LWDsimR: Simulation of Woody Debris Dynamics during Floods

User Manual

Niccolò Galatioto & Andreas Paul Zischg

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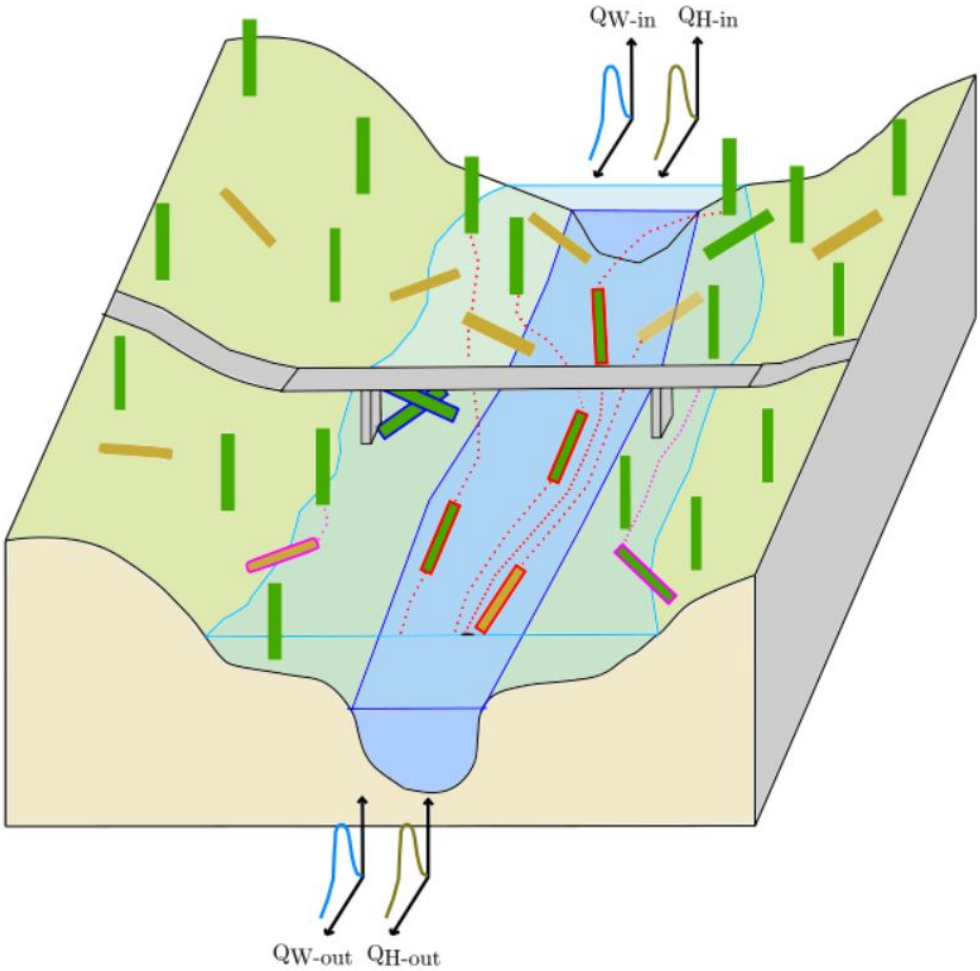


Contents

1 Introduction

Large woody material and woody debris transported by rivers during floods often comes along with severe problems. The woody material can be jammed in naturally or artificially narrowed stream sections. This leads to a dramatically increase of the destructive power of the flood and can cause severe damages and high costs. Therefore it is crucial to consider the woody debris dynamics during floods as hazard in a sound risk management.

Since direct observation of these processes are difficult and rare, numeric modelling is an promising alternative. The presented model "LWDsimR" was developed in a master thesis at the Institute of Geography at the University of Berne (Galatioto, 2016) and is an adaptation of the model of Mazzorana et al. (2011) which enables a raster based and object-oriented simulation of the woody debris dynamics during floods based on hydrodynamic simulations. Mobilisation, transport, deposition and entrapment of the woody material can be modelled with temporal and spatial high resolution. This allows the identification of possible recruitment areas, transport pathways, deposition areas and critical stream configuration for log jams as well as an estimation of the expected volume of the woody material. Here, this model was adapted and transferred to a vector based approach that enables the simulation of large wood debris dynamics on the basis of irregular meshes and on the basis of outcomes of 2D inundation models.

This user manual should guide through all necessary steps to run the model successfully. It explains in detail which software and geodata are required, how to preprocess the data, how to set up and run the model and finally how to postprocess and interpret the results. Furthermore example data from the Zulg river in the Eriz, Canton of Berne, Switzerland, is provided on which the procedure can be followed and an exemplary model run can be executed.

For a detailed description of the transport equations and further information please see Mazzorana et al. (2011). For the vector based version in R please refer to the Galatioto (2016).

2 Requirements

The following software and data are required to set up and run the model properly. All necessary software are open-source and can be downloaded on the referencing websites. To get the scripts and example data please download "LWDsimR_Simulation of Woody Debris Dynamics during Floods" on `https://zenodo.org/`. The example data are provided by Amt für Wald des Kantons Bern (2014) and Amt für Geoinformation des Kantons Bern (2014).

2.1 Required Software

- R: Programming language in which the model is written. (R Core Team, 2015)
- RStudio: Required to open the scripts and pre- and postprocess the data.(RStudio Team, 2015)
- BASEMENT v2.5 or v2.6: Required to run the hydrodynamic simulations. (Basement, 2015; Vetsch et al., 2015)
- BASEmesh: Required QGIS plugin to generate the Mesh for the hydrodynamic simulation. (VAW ETH Zürich, 2014)
- QGIS: Required to edit the geodata. (QGIS Development Team, 2016)

2.2 Geodata

The following Data and Geodata are required to run the model:

- Digital surface model DSM
- Digital terrain model DTM
- Polygon shapefile of vegetation. (Here the structure of the dataset "Wald BE" from the Canton of Berne was used (Amt für Wald des Kantons Bern, 2014).)
- Hydrodynamic simulation results from BASEMENT with flow depth and flow velocities for each time step.

3 Preprocessing

3.1 Structure of the folders

In a first step the predefined folder structure (without the containing files) shown in figure 1 should be created. It can alternatively be taken from the downloaded example data. It is very important to consider the naming accurately.

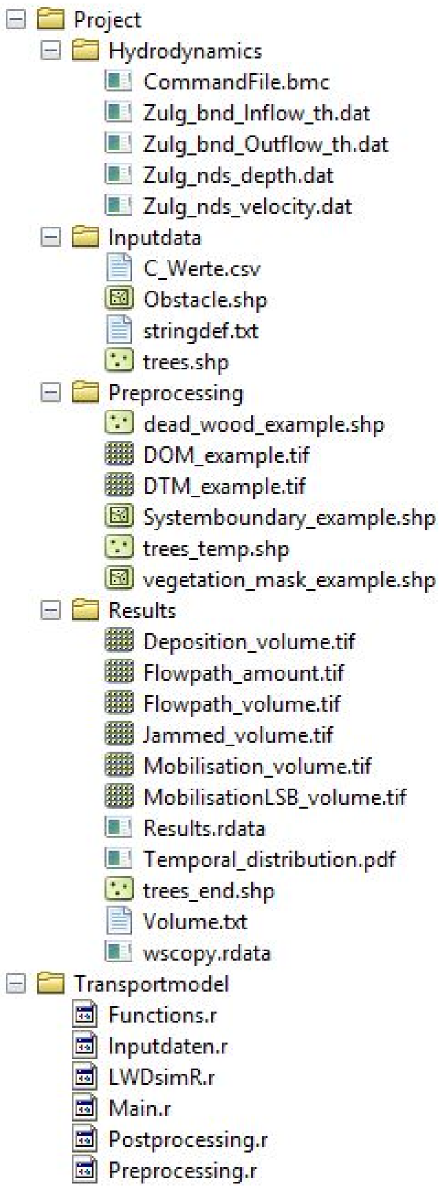


Figure 1: Predefined folder structure with all files after a successful model run and postprocessing.

The folder "Project" can be renamed with the name of the actual project. This folder should be used as data directory containing all necessary data and the simulation results. The folder "Transportmodel" should only be used as working directory containing all R-Scripts. The single folders, their contents and how to generate the particular data are described in the following sections.

3.2 Folder "Transportmodel"

The folder "Transportmodel" contains all R-Scripts for pre- and postprocessing as well as the model itself. When executing a particular script, this folder should always be defined as working directory in the head of the script.

- Preprocessing.R (Script for executing the preprocessing, mainly to generate the vegetation layer as point shapefile)
- Postprocessing.R (Script for evaluating and plot the model results)

The model itself consists out of four scripts. Normally only the script "Main.R" is needed to set up and run the model. The other scripts contain the functions which will be executed automatically from the main script.

- Main.R (Starting script to set up and run the model)
- LWDsimR.R (The main model)
- Inputdata.R (Script for loading the data into the model)
- Functions.R (Script containing all necessary functions)

3.3 Folder "Hydrodynamics"

The folder "Hydrodynamics" should contain the following information and results from the hydrodynamic simulation with BASEMENT. It is important to consider the correct naming of the files. For further information about hydrodynamic simulations with BASEMENT please see Vetsch et al. (2015).

- Command file ("CommandFile.bmc")
- Mesh as .2dm file ("name.2dm")
- Node centered velocity ("name_nds_velocity.dat" or "name_nds_velocity.sol")
- Node centered flow depth ("name_nds_depth.dat" or "name_nds_depth.sol")
- Optional: Input-Hydrograph ("name_bnd_Inflow_th.dat")
- Optional: Output Hydrograph ("name_bnd_Outflow_th.dat")

3.4 Folder "Preprocessing"

The folder "Preprocessing" should contain all the necessary data for the preprocessing. It is mainly about generating the vegetation layer with single tree resolution out of the digital elevation model. The data in this folder is not directly loaded into the model.

- Digital surface model (DOM_example.tif)
- Digital terrain model (DTM_example.tif)
- Systemboundary from BASEMENT to define the research area (Systemboundary_example.shp)
- Shapefile of vegetated area (vegetation_mask_example.shp)
- Optional: Point Shapefile of dead wood (dead_wood_example.shp)

The required vegetation layer with single tree resolution can be generated and exported as a point shapefile with the script "Preprocessing.R". The comments in the script describe the procedure in detail. Basically a canopy raster is calculated (subtraction of the DTM from the DSM) in a first step and local maxima where identified using a moving window approach secondly. All local maxima which are higher than a predefined height above ground where defined as single trees and exported as a point shapefile named "trees_temp.shp".

In a further step, the necessary attributes for every tree are calculated. All attributes of the final vegetation layer are listed and explained in table 1. Therefore the vegetation mask of the canton of Berne "Wald BE" is crucial (Amt für Wald des Kantons Bern, 2014). If this layer is not available or the research area is not in the Canton of Berne, the attributes "DBH" and "Structure" have to be specified manually on the basis of forest inventories or data from field observations. If available dead wood (as a point shapefile) can be added to the vegetation layer. A point shapefile representing dead wood can be generated with the QGIS-Tool "Random Points" in a predefined area (normally the vegetated area) with a specific density. The point shapefile of the final vegetation layer and it's attribute table are exemplary shown in figure 2. This layer is finally exported and saved in the folder "Inputdata" as "trees.shp".

It is possible to combine several simulation results e.g. to include previous modelled tributaries. Therefore the woody material which reached the lower system bondary (LSB) in the simulation of a tributary is used as additional input for the simulation of the main river. If doing so, the vegetation layer "trees.shp" needs to be adapted. The original vegetation layer "trees.shp" of the main river must be extended with the trees which reached the LSB in the previous simulation (of the tributary). It is important to assure that the ID numbers are still unique and to adapt them manually if necessary. The status of the additional trees must be set to 2 (lying). The attribute "TS_in" of the added trees must be set manually equal to their "TS_out" from the previous simulation. This time step refers to the output time step of BASEMENT (TS) . It is therefore important to use the same timesteps for the different simulations.

Table 1: Attributes of the vegetation layer point shapefile and their explanation.

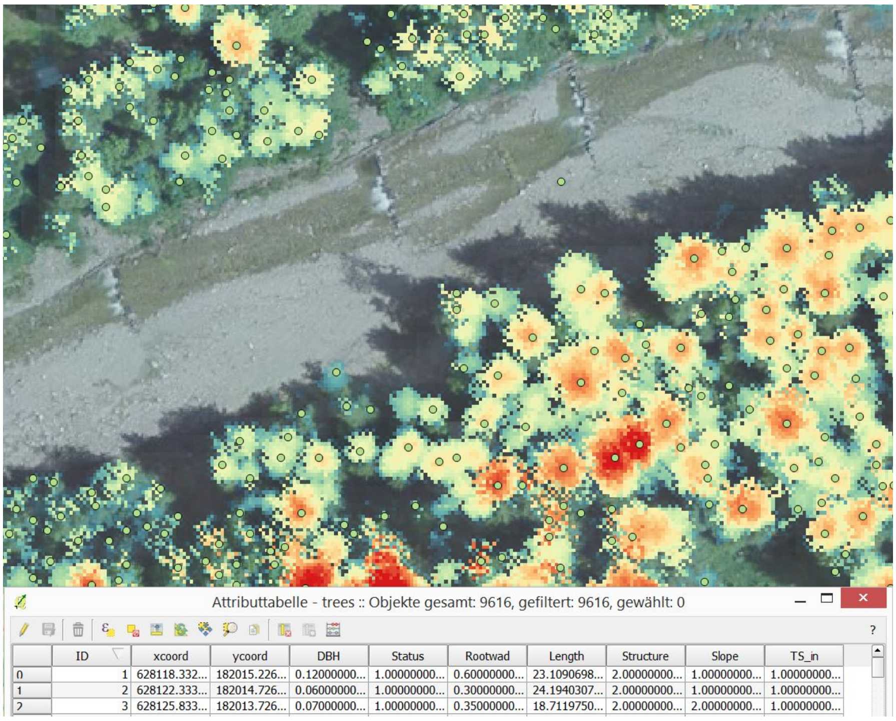
Attribute	Explanation
ID	Unique ID of each tree.
xcoord	x-coordinate of each tree.
ycoord	y-coordinate of each tree.
DBH	Diameter at breast height [m]. If the vegetation mask "Wald BE" is not available this attribute is calculated from the deciles of a sample. The deciles can be adapted manually in the script "Preprocessing.R".
Status	Status of the tree: 1 = rooted, 2 = lying, 3 = transported, 4 = jammed. As initial condition the status of living wood is allways =1 and that of dead wood =2.
Rootwad	Diameter of rootstock [m] if existent. The rootstock is 3 to 5 times the DBH.
Length	Length of the tree [m].
Structure	Characteristic structure of the forest: 1 = young and dense, 2= young and fragmentary, 3 = even aged and dense, 4= even aged and fragmentary. If "Wald BE" is not available this attribute has to be specified manually and is set to 3 by default.
Slope	Slope at the position of the tree: 1 = steep, 2 = flat. The threshold for the slope can be adapted manually.
TS_in	Point in time after which a tree is considered during the model run. The default setting is 1. In case of a coupled modelling this attribute has to be adapted manually. For details see section 3.4.

3.5 Folder "Inputdata"

This folder contains all data beside the hydrodynamics that are loaded directly in the model.

- Table with C-factor for the mobilization probability (C_Werte.csv)
- Polygon shapefile with all obstacles (Obstacle.shp)
- Table with all Nodes at the lower system boundary LSB (stringdef.txt)
- Point shapefile with the vegetation, created with the Script "Preprocessing.R" (trees.shp)

The mobilization probability based on the C-factor is adapted from Mazzorana et al. (2011) and is showed in figure 3. If needed, these values can be adapted manually in the file "C_Werte.csv".



	ID	xcoord	ycoord	DBH	Status	Rootwad	Length	Structure	Slope	TS_in
0	1	628118.332...	182015.226...	0.12000000...	1.00000000...	0.60000000...	23.1090698...	2.00000000...	1.00000000...	1.00000000...
1	2	628122.333...	182014.726...	0.06000000...	1.00000000...	0.30000000...	24.1940307...	2.00000000...	1.00000000...	1.00000000...
2	3	628125.833...	182013.726...	0.07000000...	1.00000000...	0.35000000...	18.7119750...	2.00000000...	2.00000000...	1.00000000...

Figure 2: Vegetation layer with single tree resolution as point shapefile, generated from the underlying canopy raster. The attribute table shows the corresponding attributes for every tree. Orthoimage: swisstopo

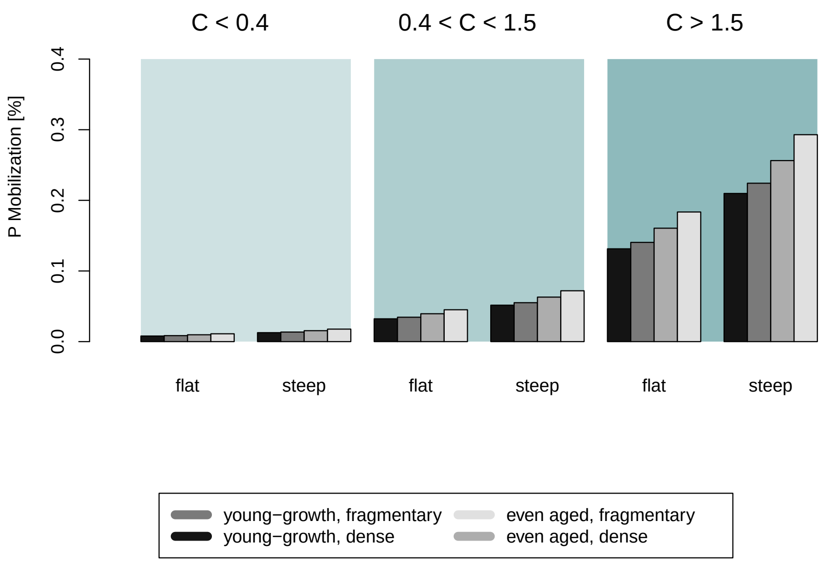


Figure 3: Mobilization probability for each tree based on the C-factor.

If bridge clogging should be considered during the simulation all bridges must be edited in a polygon shapefile named "Obstacle.shp". Each bridge should be a single polygon covering all edges of the bridge. The attribute table must be created in the predefined way, shown exemplary in figure 4. Each polygon must have a unique ID and an average height (distance between the lower edge of the deck and the channel bed) and width. The remaining columns must be named correctly but left empty. It is important that the ID of the bridges corresponds to the order their creation while editing the shapefile i.e. the first entry in the attribute table must have ID=1, the second entry ID=2 etc.

Attributtabelle - Obstacle :: Objekte gesamt: 3, gefiltert: ...

	id	Height	Width	Parameter	Amount	Volume
0	1	5.300	25.000	NULL	NULL	NULL
1	2	4.300	20.000	NULL	NULL	NULL
2	3	3.000	27.000	NULL	NULL	NULL

Figure 4: Polygon shapefile "Obstacle.shp" with its attribute table. Orthoimage: swisstopo

Furthermore the LSB must be defined in a file named "stringdef.txt". The LSB should be identical to the one used in BASEMENT. It has a specific format shown in figure 5 and contains the numbers of all nodes at the lower system boundary. The file can be created automatically by using the BASEmesh tool "String definition" in QGIS or alternatively the node numbers can be copied into the file by hand. The vegetation layer "trees.shp" and its generation is described in section 3.4.

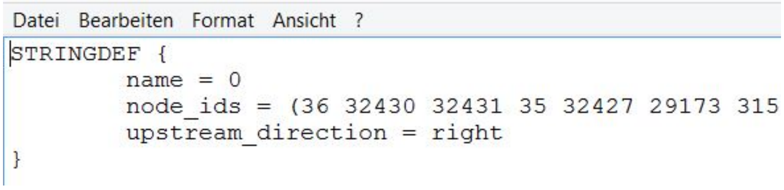


Figure 5: Format of the file "stringdef.txt" which contains the number of all Nodes at the lower system boundary.

3.6 Folder "Results"

This folder contains all simulation results and those of the postprocessing. It is described in detail in section 5.

4 Simulation

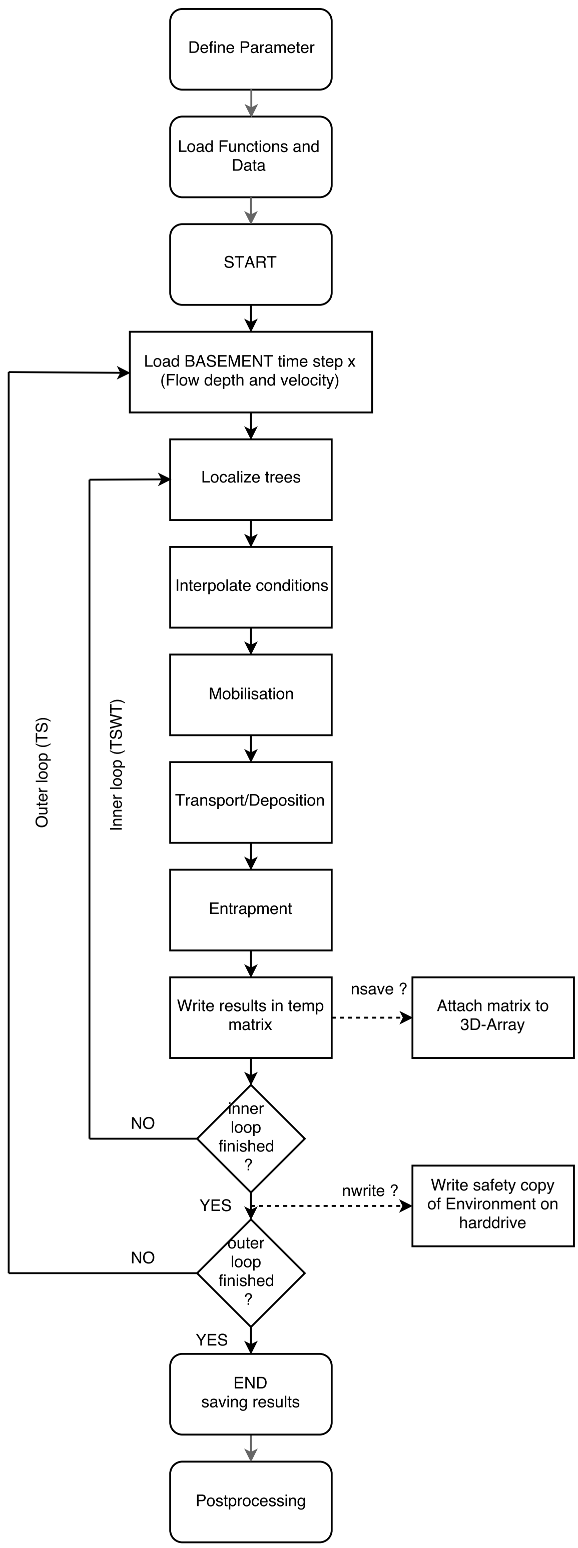


Figure 6: Schematic diagram of the model functionality. Essential are the two nested loops. In the outer loop the BASEMENT results of each specific time step are loaded whereas in the inner loop the woody debris dynamics are calculated a specific number of times during each single BASEMENT time step.

If the preprocessing is completed the simulation can be set up and started. The main simulation is done with the script "Main.R" in the folder "Transportmodel". This script is necessary to define all free model parameters and time steps, to load all data and functions, to execute the model and finally to save the results. Figure 6 gives an schematic overview over the functionality of the model when executing the script "Main.R". The significance of the parameter in this script is described in the following sections.

4.1 Time steps

Before the model can be started several different time steps have to be defined. Basically the model works with two nested loops representing two different time steps. As shown in figure 6 the outer loop loads the results of each output time step from BASEMENT into the model (i.e. for every output time step of BASEMENT information about the flow depth and velocity are loaded into the model). In the inner loop the woody debris dynamics is calculated a specific number of times within one single BASEMENT time step (i.e. the flow conditions remain the same during one iteration of the inner loop). Those different time step are necessary because it allows to simulate the woody debris dynamics on a higher temporal resolution than the simulation with BASEMENT. These time steps have to be defined before executing the model. All time steps are shown and explained in table 2.

Table 2: Different time steps and explanation

Parameter	Unit	Explanation
TRT	[s]	Total run time of the simulation in BASEMENT
TSB	[s]	Output time step of BASEMENT for velocity and depth
TS	[#]	Total number of saved simulation time steps from BASEMENT (length of the outer loop, automatically calculated in the script)
TSW	[s]	Time step for simulation of woody debris dynamic. It determines the temporal resolution of the simulation.
TSWT	[#]	Number of iterations of the woody debris dynamic simulation during a single BASEMENT time step (length of the inner loop, automatically calculated in the script). TSWT must be an integer
nsave	[s]	Time step for saving the simulation results. nsave must be bigger and a multiple of TSW
nwrite	[# of TS]	Defines how many times a safety copy ("wscopy.RData) is written on the hard drive in the folder "Results" during the simulation

4.2 Free parameters for the transport model

There are several free model parameters which are set by default. If required they can be adapted. The parameters are shown and explained in table 3.

Table 3: Free model paramaters and explanation

Parameter	Unit	Explanation
Cd	[ ]	Drag coefficient of the logs in water
g	[m/s^2]	Gravity acceleration
rho	[kg/m^3]	Density of the water
sigma	[kg/m^3]	Density of the log
mu	[ ]	Friction coefficient between log and channel bed
r	[ ]	exponent for the IDW-interpolation
dnr	[ ]	Threshold relation (depth to log diameter) for determine floating or resting condition of logs without rootstocks . "dnr" must be bigger than 1
dwr	[ ]	Threshold relation (depth to log diameter) for determine floating or resting condition of logs with rootstocks. "dwr" must be bigger than 1
vkl		TRUE=Consider bridge clogging, FALSE= neglect bridge clogging
bvers		Used version of BASEMENT (2.5 or 2.6)
name		Name of the BASEMENT input files (Project name)
name2dm		Name of the .2dm Mesh file

4.3 Running the model

If all parameters are defined the simulation can be started. Therefore the line "a.res<-LWDsimR( )" in the script "Main.R" has to be executed. The actual status of both loops as well as the progress in % are written in the console.

In case of occurring problems or errors the model can alternatively also be started by executing the whole script "LWDsimR.R". This is a more cumbersome procedure but enables a better debugging. In this case the array "a.out" has to be renamed as "a.res" at the end of the simulation.

4.4 Model results

During the simulation at the end of each iteration of the inner loop the results of the particular time step (TSWT) are temporary written into a matrix, shown exemplary in figure 7. Each row of the matrix represents a single tree with a unique ID as row name. The results for each tree during the particular time step are saved in the corresponding column. The columns are explained in table 4. This matrix is overwritten at the end of each iteration with the actual results.

	xcoord	ycoord	Status	TS_out	Obs_Nr	TS_in	TS_mobi	TS_jam
1	628118.3	182015.2	1	0	0	1	0	0
2	628122.3	182014.7	1	0	0	1	0	0
3	628125.8	182013.7	1	0	0	1	0	0
4	628117.8	182012.7	1	0	0	1	0	0
5	628115.3	182010.7	1	0	0	1	0	0

Figure 7: Structure of the temporary matrix to save the results at the end of every iteration of the inner loop. Every row represents one single tree with the rowname as unique ID. The columns are explained in table 4.

To save the results of a time step permanently a requested number of those matrices can be written out and stacked to a 3D-Array named "a.res". The number of matrices to be saved permanently can be controlled by the parameter "nsave". It defines the temporal resolution in which the matrices are being written out.

The 3D-Array "a.res" is the final result. It consist of all stacked matrices written out during the different time steps of the simulation. A second result is the matrix "m.Obstacles_Info". It shows the volume of the jammed woody material at every bridge if bridge clogging was considered in the simulation. After the completed model run, the entire Global Environment with all data is saved in the folder "Results" as "Results.RData".

Table 4: Columns of the temporary matrices and the final 3D-Array and their explanation

Column	Explanation
xcoord	x-coordinate of each tree
ycoord	y-coordinate of each tree
Status	Status of the tree: 1 = rooted, 2 = lying, 3 = transported, 4 = jammed.
TS_out	Timestep in which the tree reached the LSB
Obs_Nr	Number of the obstacle on which the tree was jammed
TS_in	Point in time after which a tree is considered during the model run.
TS_mobi	Timestep in which the tree got mobilized
TS_jam	Timestep in which the tree got jammed

5 Postprocessing

After completion of the model run, the postprocessing of the results can be started. The postprocessing is done by the script "Postprocessing.R". The single steps are explained in the script in detail. The following results (saved in the folder "Results") can be calculated using the script "Postprocessing.R":

- Table with general information and all resulting volumes of the simulation ("Volume.txt")
- Graphic with the temporal distribution of the woody debris dynamic (Temporal_distribution.pdf)
- Georeferenced raster of flow path, mobilisation, deposition, entrapment and mobilisation of woody material which reached the LSB (.tif)
- Point shapefile with the vegetation after the simulation (trees_end.shp)

In a first step the ID's of all trees which were affected during the simulation are determined. Then all the volume and other general information concerning the simulation are written into the table "Volume.txt" (figure 8). This table gives an overview over the simulation and the volume of the woody material which was moved in any way during the flood.

Volume.txt - Editor

Datei Bearbeiten Format Ansicht ?

	Amount	Unit
Total Area	118	ha
Share of Forest Area	34	%
Total wood stock	11564	m3
Total volume of water	409344	m3
Duration of event	60	min
Mobilized wood total	1002	m3
Mobilized living wood	831	m3
Mobilized dead wood	171	m3
Deposited Wood	891	m3
Jammed Wood	9	m3
Wood on LSB	97	m3

Figure 8: Example of the table "Volume.txt" with the results of a model run.

5.1 Temporal distribution

The temporal distribution of the woody debris dynamic is shown in the graphic "Temporal_distribution.pdf". This enables the determination of the volume of woody material which was mobilized, deposited, jammed or flown out of the system at a particular time step. The temporal resolution equals the output time step of BASEMENT.

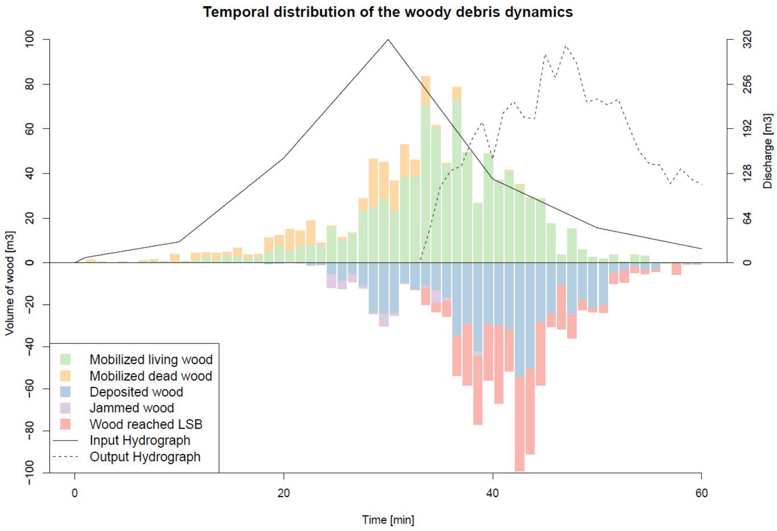


Figure 9: Temporal resolution of the woody debris dynamics. The upper part represents the mobilization whereas the lower part shows the deposition and entrapment. The lines represent the inflow and outflow hydrograph of the hydrodynamic simulation.

5.2 Spatial distribution

Different results considering the spatial resolution of the woody debris dynamics can be calculated. An example is shown in figure 10. For a very detailed information a shapefile of the vegetation can be created

- "trees_end.shp" is structured similarly as the input data "trees.shp" but it represents the vegetation at the end of the simulation. It shows therefore the position and the attributes (indicated by the suffix "2" in the column names, e.g. "Status2") of every single tree after the model run. Technically a shapefile of the vegetation could be created for every saved time step of the model run.

For a better overview it is possible to create raster of the different processes. The raster are georeferenced an can be loaded and processed with any GIS platform.

- "Flowpath_amount.tif" / "Flowpath_volume.tif": show the number of trees or the volume of woody material which flew over the specific raster cell.
- "Mobilisation_volume.tif": Shows the volume of woody material which was mobilized in a raster cell.
- "Deposition_volume.tif": Shows the volume of woody material which was deposited in a raster cell.

- "Jammed_volume.tif: Shows the volume of woody material which was jammed in a raster cell. This raster can only be created if entrapments were enabled during the model run.
- "MobilisationLSB_volume.tif": Shows the volume of the woody material which was mobilized in a raster cell and which reached the LSB.

For creating a raster an aggregation factor has to be defined manually in the script. The factor is set by default to 2 for the flow path raster and to 10 for all other raster.

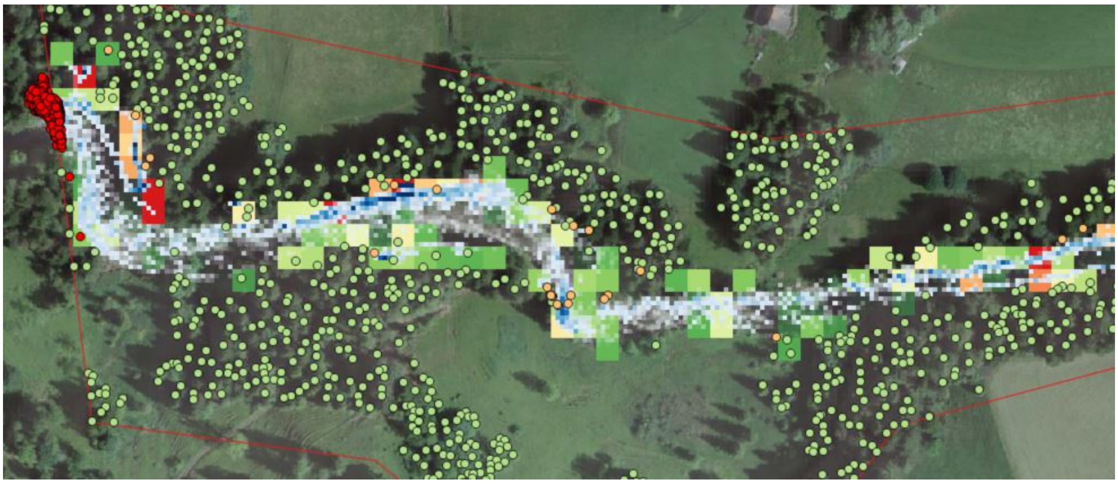


Figure 10: Example of the spatial results. The point shapefile "trees_end.shp" represents all trees at the end of the simulation. Green= rooted living wood, orange= deposited wood, red= wood at LSB. The coarse raster "Mobilisation_volume.tif" shows the volume of the mobilized wood in each raster cell. The fine raster "Flowpath_volume.tif" shows the volume of woody material which flew over each raster cell. Orthoimage: swisstopo

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