Flash Flood Modeling using TELEMAC-2D

Workshop (240min)

Athens, 6.9.2022

1. **Introduction (10 min)**
    - Aims of the workshop
    - Hydrological and hydrodynamic modeling

2. **The TELEMAC-approach (10 min)**
    - Community
    - OpenSource-development
    - Software-Suite: openTELEMAC-MASCARET

3. **Basics of Hydrodynamic Modeling (30 min)**
    - Basic equations
    - SWE-formulation
    - Modules
    - Model parameters
    - Steering parameters
    - Output options
    - Parallelization

10 minutes break

4. Tools (10 min)

1. BlueKenue (Pre- und Postprocessing)
2. Salome-Hydro (Pre- und Postprocessing)
3. Gmsh (Preprocessing)
4. PPUTILS / Python (Pre- und Postprocessing)
5. Matlab [telhead/telstep] (Pre- und Postprocessing)
6. QGIS [PostTelemac] (Postprecessing)

5. Data structure of TELEMAC-2D (40 min)

- Parameter-file (*.cas)
- Boundary definition files (*.bc2, *.cli, *.liq)
- Geometry-file (*.slf) [topography, roughness, CN-values]
- Initial condition file (*.slf)
- Control section (*.dat)
- Precipitation file (*.txt)
- User defined Fortran-files (*.f)
- Culvert data file (*.txt)
- Output data files (*.slf, *.dat)

- Parameter-file WAQTEL (*.cas)

10 minutes break

6. **Using TELEMAC-2D (30 min)**
    - Installation und compilation of TELEMAC-2D
    - Program start (Windows: *.bat, Linux: *.sh)
    - Partitioning of data
    - Examples for TELEMAC-2D (Malpasset, Pluie, SpatRain)
    - Demonstration of Triftern Flash Flood example

7. **Exercise (85 min)**
    - Set-up your own TELEMAC-2D model
    - Run your first TELEMAC-2D model

8. **Closure (5 min)**

1. Introduction

1. Introduction

Aim of this course:

- General introduction to hydrodynamic modelling using the opensource software TELEMAC-2D

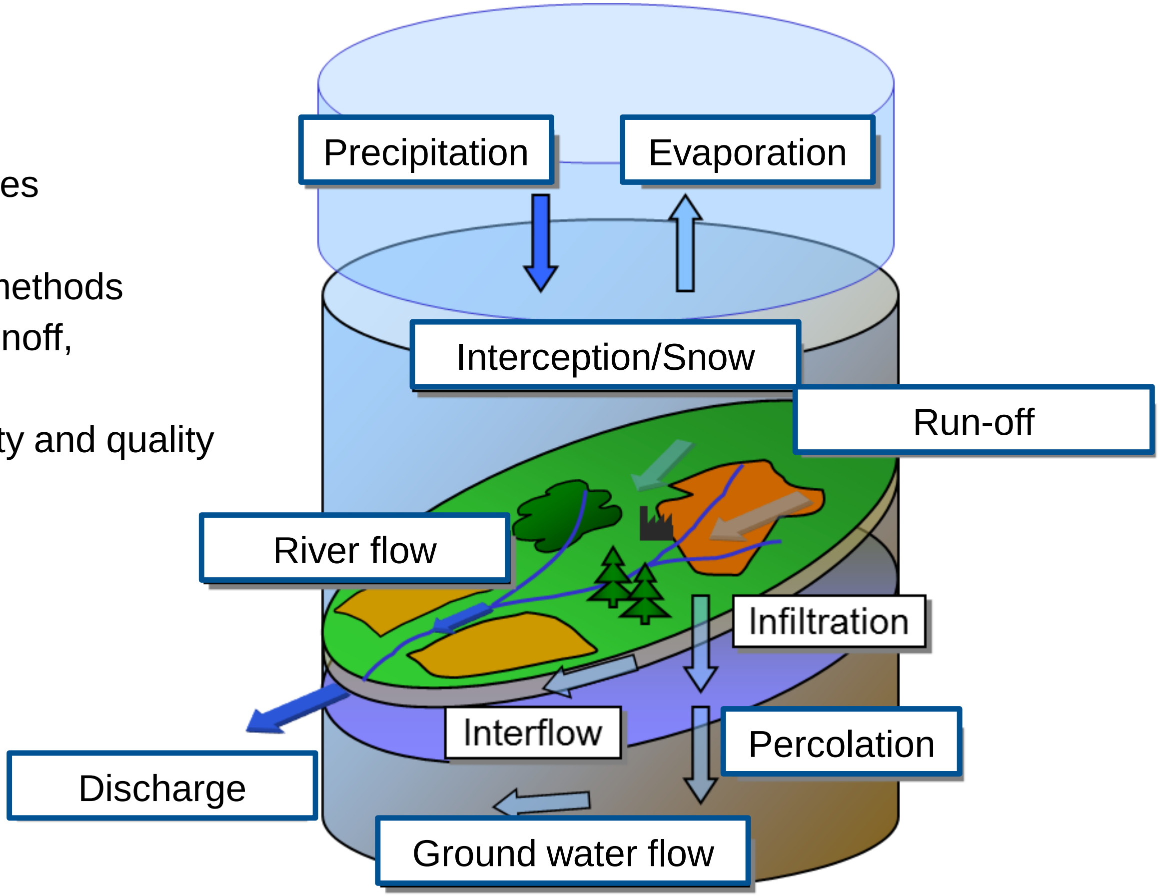
Additional aims:

- Demonstration of the advantages using open-source software in science
- Demonstration of the benefits of High Performance Computing HPC
- Introduction to HydroDynamic Rainfall Runoff Modelling (HDRRM)

1. Introduction

Hydrological modeling

- Hydrological cycle
- Hydrological processes of land surfaces
- Calculation of the water balance
- Development of hydrological design methods
- Hydrological forecasts (water level, runoff, groundwater recharge)
- Investigation of changes in the quantity and quality of water resources



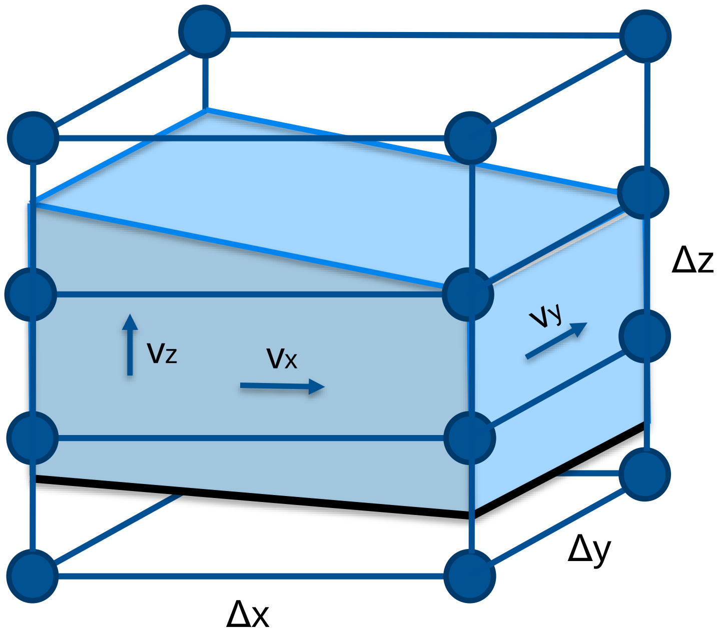
3 basic processes: **flow creation – flow concentration – flood routing**

1. Introduction

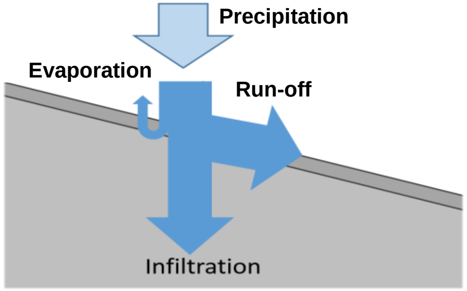
Hydrodynamic modeling

- Calculation of water flow

➡ Just <u>one</u> process considered!



Note:
For overland flow a significant amount of run-off is needed.



2. The TELEMAC-approach

2. The TELEMAC-approach

Software:

- Open-source-Software
- Full Shallow Water Equation (SWE)
- Finite Element oder Finite Volume
- Implicit fixed time stepping or variable CFL-stepping

Consortium:

- Artelia (France)
- Bundesanstalt für Wasserbau (BAW, Germany)
- Centre d’Etudes et d'Expertise sur les Risques, l'Environnement, la Mobilité et l'Aménagement (CEREMA, France)
- Daresbury Laboratory (Great Britain)
- Electricité de France R&D (EDF, France)
- HR Wallingford (Great Britain)

Modules:

- MASCARET 1: 1D Free surface - model
- **TELEMAC-2D: 2D Free surface - model**
- TELEMAC-3D: 3D Free surface - model
- SISYPHE: Sedimenttransport model
- TOMAWAC: Wavepropagation in coastal areas
- ARTEMIS: Wavepropagation in harbors

2. The TELEMAC-approach

Open-source-Software:

- The TELEMAC-software is available free of charge.
- The TELEMAC-software can be used without time restriction.
- The TELEMAC-software can be modified by the user.
- The user of TELEMAC-software should quote the usage properly.
- The user should pass back enhancements to the developer community (consortium).

3. Basics of hydrodynamic modeling

Physics & Mathematics

How to model this ?

Physics & Mathematics

Partial Differential Equations (PDE)

Navier-Stokes Equations (3D)

Euler Equations (3D)

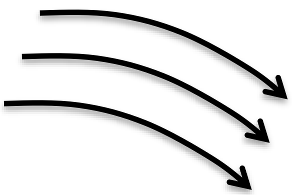
Shallow Water Equations (2D)

Shallow Water Equations (1D)

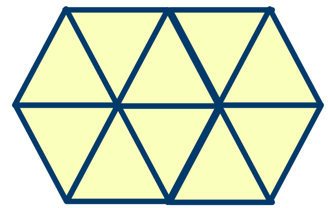
3. Basics

Physics & Mathematics

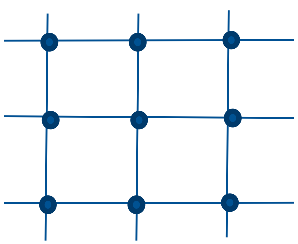
PDE – Solver in space



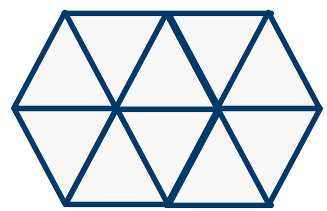
Method of Characteristics



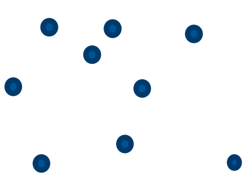
Finite Element Method FEM



Finite Difference Method FD



Finite Volume Method FV



Particle Models (f.i. LBM)

Physics & Mathematics

PDE – Solver in time

implicit → Free time stepping

explicit → Restricted time stepping

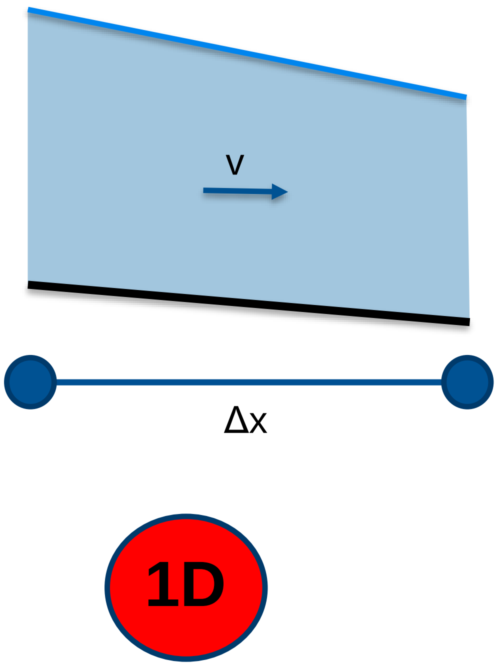
Physics & Mathematics

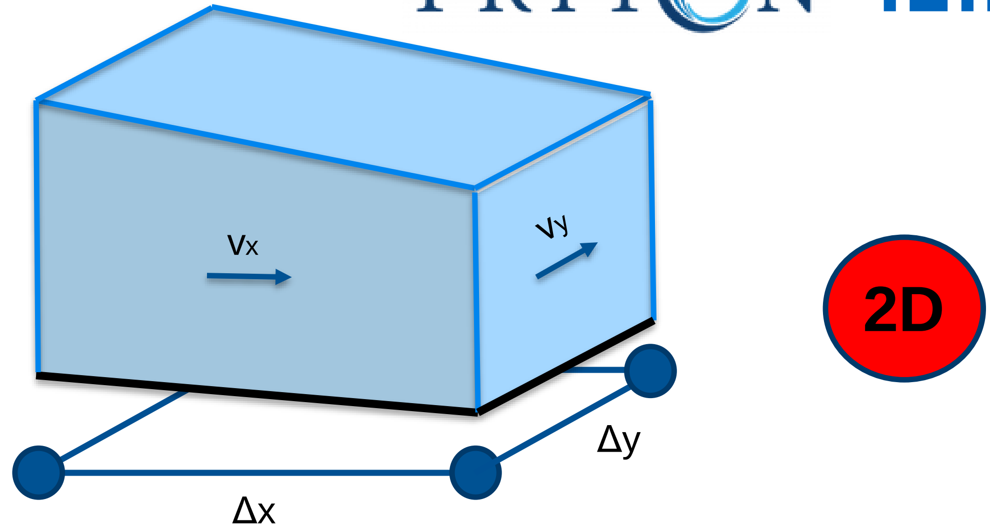
PDE – Shallow water equation SWE

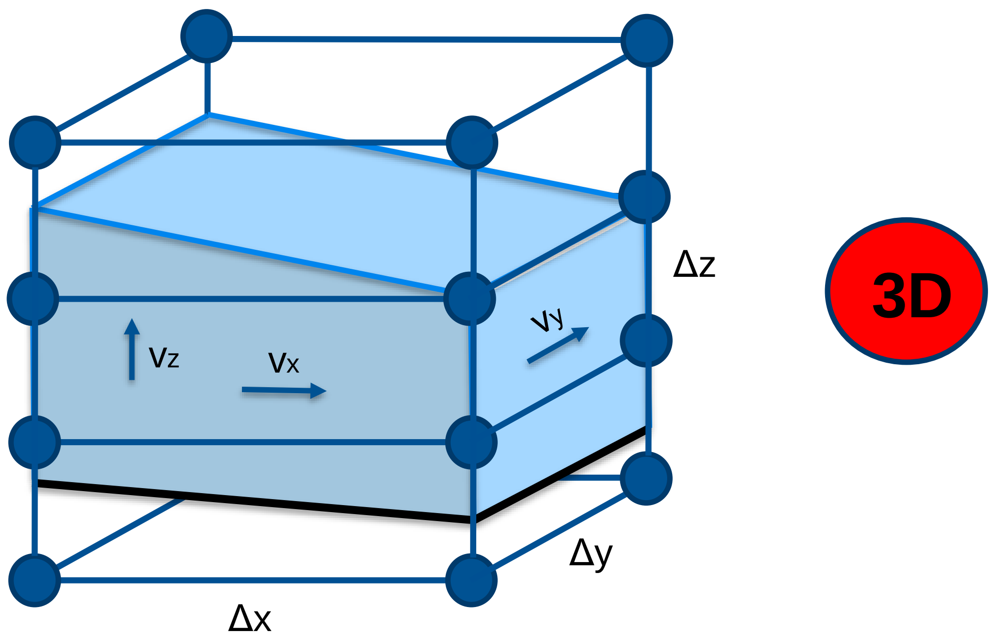
Number of calibration factors → Just Roughness !!!

3. Basics

1D – 2D – 3D





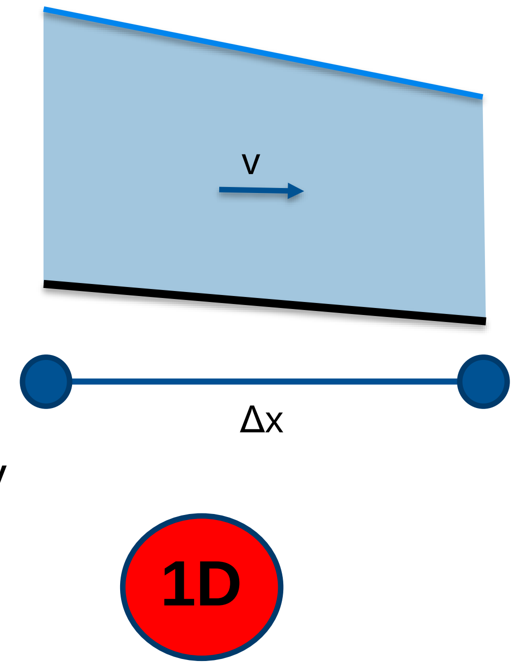


3. Basics

1D – 2D – 3D

Problems in 1d-simulation

- Non-linearity of shallow water equations
- Hydraulic jumps
- No representation of flooding and drying of areas
- No representation of full spatial variablility of topography
- No representation of buildings
- Difficult representation of bridges
- Difficult representation of junctions
- No representation of lateral waterlevel gradient

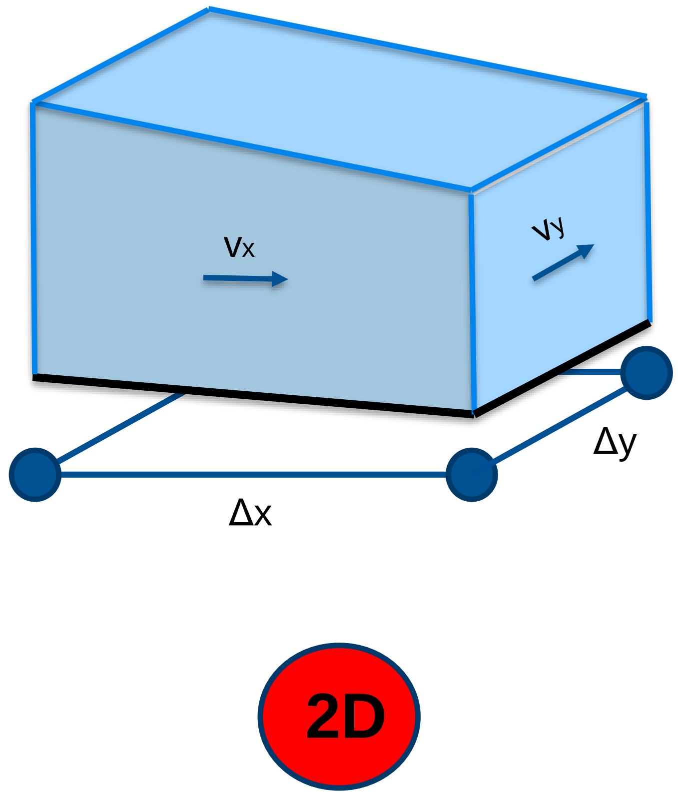


3. Basics

1D – 2D – 3D

Problems in 2d-simulation

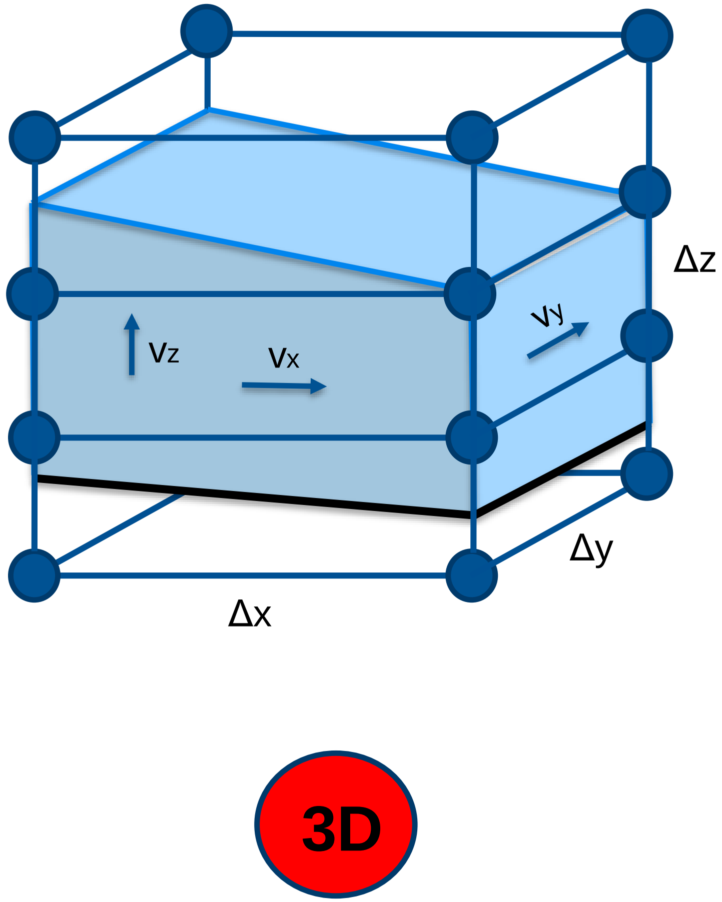
- Non-linearity of shallow water equations
- Hydraulic jumps
- Flooding and drying of areas
- Discretization of variable topography
- Discretization of buildings
- Discretization of bridges



1D – 2D – 3D

Problems in 3d-simulation

- High effort for mesh generation
- High computional effort needed
- Not used in hydrology



Equations used in hydrodynamics

Conservation of mass

Conservation of energy

} ~~**Bernoulli**~~

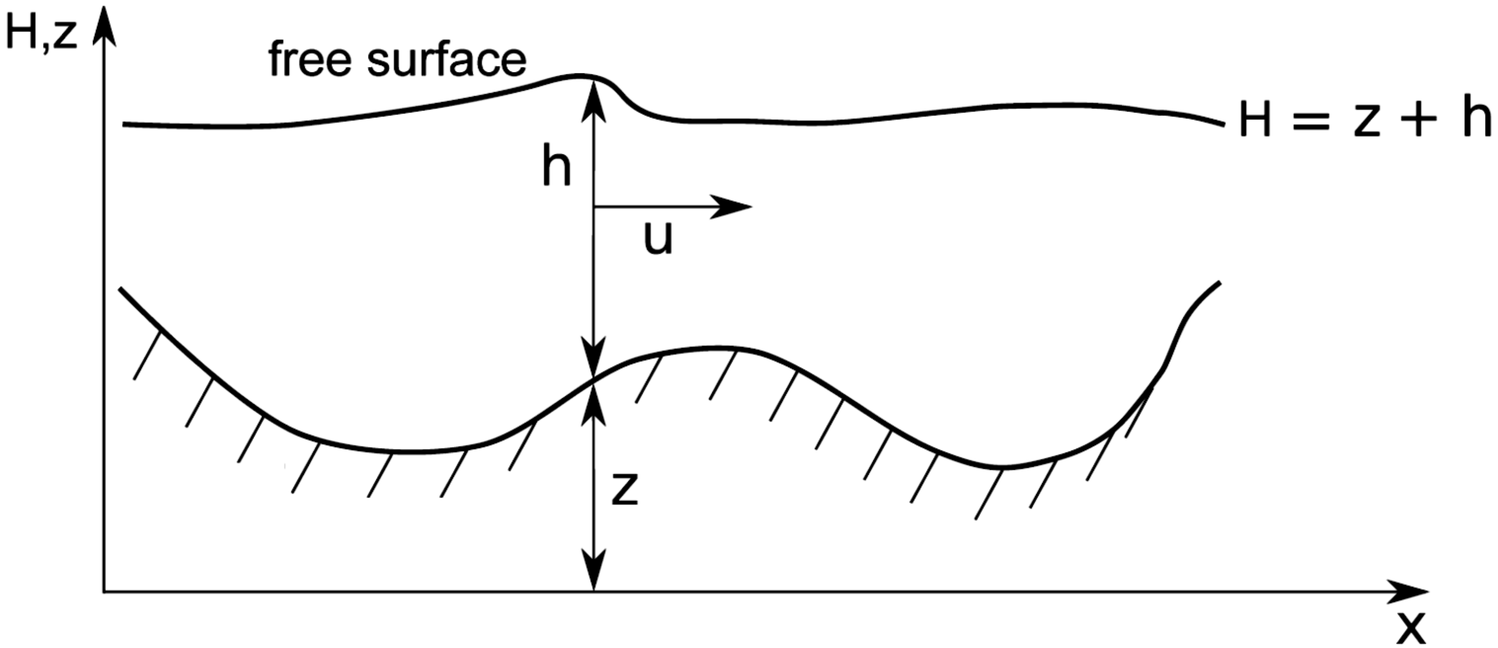
Conservation of mass

Conservation of momentum

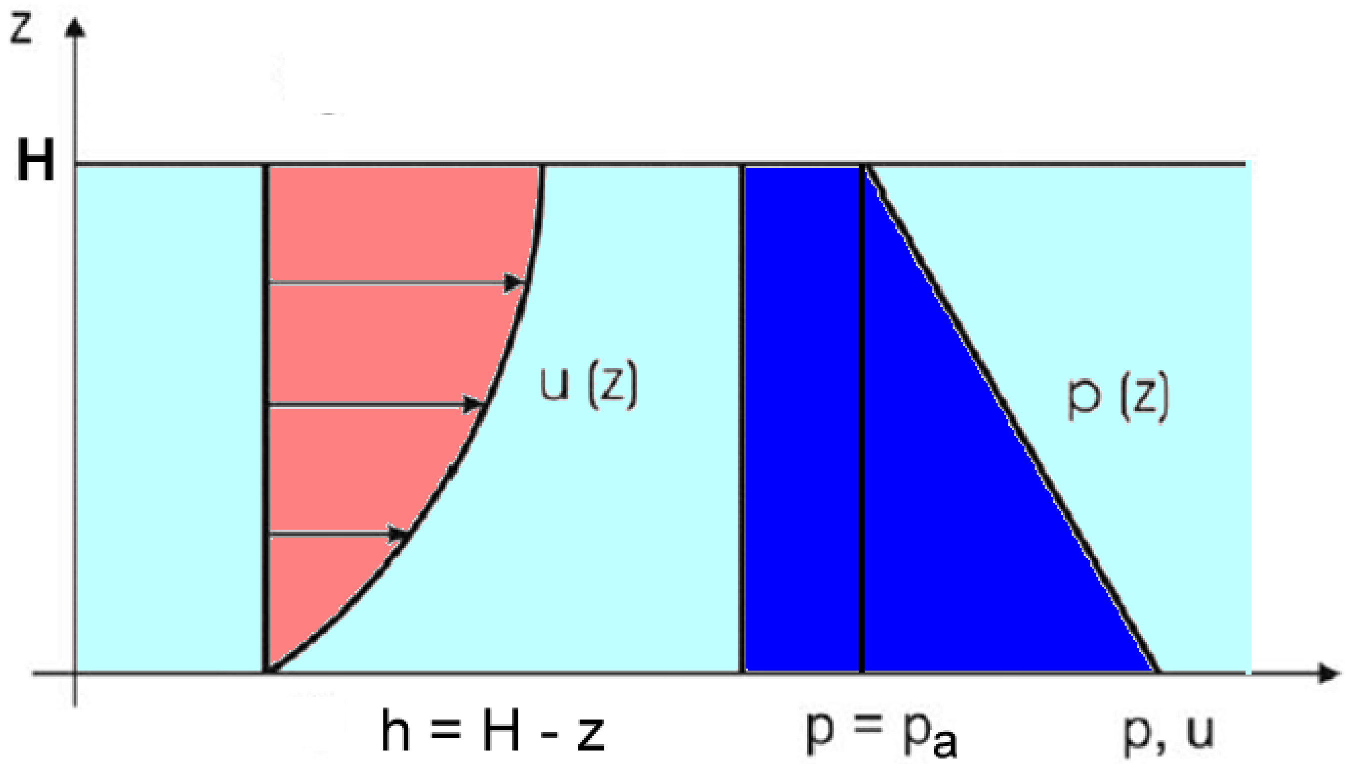
} **Navier-Stokes, St. Venant**

Note: St. Venant Equations = Shallow Water Equations

Derivation of Shallow Water Equations



Derivation of Shallow Water Equations



Hydrostatic pressure

$$p = \rho\, g\, (H - z) + p_a$$

Derivation of Shallow Water Equations

Primary assumption in shallow water theory

Horizontal scales (wave length l) are much larger, than vertical scales (undisturbed water heigth h) . Thus vertical accelarations can be neglected.

$$\Rightarrow \quad \frac{h}{l} \ll 1 \quad \Rightarrow \quad \frac{dw}{dt} = 0$$

Secondary assumption in shallow water theory

For pressure the linear hydrostatic pressure distribution holds. Thus the Right hand side pressure terms simplify.

$$\Rightarrow \quad p = \rho\, g\,(H - z) + p_a$$

Note: Air pressure p_a can be neglected.

Third assumption in shallow water theory

The velocities are constant with depth. Thus the equations can be integrated along z and be written in conservative form.

Derivation of Shallow Water Equations

Mass continuity in conservative form

$$\frac{\partial}{\partial t} h + \frac{\partial}{\partial x}(hu) + \frac{\partial}{\partial y}(hv) = 0$$

Conservation of momentum in conservative form

$$\frac{\partial}{\partial t}(hu) + \frac{\partial}{\partial x}\left(hu^2 + \frac{1}{2} g h^2\right) + \frac{\partial}{\partial y}(huv) = - g h \frac{\partial}{\partial x} b$$

$$\frac{\partial}{\partial t}(hv) + \frac{\partial}{\partial x}(huv) + \frac{\partial}{\partial y}\left(hv^2 + \frac{1}{2} g h^2\right) = - g h \frac{\partial}{\partial y} b$$

h : Water heigth
u, *v* : Depth-averaged velocity in x- and y-direction
b : Function describing the bottom profile

Final Form I of Shallow Water Equations

SWE I

$$\frac{\partial}{\partial t} h + \frac{\partial}{\partial x}(hu) + \frac{\partial}{\partial y}(hv) = 0$$

$$\frac{\partial}{\partial t}(hu) + \frac{\partial}{\partial x}(hu^2 + \frac{1}{2} g\, h^2) + \frac{\partial}{\partial y}(huv) = -g\, h \frac{\partial}{\partial x}(b-r)$$

$$\frac{\partial}{\partial t}(hv) + \frac{\partial}{\partial x}(huv) + \frac{\partial}{\partial y}(hv^2 + \frac{1}{2} g\, h^2) = -g\, h \frac{\partial}{\partial y}(b-r)$$

h : Water height
u, v : Depth-averaged velocity in x- and y-direction
b : Function describing the bottom profile
r : Function describing friction losses

Final Form II of Shallow Water Equations (vector form)

SWE II

$$\frac{\partial \mathbf{w}}{\partial t} + \frac{\partial \mathbf{f}}{\partial x} + \frac{\partial \mathbf{g}}{\partial y} = \mathbf{s}$$

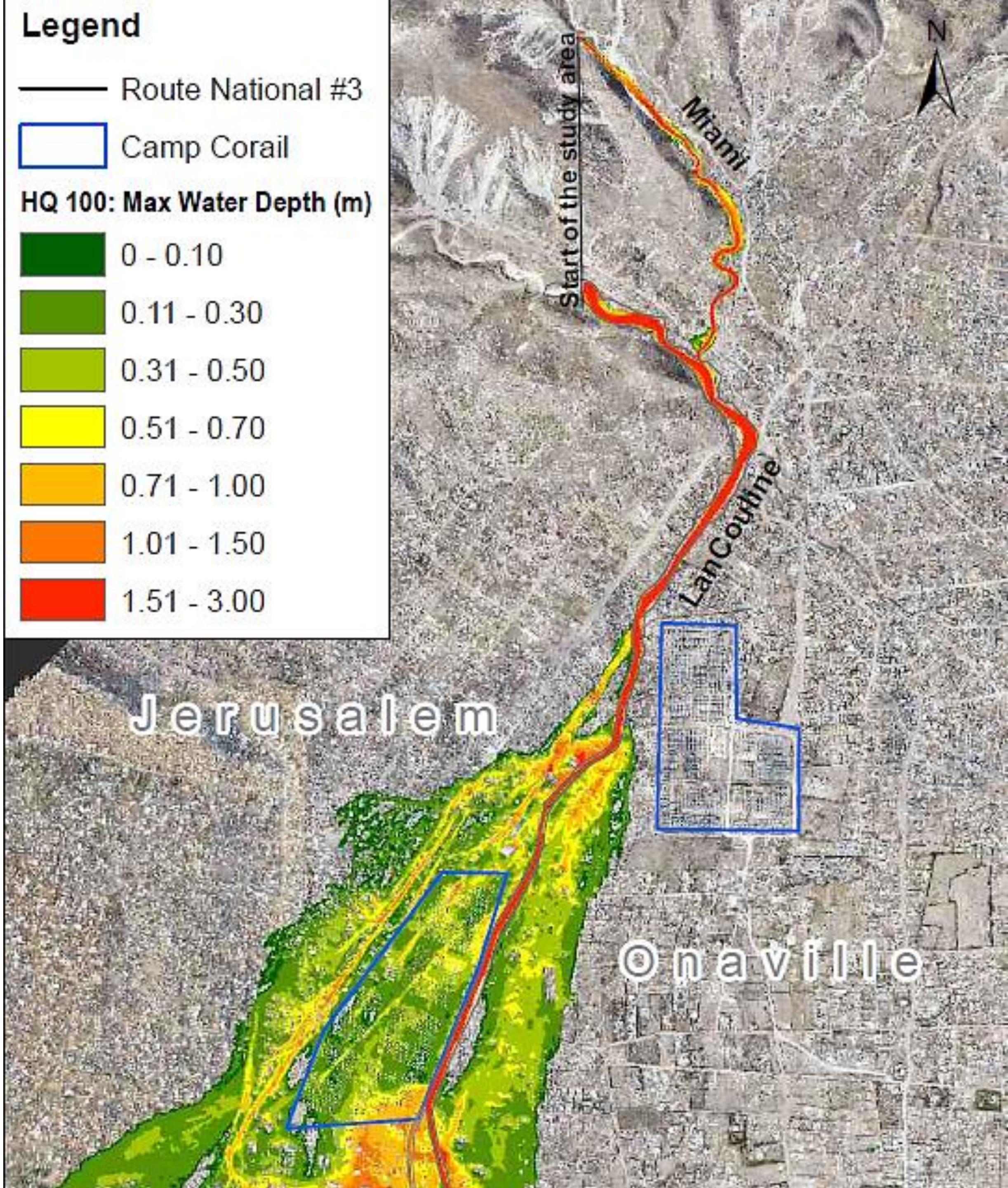
$$\boldsymbol{w} = \begin{bmatrix} H \\ uh \\ vh \end{bmatrix} \qquad \boldsymbol{f} = \begin{bmatrix} uh \\ u^2 + 0.5gh^2 - \mathrm{v}h\frac{\partial u}{\partial x} \\ uvh - \mathrm{v}h\frac{\partial v}{\partial x} \end{bmatrix}$$

$$\boldsymbol{s} = \begin{bmatrix} 0 \\ gh(I_{Rx} - I_{Sx}) \\ gh(I_{Ry} - I_{Sy}) \end{bmatrix} \qquad \boldsymbol{g} = \begin{bmatrix} vh \\ uvh - \mathrm{v}h\frac{\partial u}{\partial y} \\ v^2 + 0.5gh^2 - \mathrm{v}h\frac{\partial v}{\partial y} \end{bmatrix}$$

Note: This formulation is used in the Hydro_AS-2d-manual.

3. Basics

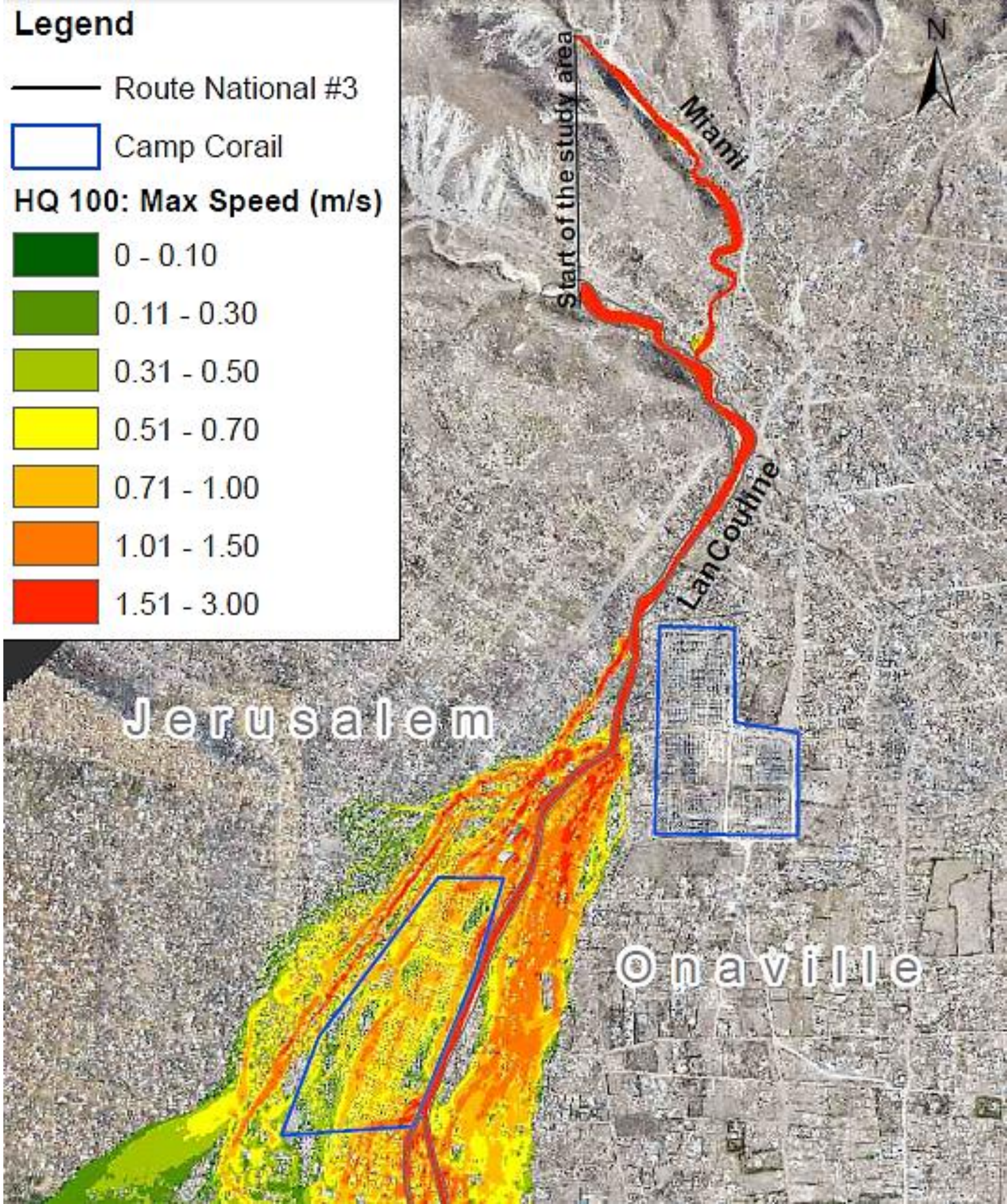
1D – 2D – 3D



Krötzinger, 2015

3. Basics

1D – 2D – 3D



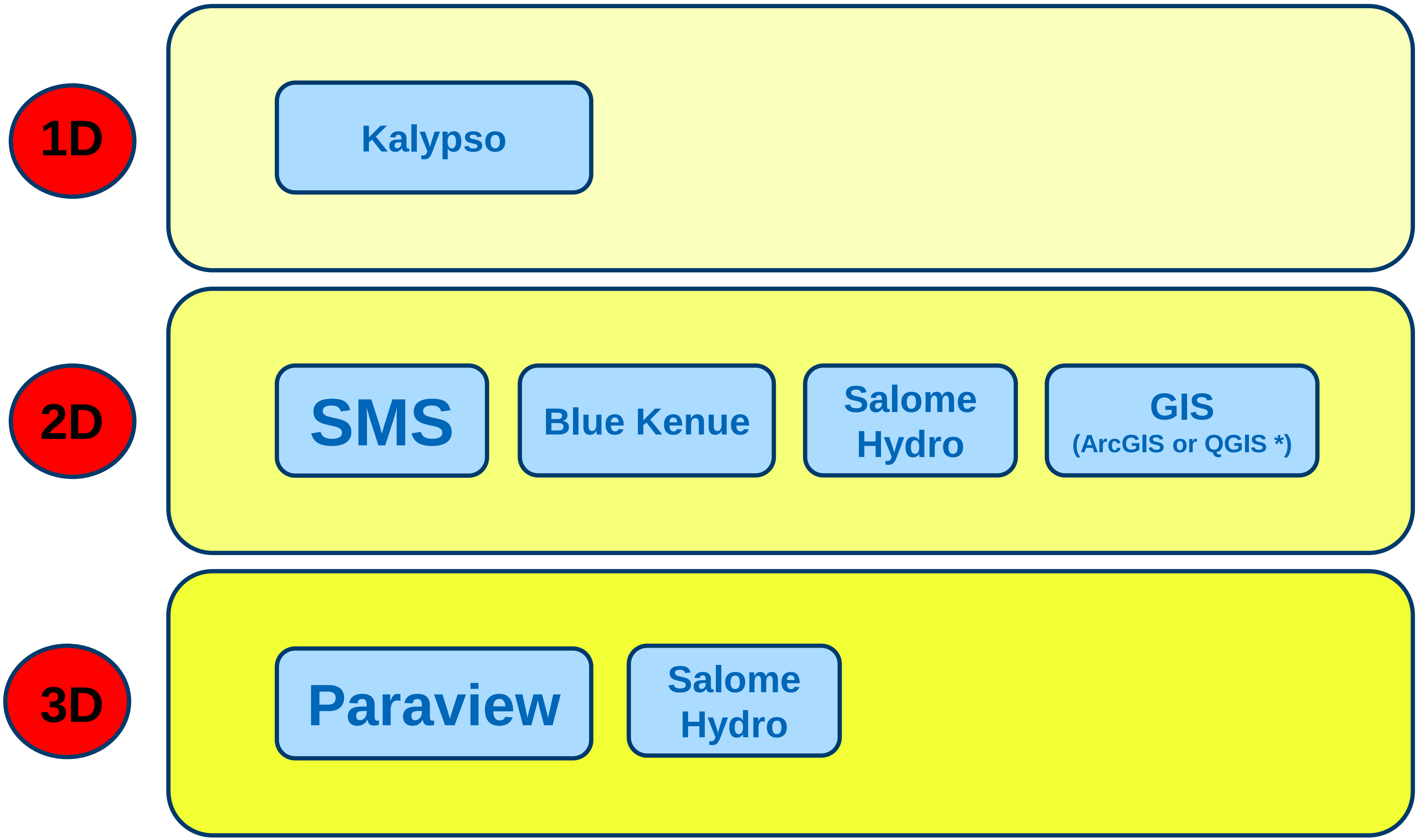
Krötzinger, 2015

TRITON TUM

HD-Model Overview

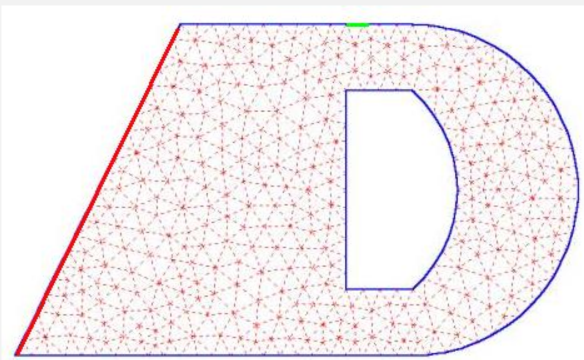
1D	MIKE11	SWMM	Mascaret
2D	MIKE21	HYDRO_AS-2D	TELEMAC-2D
3D	FLOW3D	TELEMAC-3D	

Pre/Postprocessor Overview



3. Basics

Workflow



Define the outline

Build the net

Define the boundary conditions

Define structures (internal boundary conditions)

Define the nodal conditions

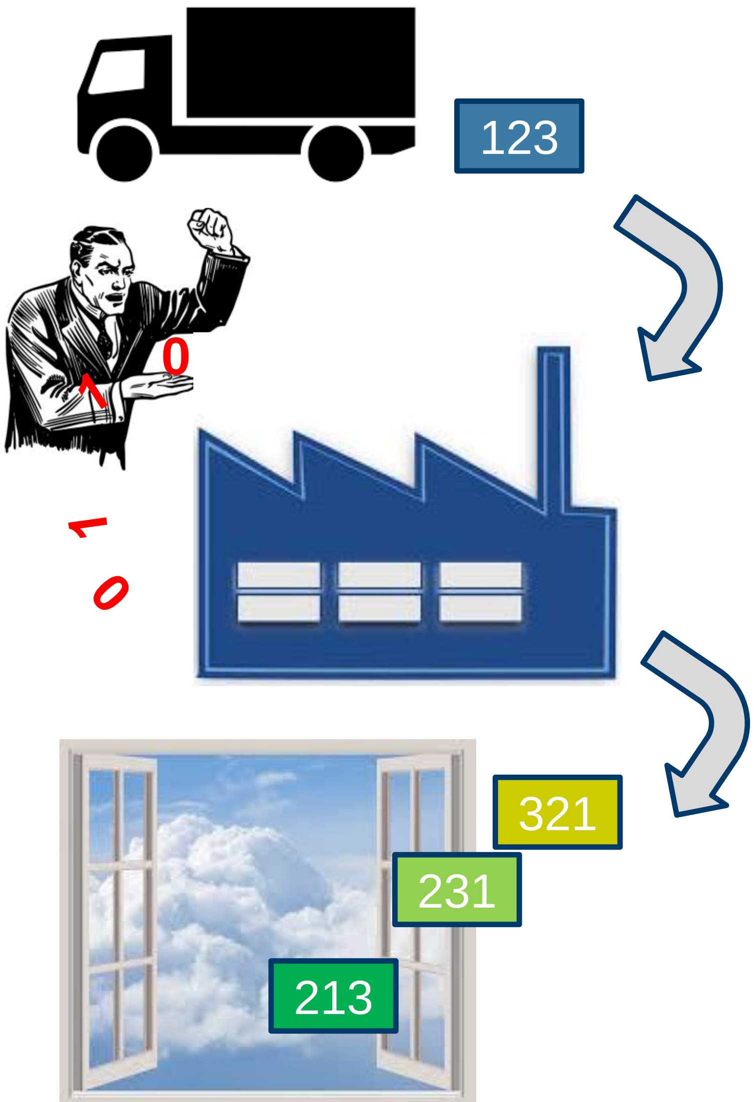
Define the roughness distribution

Define the initial conditions

Define the global parameters

Define the steering parameters of the computational run and kickoff

Needed Components



Preprocessor

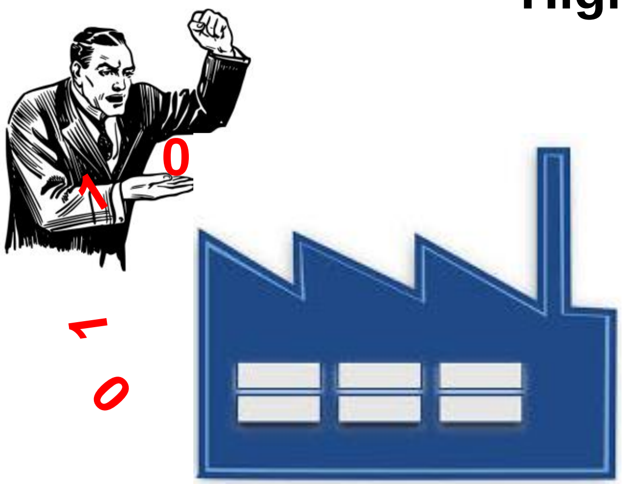
↓

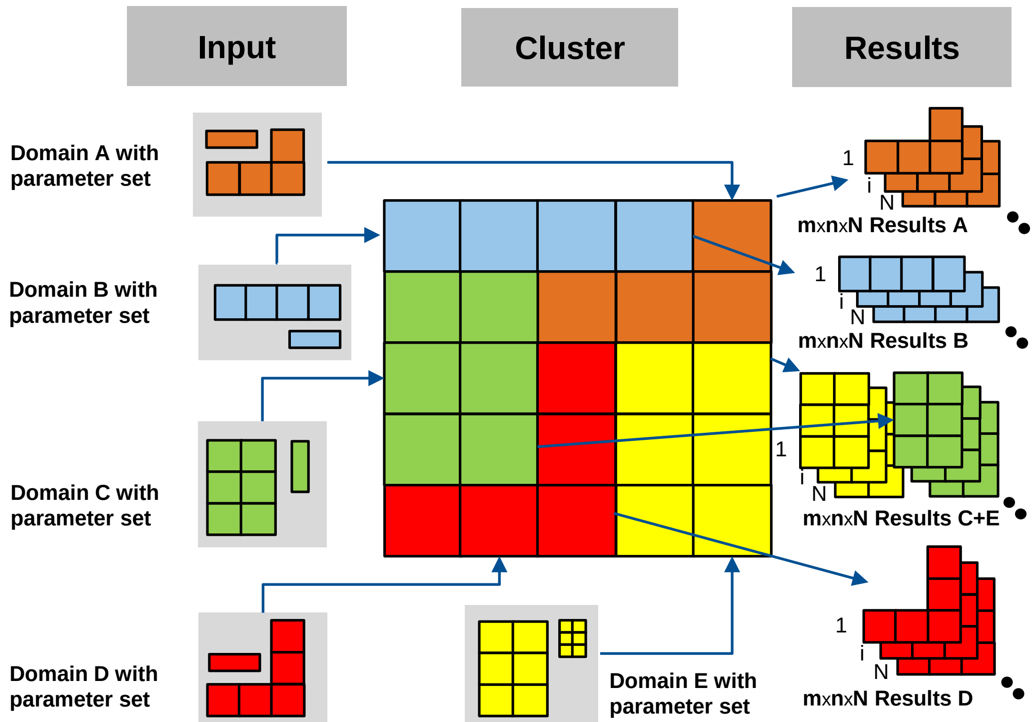
Hydrodynamic Model (HD)

↓

Postprocessor

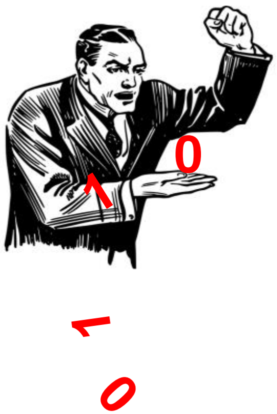
High Performance Computing

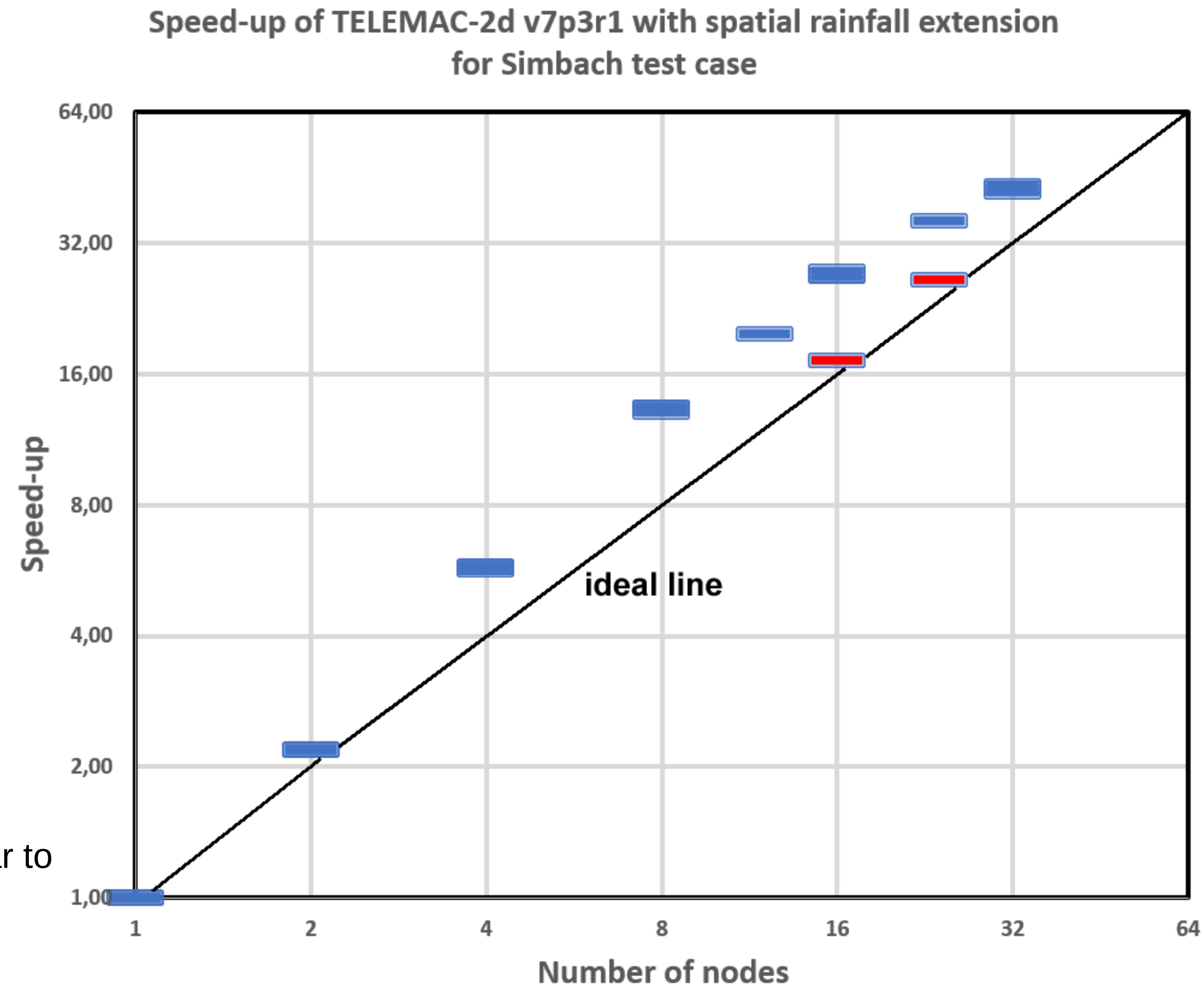




Topology for HPC cluster, each box represents a node/part consisting of n-cores/ subdomains (n=28 for SuperMUC at LRZ), N=number of timelevels.

High Performance Computing





Strong scaling test

Optimal node number : 4
(= 112 cores)

Note:
The performance gain is not linear to the number of processors used (Amdahl's law).

Hydrodynamic Rainfall Run-off Modeling

= HDRRM = 2D-hydrodynamic model with nodal run-off generation

Basic idea

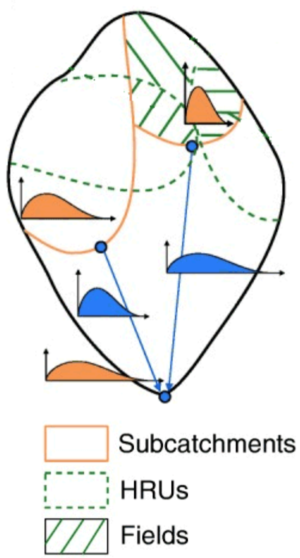
Hydrological model

Conceptual model frame work

Generation

Concentration

Routing



(Fenizia et al., 2016)

$Q = f(t, x_c, y_c)$

Smallest computational unit = HRU
Standard dimension = 10000 m²
Standard timestep: Minutes to hours

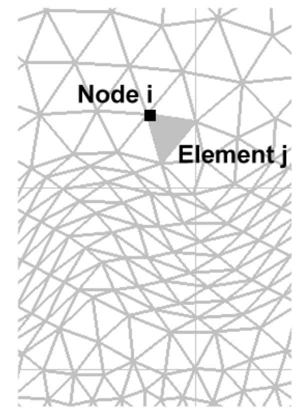
Hydrodynamic model

Physical model frame work

Generation

SWE-solver

Concentration + Routing



Triangular mesh

$h = f(t, x_i, y_i)$

$v_x = f(t, x_i, y_i)$

$v_y = f(t, x_i, y_i)$

Model choice: TELEMAC-2D using Finite Elements and SCS-CN-method (Ligier, 2016)

Smallest computational unit = Element
Standarddimension = 10 m²
Standard timestep: Seconds

3. Basics

Hydrodynamic Rainfall Run-off Modeling

Concept

Data

DEM	Laserscan 1x1m raster
Percipitation	DWD RADOLAN YW 5min
Soil	Hydrological soil classes
Landusage	TN, INVEKOS

Demands

- The HD-model has to be able to simulate varying precipitation in time and space.
- Usage of data in high resolution for DEM, precipitation, landusage and soil.
- Calculation of infiltration as sink term at each node
- The quality of the simulation procedure shall be validated using case studies.

Model choice

Suitable HD models :

- **TELEMAC-2D**
- **HYDRO_AS-2D**
- ...

Validation

Case study for the two neighboring catchements Simbach and Triftern. Kalibration Simbach, Validation Triftern.

Goal

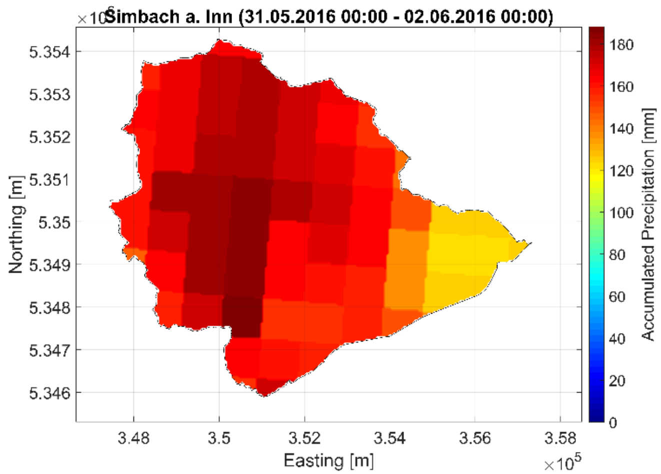
Validated **H**ydro**D**ynamic **R**ainfall-**R**unoff **M**odel **HDRRM**

3. Basics

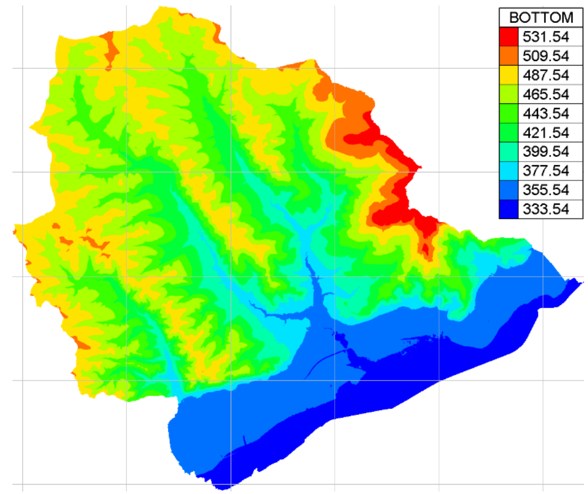
Hydrodynamic Rainfall Run-off Modeling

Data

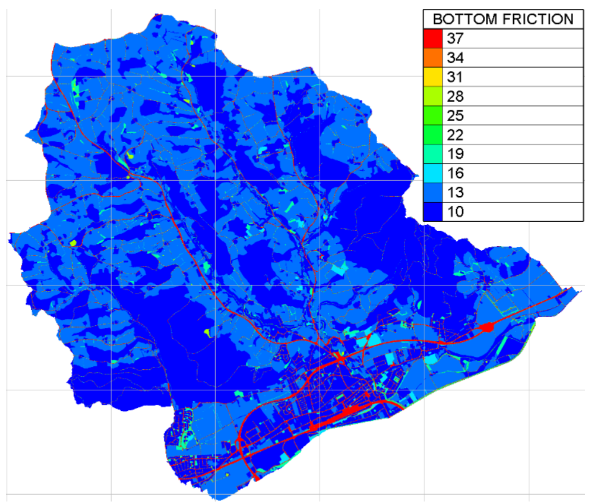
Precepitation [mm]



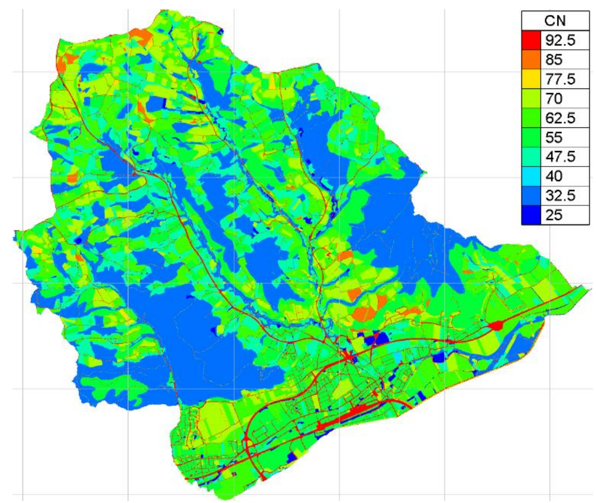
DEM [m]



Roughnes [m^1/3/s]



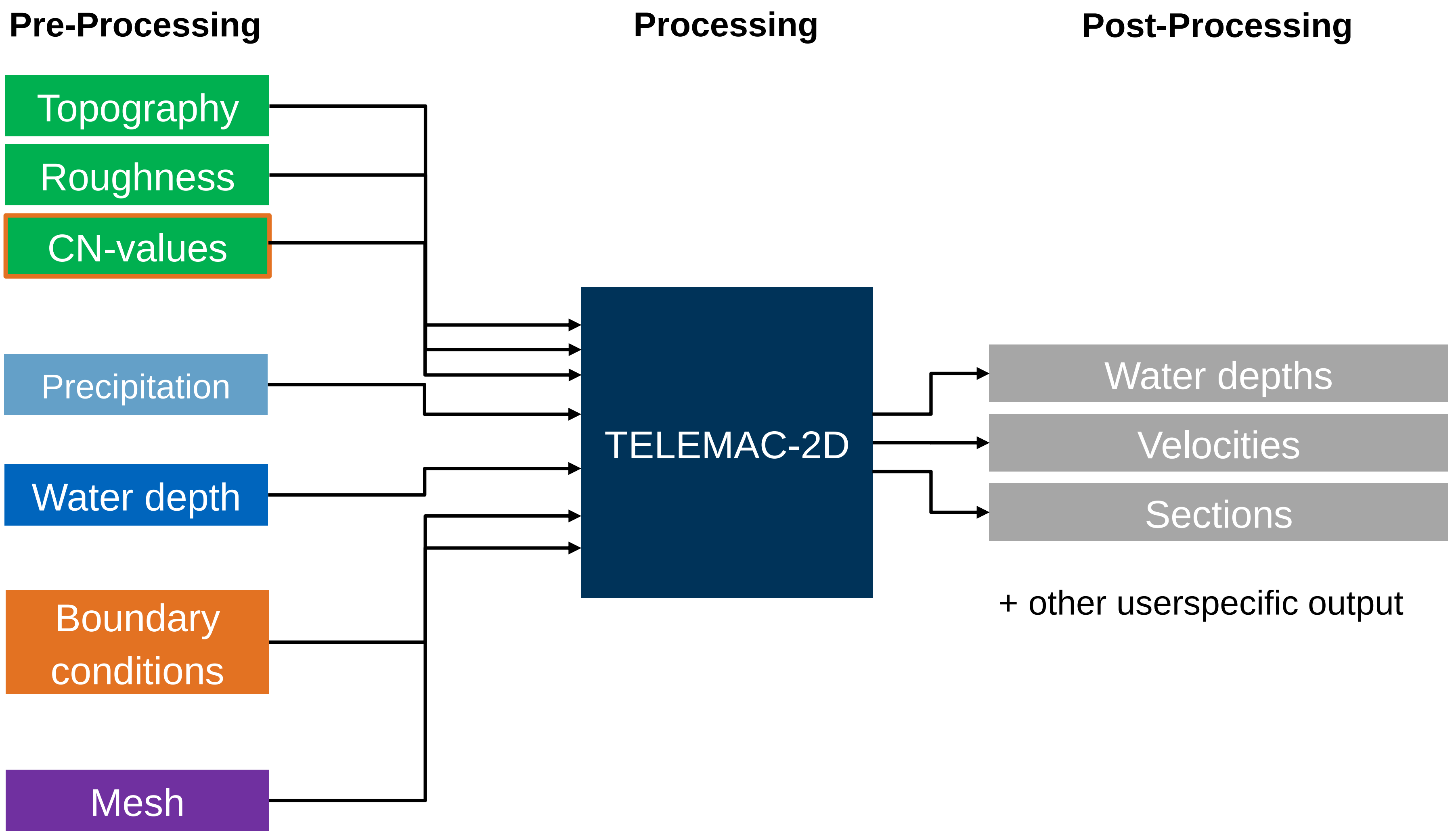
CN-values [-]



4. Tools

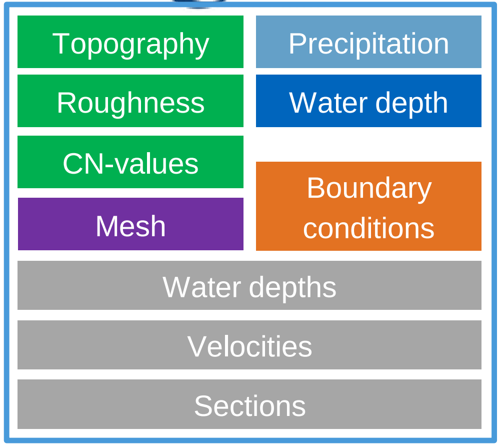
- Topography
- Precepetation
- Roughness
- Water depth
- CN-values
- Boundary conditions
- Mesh
- Water depths
- Velocities
- Sections

I/O data structure of TELEMAC-2D



4. Tools

BlueKenue



Software:

- Pre- and Postprocessor for TELEMAC-2D

Advantage:

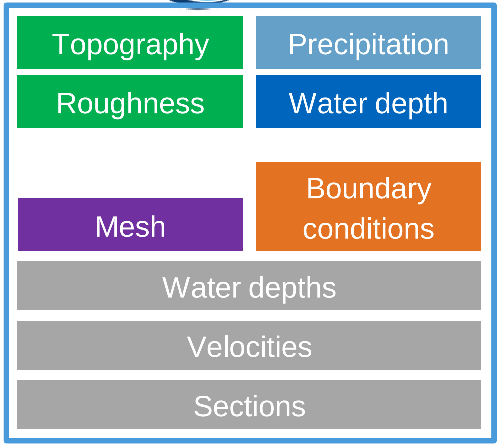
- Simple generation of Selafin-files
- Simple generation of high-quality meshes (needed by TELEMAC-2D)
- Simple generation and editing of boundary conditions
- Visualization of results (post-processing)
- Freely available for Windows

Disadvantage:

- Slow mesh generation
- Slow visualization and editing of big data files
- Not maintained (?)

4. Tools

Salome-Hydro



Software:

- Pre- and Postprocessor for TELEMAC, download from http://opentelemac.org

Advantage:

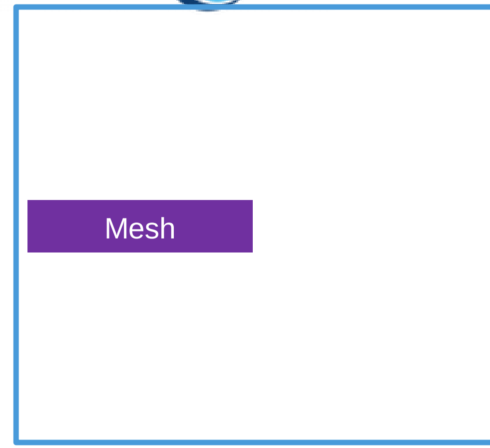
- Simple generation of Selafin-files
- Simple generation of high-quality meshes (needed by TELEMAC-2D)
- Simple generation and editing of boundary conditions
- Visualization of results (post-processing)
- Freely available for Windows and Unix

Disadvantage:

- --

4. Verwendete Tools

Gmsh



Software:

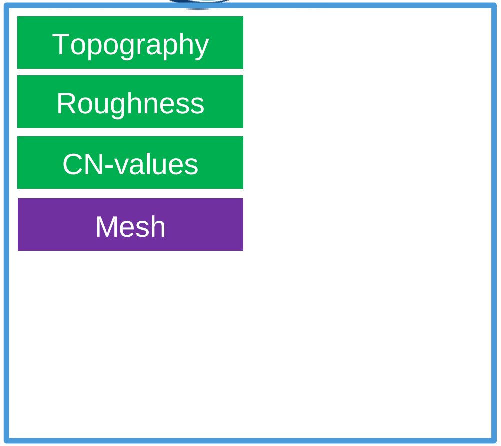
- Generation of Finite-Element-meshes (http://gmsh.info/)

Advantage :

- Fast generation of high-quality meshes (needed by TELEMAC-2D)
- Generation of meshes either by GUI or by a special API (Gmsh API) or a programming language (C++, C, Python or Julia)

Disadvantage :

- High training effort



4. Verwendete Tools

PPUTILS

Software:

- Python-toolkit supporting the processing of data for TELEMAC-2D

Advantage :

- Standard software
- The small scripts can easily be adopted.
- Batch-mode for pre- and postprocessing tasks

Disadvantage :

- Python-Kenntnisse erforderlich.
- Performance ist nicht optimal

Precipitation
Water depth

Water depths
Velocities
Sections

4. Verwendete Tools

MATLAB

Software:

- commercial software for mathematical problems

Advantage :

- Standard software
- Possible usage of available functions („Telemac Tools“)
- Definition of own functions (f.i. RADOLAN-data processing, visualization of section data)

Disadvantage :

- Non open-source

4. Verwendete Tools

QGIS

Water depths

Velocities

Sections

Software:

- Open Source GIS-Software

Advantage :

- Simple visualization of results and plotting with GIS-GUI using the QGIS-tool „PostTelemac“
- Freely availabe for Windows and Unix

Disadvantage :

- Very slow when applied to big data

(Note: ArcGIS can be used as well.)

5. Data structure of TELEMAC-2D

5. Data structure of TELEMAC-2D

- Fortran_Tri_EZG1_HD0_2016-05_CN3_r01
- BC_Tri_EZG1_HD0_2016-05_CN3_r01.cli
- Geometry_Tri_EZG1_HD0_2016-05_CN3_r01.slf
- Parameter_Tri_EZG1_HD0_2016-05_CN3_r01.cas
- Rainfall_Tri_EZG1_HD0_2016-05_CN3_r01.txt
- Results_S_Tri_EZG1_HD0_2016-05_CN3_r01.dat
- Results_Tri_EZG1_HD0_2016-05_CN3_r01.slf
- Sections_Tri_EZG1_HD0_2016-05_CN3_r01.dat
- StartCool_Tri_EZG1_HD0_2016-05_CN3_r01.sh
- StartWin_Tri_EZG1_HD0_2016-05_CN3_r01.bat

6. How to use TELEMAC-2D

6. How to use TELEMAC-2D

Using TELEMAC-2D (30 min)

- Installation und compilation of TELEMAC-2D
- Recommended software: Notepad++ (editor)
- Program start (Windows: *.bat, Linux: *.sh)
- Partitioning of data
- Examples for TELEMAC-2D (Malpasset, Pluie, SpatRain)
- Demonstration of Triftern Flash Flood example

7. Exercise

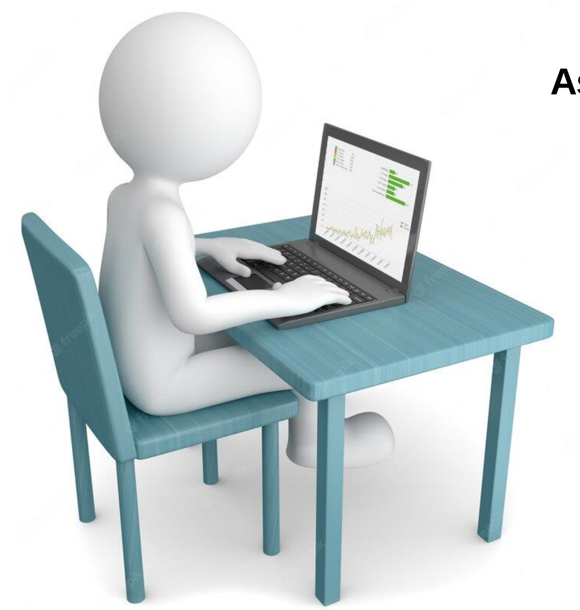
TRITON

7. Exercise

It's your turn !

Exercise (85 min)

- Get the data
- Install TELEMAC and BlueKenue
- Run your first TELEMAC-2D model (If TELEMAC installation succeeded)
- Analyze the results of Telemac using BlueKenue
- Make your own assumptions, run TELEMAC and check the changes.



Assignment for report

- Analyze the given data set for the municipality Triftern
- Derive from this data:

a) Risk zones for the flood emergency plannings and flood risk communication

b) Propose different possible NBS for this case study including its location

8. Closure

7. Literature

Manual:
TELEMAC-2D-Manual (part of the distribution)

Tutorial:
For learning how to setup a TELEMAC-model from scratch see
Baxter-Tutorial from Gifford-Miears and Leon (Oregon State University) downloadable at
http://opentelemac.org/index.php/training-and-tutorials

7. Literature

Reference:
Hervouet, Jean-Michel (2007):
Hydrodynamics of Free Surface Flows.
Chichester, UK: John Wiley & Sons, Ltd.

Papers:
Ligier, P.-L. (2016):
Implementation of a rainfall-runoff model in TELEMAC-2D.
Paris. In: *Proceedings of the XXIIIrd TELEMAC_MASCARET User Conference* 2016 (23).

Smolders, Sven; Leroy, Agnés; Teles, Maria Joao; Maximova, Tatiana; Vanlede, Joris (2016):
Culverts modelling in TELEMAC-2D and TELEMAC-3D.
Paris. In: *Proceedings of the XXIIIrd TELEMAC_MASCARET User Conference* 2016 (23).

Broich, Karl; Pflugbeil, Thomas; Nguyen, Hai; Disse, Markus (2019):
Using TELEMAC-2D for Hydrodynamic Modeling of Rainfall-Runoff. Telemac User Conference 2019, CERFACS, Toulouse.