How to set up the Landscape Modeling Framework for a new study area

1 Introduction

Setting up the Landscape Modeling Framework (LMF) for a new study area includes the following steps

- selection of modules from the Library of Hydro-Ecologic models (LHEM) which should be included in the model
- data preparation
- building the project within the Spatial Modeling Environment (SME)
- model calibration and testing, evaluation of results

Here, it is described how to prepare the input data and how to set up the project within SME.

The selection of modules from the LHEM depends on the aim of the study, data availability and properties of the study area. Information on the different modules can be found on the internet pages of the Library of Hydro-Ecologic Modules: http://www.uvm.edu/giee/LHEM/.

Some ideas about the calibration of spatial hydrology can be taken from the descriptions of the application of LMF to the Patuxent watershed (Voinov et al., 1999a; Voinov et al., 1999b; Constanza et al., 2002; Voinov et al., 2004) and to the Parthe watershed (Düthmann, D., 2005, chapters 2.5 and 4 – sorry, only in German).

This documentation uses the Parthe project as an example (http://www.uvm.edu/giee/IDEAS/parthe/). The objective of this study was to simulate the hydrology of the Parthe watershed, which is a 320 km² watershed Southeast of Leipzig, Germany. This project includes modules for local hydrology, surface water transport, groundwater transport, Penman-Monteith evaporation, radiation, global inputs and plant inputs. The plant inputs module provides time series for root depth, LAI and plant height for the different landuse types.

An (incomplete) list about literature on LMF, SME and the LHEM modules is given at the end.

2 Preparation of input data

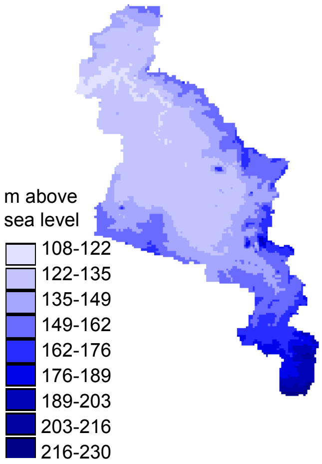
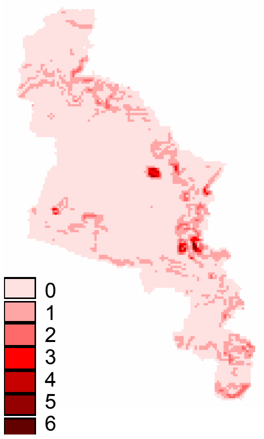
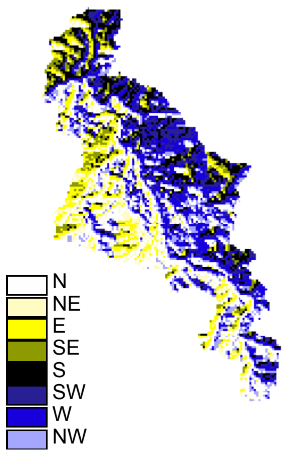
2.1 Spatial data

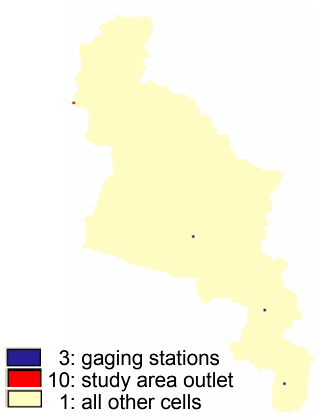
SME reads asci maps and also some other data formats (see: http://www.uvm.edu/giee/IDEAS/sme/docs/SME_guide.html#7.1.2). Asci maps can easily be exported from GIS like ArcView. An exception is the flowdirection, for which SME only takes the format M2. If you cannot produce M2 maps, you can use SME to convert an asci map to a M2 map. Therefore you import the asci map for any variable and then output it as a M2 map. SME only reads integer maps. In order to import a map with floating point numbers you have to multiply your map with e. g. 1000 and then use a scaling factor of 10^{-3}, when you read your map into SME.

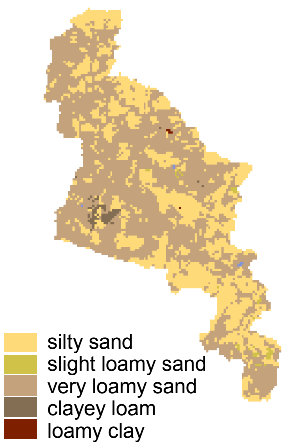
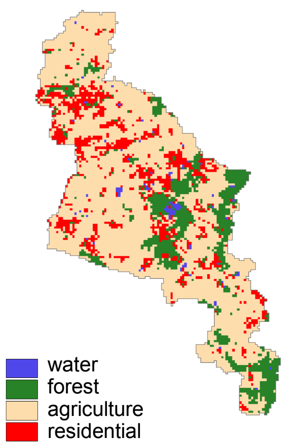
Besides the study area the maps have to enclose all weather stations from which you want to use data in your model.

For the simulation of hydrology with LMF the following spatial data sets are needed:

study area 	This map defines the study area. It has a one for the cells inside the study area and a zero everywhere else. If you want to run your model separately for different subwatersheds, you only have to change the study area map, all other maps can contain the full watershed. The study area map can be derived from the elevation map with e. g. ArcInfo or ArcGIS.

elevation 	Elevation is in meters above sea level.
slope 	Slope is in degrees. The slope influences the infiltration rate and the velocity of surface water transport. It can easily be generated from the elevation map.
flowdirection 	This map tells for each cell in the watershed in what direction water flows from this cell. When implemented spatially the map creates a drainage network. It assumes that water flows in the direction of the steepest slope. The flowdirection map is created from the elevation map. Before calculating the flowdirection map local sinks have to be filled because they would cause errors. The flowdirection map has to be reclassified according to SME conventions, the legend in SME is NE=2, EE=3, SE=4, SS=5, SW=6, WW=7, NW=8, NN=9. (also have a look at the SME User's Guide: Tree-network Frame Config-cmd t())

<table>
<tr>
<td>hydro
</td>
<td>This map has a three at the gauging station, a ten at the study area outlet and a one everywhere else. The gauging stations should match the calculated stream network. (In ArcInfo you can visualize the calculated stream network with the command flowaccumulation).

If for surface water transport a different algorithm, which also calculates balancing of water in lakes, is used, you have to mark the outlet cell for each lake on the hydro map, too. These cells would get a four.</td>
</tr>
<tr>
<td>soil
</td>
<td>The soil map is needed to assign soil physical parameters spatially,</td>
</tr>
<tr>
<td>landuse
</td>
<td>and the landuse map is needed to assign landuse dependent parameters spatially.</td>
</tr>
</table>

The initial conditions for the groundwater table and the soil moisture also should be spatial data sets. However, these data are rarely available and often can only be roughly estimated. In order to minimize the influence of the initial values on the model results one possibility is to evaluate the model results after an initialization period, in which groundwater and soil moisture can adjust to model dependent values.

2.2 Time series

Time series with daily values are needed for the climatic data precipitation, minimum temperature, maximum temperature, wind velocity and humidity. These data come from weather stations and additional precipitation gauges. The values are interpolated linearly by SME at the beginning of each time step. Data from stations outside the study area can be included, too.

The units used by LMF at the moment are shown in tab. 1. If your data is in different units it will be easier to change the "Globals" module (which reads the input data) than to convert the units of your data.

Tab. 1: Units used in LMF for climatic data.

Climate variable	Unit
Wind velocity	Nautic miles d^{-1}
Temperature	F
Precipitation	Inch d^{-1}
Humidity	%

SME can read time series in different formats. Format 2 consists of a single column of data with a header to define time step and the beginning of the time series (Fig. 1). These time series files have to be saved with the extension .ts.

```
dt = 1
year = 1990
0.00
0.00
0.00
0.01
...
```

Fig. 1: Example for a time series file in SME format 2.

Point time series files with the extension .pts tell, which time series are included in the spatial interpolation and what points these time series are assigned to (Fig. 2).

```
Data Directory = /home/duethman/data/parthe/climate
Format = 5
Year = 1990
Data =

69      56     prcp_brandis
108     37     prcp_threna
86      69     prcp_ammelsh
110     71     prcp_steinb
121     79     prcp_grethen
137     93     prcp_grossba
163     93     prcp_glasten
148     80     prcp_bernbr
175     92     prcp_ballend
108     55     prcp_naunhof
106     89     prcp_beiersdorf
17      39     prcp_jesewitz
164     126    prcp_sermuth
```

Fig. 2: Example for a point time series file, which describes what time series are included in the spatial interpolation.

In these files “Data directory” is the path to the folder where the time series (files with the extension .ts) are saved. Under “Data = “ the row, column and name of the time series which should be included in the spatial interpolation are listed. Row and column refer to the output maps from SME. The output map is the smallest rectangle containing the study area. So it might be different from the input map, which e. g. also encloses weather stations outside the study area. In order to get these coordinates you may feed SME with a map of your measurement points and then read the coordinates from the viewserver output, or you can also calculate them from your original coordinates.

2.3 Map dependent parameters

LMF uses different parameters for different soil and landuse types.

The soil dependent parameters which are needed by the model are listed in Tab. 2. Sometimes these parameters may be given in a database belonging to the soil map, or there may be some measured values. Otherwise you may assign these parameters to variables given in your soil map, like the soil texture. Tables which give mean values for these parameters depending on soil texture are for example given in the Bodenkundliche Kartieranleitung (AG Boden, 1996).

Tab. 2: Soil dependent parameters.

Parameter name	Explanation and unit	Name in "DBH_Soils"	Module
P1_C_POROSITY	Porosity (-)	Poros	Local hydrology, groundwater transport
P1_C_FIELCAP	Volumetric water content at field capacity (-)	FICap	Local hydrology
P1_C_HORIZ_HYDR_COND	Saturated horizontal hydraulic conductivity in the groundwater zone (m d^{-1})	Hyd_C	Local hydrology, groundwater transport
P1_C_INF_SOIL	Soil dependent infiltration rate (m d^{-1})	INF	Local hydrology
P1_C_VERT_HYDR_COND	Saturated vertical hydraulic conductivity in the unsaturated zone (m d^{-1})	Perc	Local hydrology

In the Parthe project landuse dependent parameters are only needed for the module "local hydrology" (Tab. 3).

These parameters are mainly based on calibration. In order to get the model running you may first use the landuse dependent parameters from one of the existing applications of LMF. However, the model has problems with evapotranspiration and this part will be changed. Infiltration will probably also be changed. Instead of depending on a calibration parameter it should depend on percentage impervious cover, which may be estimated easier.

Tab. 3: Landuse dependent parameters used in the module "local hydrology".

Parameter name	Explanation and unit	Name in "DBH_Habs5"
P1_C_INF_HAB	Parameter, which modifies the infiltration rate depending on land use (-)	infilt
P1_C_INTERCEP	Interception parameter (m d^{-1})	interc
P1_C_UW_EVAP	Parameter for soil evaporation (-)	uw_ev
P1_C_TRANSP	Coefficient for transpiration (-)	transp
P1_C_EVAP	Parameter for surface water evaporation (-)	sw_ev
P1_C_INTERCEPVEG	Interception parameter (m d^{-1})	int_veg

P1_C_ZIG	Parameter for the calculation of backflow (-)	zigzag

The soil dependent parameters are saved in the file “DBH_Soils” (Fig. 3), landuse dependent parameters in the file “DBH_Habs5”. The value in the soil (landuse) map corresponds to the table row, e. g. the soil with the texture Sl2 (slight loamy sand) has the value one in the soil map, Sl4 has a two and so on.

***Info	Sector	Poros	INF	FlCap	Perc	…	Perc	*TEXTUR
É1	Hyd¥1	0.365	0.49	0.24	0.49	…	0.49	Sl2
É2	Hyd¥1	0.385	0.21	0.285	0.21	…	0.21	Sl4
É3	Hyd¥1	0.35	0.88	0.215	0.88	…	0.88	Su2
É4	Hyd¥1	0.54	0.03	0.505	0.03	…	0.03	Tl
É5	Hyd¥1	0.47	0.1	0.435	0.1	…	0.1	Lt3
É6	Hyd¥1	0.385	0.21	0.285	0.21	…	0.21	see
É7	Hyd¥1	0.385	0.21	0.285	0.21	…	0.21	siedlung

Fig. 3: Example for the soil parameter table “DBH_Soils”.

2.4 Map independent parameters

No extra files have to be prepared for the map independent parameters of the Stella modules. The values are directly given in the configuration file, which is described in the next chapter.

The user functions for the groundwater and the surface water transport read their parameters from the files “GWData” and “SWData”.

The file “GWData” contains two parameters. The first one is a calibration parameter for the hydraulic conductivity in the groundwater, the second one is only needed for nutrient transport.

The important parameters in “SWData” are MAXDRUN and HSHEAD, both of them are calibration parameters.

3 Building the spatial model in SME

Within the Spatial Modeling Environment (SME) the modules are connected and the spatial model is build. Data input / output and running the model is also handled in SME.

The following figure gives an overview on how to set up a project in SME.

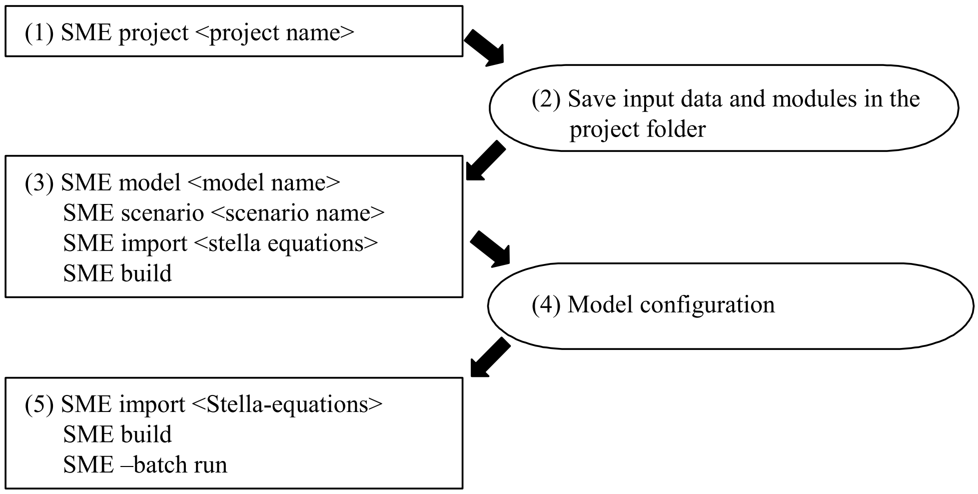


Fig. 1: Building the spatial model in SME. SME commands are in boxes on the left side, other actions are shown on the right side.

3.1 Setting up the project folder

In the first step the project name is given. Typing

```
SME project <project name>
```

will produce the project folder with its subfolders (Fig. 4).

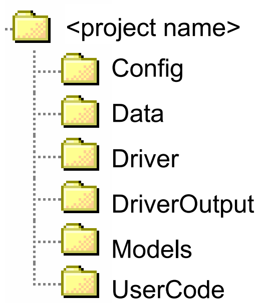


Fig. 4: Directory structure of an SME project.

3.2 Saving modules to the project folder

The equation files of the Stella modules, which have the extension .eqns, are saved in the folder "Models".

If you have build your own Stella modules or changed the original ones, you have to save the Stella model to an equation file: Go to equations, Edit □ Select All , Edit □ Copy and then paste the equations in a text editor (edit □ save as text won`t work!). This file has to be saved with the extension .eqns.

If you are working with Windows there may be an end of line problem. You should be able to fix this with the unix command dos2unix.

3.3 Model and scenario names, generation of configuration files

A project can contain different models (with different modules), and a model again can contain different scenarios (with different scenario configurations). With the SME commands

```
SME model <model name>
SME scenario <scenario name>
```

you name the model and scenario. In the example the model name is “simple3” and the scenario name is “1993”. The next command is

```
SME import <stella equations>
```

All Stella equations need to be imported at once, in the example this would be:

```
SME import ET.eqns GLOB.eqns HYD.eqns MAC.eqns PAR.eqns
```

The Stella equations are translated into MML (modular modeling language). At the same time the first config file “<model>.MML.config” is written to the folder “<project>/<Config>”. The command

```
SME build
```

invokes the code generation and more configuration files are produced. The folder “Config” now contains the files:

<model>.biflows
<model>.conf
<model>.MML.config
<model>.<scenario>
<model>.<scenario>.conf.out

Most important are the files "<model>.MML.config", in which the integration of user code is specified, and the file "<model>.conf", which controls the data input/output and the simulation start/end.

3.4 Configuration

3.4.1 Editing "<model>.MML.config": integration of user code modules

The file "<model>.MML.config" contains a list of all variables and parameters in the model and specifies, which user code modules are going to be included. The configuration commands are listed in the SME Users Guide (http://www.uvm.edu/giee/IDEAS/sme/docs/SME_guide.html). The user function command UF() includes the user code modules. In order to include horizontal transport of surface water and groundwater and the configuration information behind the variables SAT_WATER and SURFACE_WATER in the hydrology module. The changed lines will then look like this:

```
* SAT_WATER                  UF( GWater,END^GWTrans_I,POROSITY, H_CONDUCT,
ON_MAP, DIN_SD, UNSAT_WATER, OUT_F_SD)

* SURFACE_WATER          UF( SWater_b,END^SWTransport_b,HYDRO, HABITATMAP,
ELEVATION, P1_C_INF_SLOPE, DIN_SF, OUT_F_SF)
```

3.4.2 Editing "<model>.conf"

The file "<model>.conf" handles data input, results output and begin/end of the simulation period. Similar to "<model>.MML.config" this file also contains a list of all variables and the configuration commands are written behind the variables.

Data input

There are different configuration commands for different kinds of input data:

examples from "simple3.conf"	explanation
pm(0.25)	This command sets the value for a **constant parameter**.
c(A,${MAPS}/landuse-ni.asc,${RMAP}) d(A,${MAPS}/elevation1000-	There are two configuration commands for the input of **spatial data sets**: the c-command is for maps with class values and the d-command for maps with continuous values.

ni.asc,${RMAP})	
p(${CLIM}/!parthe_prcp.pts,0)	This command is used to read **time series**, the structure of the time series files is described under chapter 2.2.
m1(DBH_Habs5,HABITATMAP,2,5)	This command reads the value of a **map dependent parameter**. The variable is read from the table “DBH_Habs5”. The value of the variable HABITATMAP determines the line from which the variable is read. The column is given by “2, 5”, which has to be read as sector 2 (which is the hydrology sector), 5^{th} column.

For maps and time series the path to the data has to be given. The full path can be replaced by a shortcut specified in the environment file (Fig. 5). “${…}” in the configuration file refers to such a shortcut. The environment file has to be saved to the folder “<project>/Data”.

```
MAPS=/home/duethman/data/parthe/maps
PTS=/home/duethman/data/parthe
CLIM=/home/duethman/data/parthe/climate
RMAP=/home/duethman/data/parthe/maps/studyarea_one.asc
```

Fig. 5: The environment file of the example project.

Data output

Simulation results can be output to files in the form of time series or spatial data sets, or they can be shown on the viewserver. The output is also specified in “<model>.conf”:

examples from “simple3.conf”	explanation
P(row, column)	time series output
M()	map output
DD()	output to viewserver

Besides, some files are automatically generated by the user code functions. The file "WSOut", contains the runoff at the gauging stations and the study area outlet. The unit is m (cell area * d)$^{-1}$, so the values have to be multiplied with the cell area to get the runoff in m d^{-1}.

Specification of simulation start and end and time step

examples from "simple3.conf"	explanation
Y(1985.000000,0.002740)	starting date and time step, in years
OT(1.000000,0.000000,3650.000000)	time step, simulation start and stop
d(2)	debug level, 0 gives the least and 2 the most output.

3.4.3 The file "<model>.<scenario>.conf"

The file <model>.<scenario>.conf can overwrite the configuration commands in the file <model>.conf. This file just needs to contain the lines with the variables whose configuration you want to change. If you want to use this file you have to generate it yourself.

3.5 Module import, code generation and simulation start

After model configuration the steps module import and code generation have to be repeated (see chapter 3.3). This is not necessary if changes were made only to the file "<model>.conf" and not to the file "<model>.MML.config".

The command to start a simulation run is

```
SME –batch run
```

If you don't want to run the whole simulation run, you can run the model for n time steps with

```
SME run
r <n>
```

If you have send results to the viewserver, open it with

```
startup_viewserver
```

(new terminal). In order to view the results click on "Animation2D", "DataSpreadsheet" or "ImageSpreadsheet" and then on "Create" (Fig. 6).

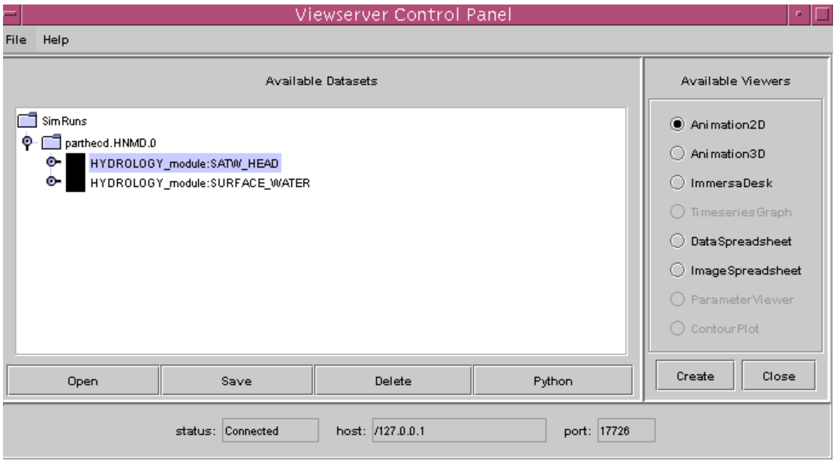


Fig. 6: SME viewserver.

4 Literature

Internet sources:

SME User's Guide (2005): http://www.uvm.edu/giee/SME3/ftp/Docs/UsersGuide.html

Landscape Modeling Framework: http://www.uvm.edu/giee/IDEAS/lmf.html

Library of Hydro-Ecologic Modules: http://www.uvm.edu/giee/LHEM/

Applications of LMF:

Patuxent Landscape Model: http://www.uvm.edu/giee/PLM/PLM.html

Hunting Creek Model: http://www.uvm.edu/giee/PLM/HUNT/

Northern Forest Project / St. Albans Watershed: http://www.uvm.edu/giee/AV/NF/

Parthe Model: http://www.uvm.edu/giee/IDEAS/parthe/

Articles in journals and books:

Binder, C.; Boumans, R.M.; Constanza, R. (2003): Applying the Patuxent Landscape Unit Model to human dominated ecosystems: the case of agriculture. In: *Ecol. Mod.*, 159(2-3): 161-177.

Boumans, R.; Villa, F.; Costanza, R.; Voinov, A.; Voinov, H.; Maxwell, T.; (2001): Non-spatial calibrations of a general unit model for ecosystem simulations. In: *Ecol. Mod.*, 146(1-3): 17-32.

Costanza, R.; Voinov, A.; Boumans, R.; Maxwell, T.; Villa, F.; Wainger, L.; Voinov, H. (2002): Integrated ecological economic modeling of the Patuxent River watershed, Maryland. In: *Ecological Monographs*, 72: 203-231.

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Fitz, C.; Sklar, F.; Waring, T.; Voinov, A.; Costanza, R.; Maxwell, T. (2004): Development and application of the Everglades Landscape Model. In: Costanza, R.; Voinov, A. (Hrsg.): *Landscape simulation modeling – A spatially explicit dynamic approach*. New York: Springer, 143-172.

Maxwell, T.; Voinov, A.; Costanza, R. (2004): Spatial simulation using the SME. In: Costanza, R.; Voinov, A. (Hrsg.): *Landscape simulation modeling – A spatially explicit dynamic approach*. New York: Springer, 21-42.

Seppelt, R.; Voinov, A. (2002): Optimization methodology for land use patterns using spatially explicit landscape models. In: *Ecol. Mod.*, 151(2-3): 125-142.

Seppelt, R.; Voinov, A. (2003): Optimization methodology for land use patterns—evaluation based on multiscale habitat pattern comparison. In: *Ecol. Mod.*, 168(3): 217-231.

Voinov, A.; Fitz, C.; Costanza, R. (1998): Surface water flow in landscape models:: 1. Everglades case study. In: *Ecol. Mod.*, 108(1-3): 131-144.

Voinov, A.; Costanza, R.; Wainger, L.; Boumans, R.; Villa, F.; Maxwell, T.; Voinov, H. (1999a): Patuxent landscape model: integrated ecological economic modeling of a watershed. In: *Environ. Modell. Softw.*, 14(5): 473-491.

Voinov A.; Voinov, H.; Costanza, R. (1999b): Surface water flow in landscape models: 2. Patuxent watershed case study. In: *Ecol. Mod.*, 119(2-3): 211-230.

Voinov, A.; Costanza, R.; Boumans, R.; Maxwell, T.; Voinov, H. (2004a): The Patuxent Landscape Model: Integrated modeling of a watershed. In: Costanza, R.; Voinov, A. (Hrsg.): *Landscape simulation modeling – A spatially explicit dynamic approach*. New York: Springer, 197-232.

Voinov, A.; Fitz, C.; Boumans, R.; Costanza, R. (2004b): Modular ecosystem modeling. In: *Environ. Modell. Softw.*, 19(3): 285-304.

other:

Schulze, Kerstin: *Stella abbrevations*

Düthmann, Doris (2005): *Modellierung des Wasserhaushalts im Einzugsgebiet der Parthe mit dem Modellsystem LHEM/SME*. Diploma thesis, Technical University of Braunschweig, Germany.