzip2", the associated library "libbzip2", and all
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DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE
GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS
```

Double-conversion

Egl-registry

Freetype

```
The contributed BDF and PCF drivers  come with a license similar to that
of the X Window System.  It is compatible to the above two licenses (see
file src/bdf/README and  src/pcf/README).  The same holds  for the files
`fthash.c' and  `fthash.h'; their  code was  part of  the BDF  driver in
earlier FreeType versions.

The gzip module uses the zlib license (see src/gzip/zlib.h) which too is
compatible to the above two licenses.

The MD5 checksum support (only used for debugging in development builds)
is in the public domain.
```

Glibc-queue

Google Test

Harfbuzz

HDF5

HighFive

JSON for Modern C++

Libjpeg-turbo

```
libjpeg-turbo Licenses
======================

libjpeg-turbo is covered by three compatible BSD-style open source licenses:

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  [README.ijg](README.ijg)

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  well as the build system.

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=========================================

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===================

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desirable to choose a license that granted us the same protections for new code
that were granted to the IJG for code derived from their software.
```

Libpng

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```

```
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---------------------------------------

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```
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-------------

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The basic library functions are written in C and are freestanding. Also
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optimize pattern matching. This is an optional feature that can be omitted when
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THE BASIC LIBRARY FUNCTIONS
---------------------------

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Email domain:     cam.ac.uk

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Jean-loup Gailly        Mark Adler
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```

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