4. How to Prepare Data and Run SWIM

The model runs under the UNIX environment with the daily time step. The SWIM/GRASS interface is used to initialise the model by extracting spatially distributed parameters of elevation, land use, soil types, closest climate/precipitation station, and the routing structure.

The preparation to the modelling consists of the following steps:

- preparation of spatial data in GRASS (described in 4.1),
- run SWIM/GRASS interface using the spatial data in GRASS (described in 4.2),
- preparation of relational data (described in 4.3), which includes:
    - climate data (in 4.3.2),
    - soil data (4.3.3),
    - crop management data (4.3.4)
    - hydrological and water quality data (4.3.5)
- copy all input data in the working directory and modification of several data-handling routines, if necessary (described in 4.4).

After that the model can be run. The calibration parameters and some examples of the model sensitivity studies are given in 4.5.

4.1 Spatial Data Preparation

First, an overview of necessary spatial data in given in 4.1.1. After that, two important questions: how the resolution of the Digital Elevation Model is related to the basin area, and how the average sub-basin area must be chosen, are discussed in 4.1.2 and 4.1.3. Then a short overview of GRASS GIS is given in 4.1.4, and some GRASS operations, useful for spatial data preparation, are described in 4.1.5 and 4.1.6. A specific program for watershed analysis *r.watershed* is described separately in 4.1.7. A DEMO data set is given in 4.1.8

4.1.1 GIS Data Overview

The full list of necessary spatial data (digitised maps) is the following:
1. Digital Elevation Model (DEM),
2. land use map,
3. soil map,
4. map of basin and sub-basins boundaries,
5. map of river network,
6. map of river gage stations,
7. alpha-factor map for groundwater,
8. map of climate stations,
9. map of Thiessen polygons for climate stations,
10. map of precipitation stations,
11. map of Thiessen polygons for precipitation stations
12. map of point sources of pollution.

All the maps can be provided in ARC/INFO or GRASS format.

The first four maps: DEM, land use, soil and sub-basins are absolutely necessary to run the SWIM/GRASS ínterface and initialise the model (see, for example, **Fig. 4.1**).

For the DEM resolution is important (see 4.1.2). The soil map has to be connected to soil parameters (see a detailed description in 4.3.3). The land use map has to be reclassified for SWIM to a map with the following categories:

n = 1 - water
n = 2 - settlement
n = 3 - industry
n = 4 - road
n = 5 - cropland
n = 6 - set-aside
n = 7 - grassland, extensive use (meadow)
n = 8 - grassland, intensive use (pasture)
n = 9 - forest mixed
n = 10 - forest evergreen
n = 11 - forest deciduous
n = 12 - wetland nonforested
n = 13 - wetland forested
n = 14 - heather (grass + brushland)
n = 15 - bare soil

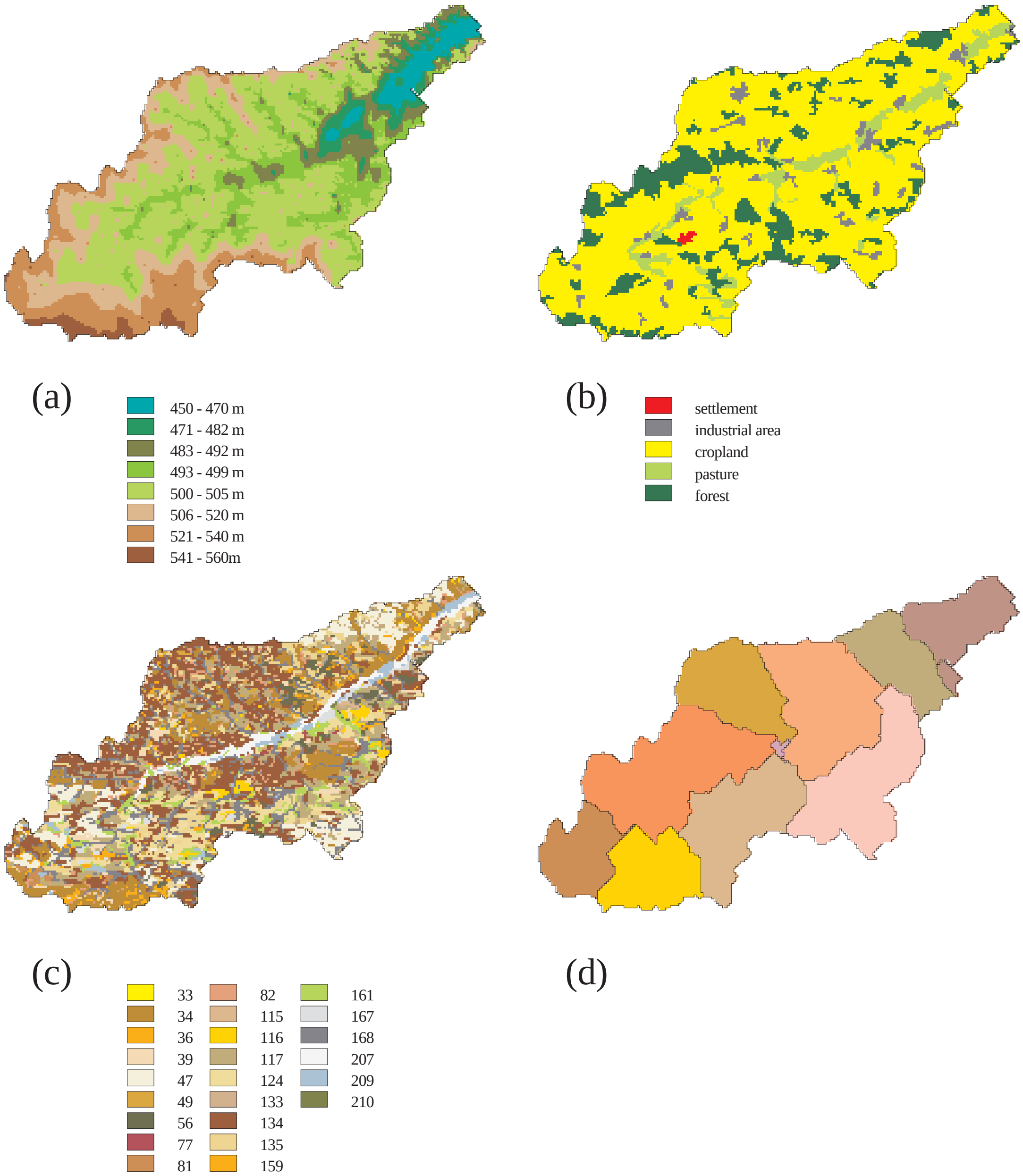


Fig 4.1 A set of four maps: Digital Elevation Model (a), land use (b), soil (c), and sub-basins (d) that are necessary to run SWIM/GRASS interface

The fourth, sub-basin map, can be created in GRASS based on the DEM map using the *r.watershed* program. Here the DEM resolution is important (see 4.1.2 for more details). There is a certain restriction on the average sub-basin area in SWIM, which has to be kept (see more details in 4.1.4). Together with sub-basins, the virtual river network can be calculated, which is useful for checking the routing structure.

The map of river network (5) is useful for comparison with the virtual river network calculated by *r.watershed*, and for checking the routing structure. Comparison of river networks calculated in GRASS and digitazed is demonstrated in **Fig. 4.2** for the Mulde basin.

The map of river gage stations (6) can be used for delineation of the basin boundaries, if the sub-basin map is created in GRASS.

The alpha-factor map for groundwater (7) is useful, if the ground water table has to be modelled specifically for the basin under study.

Maps of climate and precipitation stations and the corresponding maps of Thiessen polygons (8-11) are more important for larger basins, having several climate/precipitation stations. For smaller basins this information can be extracted directly from available paper maps. The Thiessen polygons can be also calculated in GRASS version 4.2 using the functions *s.geom* or *v.geom*.

A map of point sources of pollution (12) is necessary in case of water quality modelling, when the simulated load is compared with the observed load, and the point sources of pollution contribute a significant part in the river load and must be taken into account.

An important question is how to choose an adequate spatial resolution for the mesoscale river basin under study. This problem is of fundamental significance for hydrological and hydrochemical process modelling.

First of all, the spatial resolution and the time increment of the model are interrelated. SWIM is not designed for detailed modelling of flood processes with $\Delta T < 1$ day. Also, we exclude very flat areas with many lakes, where travelling time becomes too large. These problems require specific modelling tools. With these exceptions, the problem of spatial resolution appears in at least two very important questions:

- how the resolution of the Digital Elevation Model (DEM) is related to the watershed area, and
- whether an upper limit of a sub-basin area exists below which the effect of the river network can be neglected.

These two questions are discussed in 4.1.2 and 4.1.3.

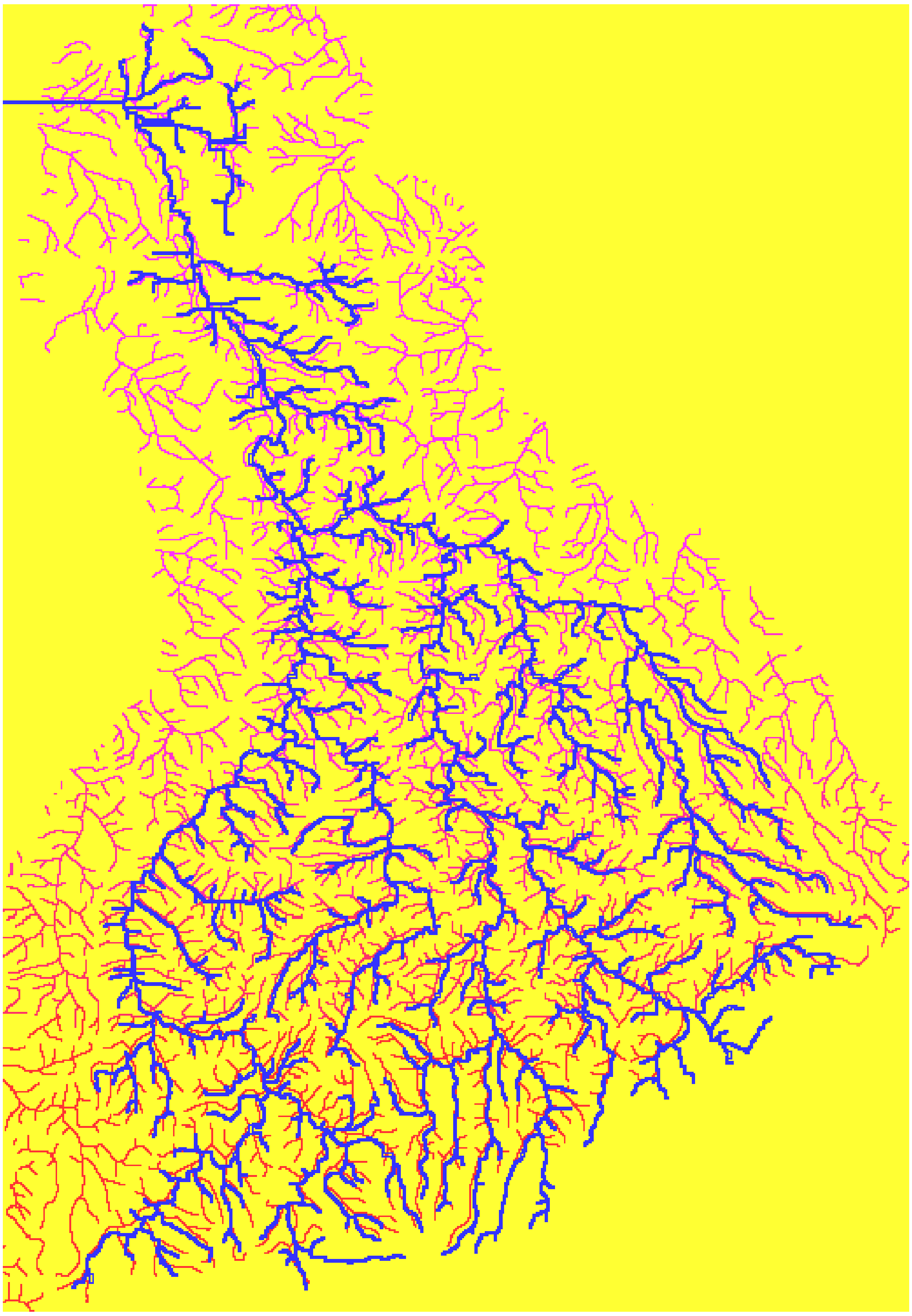


Fig. 4.2 Comparison of a virtual river networks produced by GRASS (blue) and a digitazed river network (red)

4.1.2 How to Choose Spatial Resolution?

Answering the first question, Maidment (1996) suggests using the so-called „thousand-million“ rule as a rough guide: take the area of the region under study and divide it by one million to give the appropriate cell size (area) to be used, then multiply the cell size chosen by one thousand which is then the minimum drainage area of watersheds that should be delineated from this DEM. This rule should not be understood as an absolute one, but should be treated with a certain level of approximation.

According to this rule, 930 m resolution should be used for delineation of a watershed with the drainage area of 4000 km^2, 460 m resolution for a 1000 km^2 watershed, 90 m for a 40 km^2 watershed, and 30 m for a 5 km^2 catchment. This is in agreement with our modelling experience from the studies performed in the Elbe drainage basin, where 100 m resolution was acceptable to represent a catchment of 64 km^2, 200 m resolution was sufficient to delineate a watershed with an area of 535 km^2, and 1000 m resolution was satisfactory for extracting watersheds with an area of 3,000-4,000 km^2.

Maidment (1996) also provides a useful Table showing the recommended cell size of DEM for some typical applications. For example, for a region size of 1000 km^2 a linear cell size of 30 m, and a sub-basin size of 5 km^2 are recommended. In the region with an area of 8000 km^2 the sub-basins of 40 km^2 can be delineated based on 90 m resolution. For a region size of 200,000 km^2 the recommended resolution is 460 m, and the sub-basin size 4000 km^2.

Following this rule more strictly, we can suggest the following **Tab. 4.1** for some commonly used resolutions:

Table 4.1 Recommended resolution of DEM for some typical applications

Linear cell size, m	*Cell area, km^2*	*Sub-basin area, km^2*	*Region or basin size, km^2*
30	0.0009	1	1,000
100	0.01	10	10,000
200	0.04	40	40,000
500	0.25	250	250,000
1000	1.	1,000	1,000,000

Of course, in practice these recommendations should be used with some degree of freedom.

4.1.3 How to Choose the Average Sub-basin Area?

The second question relates to the upper limit of the sub-basin area, below which the effect of the river network can be neglected, and the choice of the average sub-basin area when creating the sub-basin map.

According to Beven and Kirkby (1979), the effect of the channel network becomes important for basins larger than about 10 km^2, where the time constant of the network (i.e. travel time through it) becomes as long as for the infiltration phase. This is especially important for lowland, where the time constant may be very large.

On the other hand, in mountainous areas, where the time constant is rather low, the sub-basin area must be restricted due to climate gradients, because, as it was already explained in Chap. 1, the climate input in SWIM is considered to be homogeneous in sub-basins.

It is also known that 5 to 10 km (or 25 to 100 km^2) appears to be the minimum scale, above which inhomogeneities in land surface properties can trigger specific mesoscale atmospheric circulation systems, which have a definite impact on interactions between land surface and the atmosphere (Kuchment, 1992).

So the following pragmatic conclusion might be drawn: an average sub-basin area, where the effect of the river network may be neglected, should be in a range of 10 to 100 km^2 and definitely not larger than 100 km^2.

The restrictions on average sub-basin area and time step influence the computing time, and, taken together with the data availability, define the upper limit of the sub-basin area for the model application. An adequate spatial disaggregation should allow the applicability of the model to be extended to larger basins.

4.1.4 GRASS GIS Overview

GRASS (Geographic Resource Analysis Support System) (GRASS4.1, 1993) is a public domain raster GIS originally developed by the Environmental Division of the US Army Construction Engineering Research Laboratory (USA-CERL) as a general-purpose spatial modelling and analysis package. Since then, GRASS has evolved into a powerful tool with a wide range of applications in many different areas of scientific research. The new headquarters for GRASS support, research, and development is at Baylor University, the Department of Geology. Recently GRASS was upgraded to version 4.2, and the version 5.0 is underway.

GRASS is highly interactive and graphically oriented, providing tools for developing, analysing, and displaying spatial information. GRASS runs through the use of standardised command line input or under the X Window system under the UNIX environment. The following data formats are supported by GRASS:

- raster,
- vector,
- sites,
- satellite and air-photo image,
- import from ASCII, DXF, Image, and others,
- export to ASCII, DXF, Image, and others.

Though GRASS is the raster-based GIS, it can handle different data representations:

- raster (or grid cell) data can be analysed, overlayed, recalculated,
- vector data can be combined with raster data for display or analysis,
- point data can be used to represent the locations of significant sites.

New maps can be digitised or scanned. Maps can also be transferred from other GIS systems like ARC/INFO. Data files can be developed for large or small geographic regions at any scale desired within the limits of the source data and the storage capacity of the hardware.

GRASS was successfully coupled with a number of hydrological and water quality models, like ANSWERS, AGNPS, TOPMODEL, SWAT, and SWIM (Srinivasan and Engel, 1991; Rewerts and Engel, 1991; Chairat and Delleur, 1993; Srinivasan and Arnold, 1994; Krysanova *et al*., 1998a) in order to facilitate input of spatially-distributed information and enhance the use and utility of the models.

First of all, GRASS raster capabilities are very attractive for the use in spatially-distributed hydrological modelling, because spatial data can be easily translated from the GIS to the model in order to initialise it, and the model outputs can be transferred to GIS again for visualisation and analysis purposes. Second, GRASS is a public domain GIS, all program codes are available. This is different from other packages like ARC/INFO, and significantly facilitates further software development. Third, GRASS is written in the C programming language, which is also widely used for modelling. Forth, GRASS is flexible enough for a variety of applications, as soon as data layers can be transported to and from several other GIS, including ARC/INFO. Last, but not least, GRASS has specific programs for hydrological modelling and interpolation, which can be very useful.

According to our experience the combination of ARC/INFO and GRASS packages can be especially powerful, when ARC/INFO is used mainly for preparation and editing of basic map layers, and afterwards GRASS is used for analysis, reclassification, overlaying, recalculation and application of specific hydrological tools.

4.1.5 Useful GRASS Programs and Functions

GRASS includes special programs and functions for Display (starting with d.), General functions (g.), Raster functions (r.), Vector functions (v.), Sites functions (s.), Imagery functions (i.), as well as some other contributed programs and shell scripts.

Import/Export programs There are a number of transformation programs between GRASS and different other formats: ASCII (*v.in.ascii, v.out.ascii, r.in.ascii, r.out.ascii*), ARC/INFO (*v.in.arc, v.out.arc, r.in.ascii, r.out.ascii*), DXF (*v.in.dxf, v.out.dxf*), DLG (*v.import*), DLG-3 (*v.in.dlg, v.out.dlg*), MOSS (*v.out.moss*). When a map layer has been converted to a GRASS raster format, all raster support files (cellhd, cell_misc, cats, colr, and hist) must be checked for accuracy and completeness. The *r.support* program must be run to modify these files if necessary. Transformation routines sometimes do not work smoothly. It can be due to the fact that the requirements and steps are not sufficiently described in the Manual.

Conversion programs A GRASS database can be based upon one of four different coordinate systems: UTM, SPCS (State Plane Coordinate System), latitude/longitude, or Cartesian coordinate (x/y) system. The map projection that is most commonly used for maps in a GRASS database is the Transverse Mercator projection which is the basis for the to Universal Transverse Mercator (UTM) coordinate system. There are five programs available for conversion purposes:

m.ll2u	- converts geographic coordinates to Universal Transverse Mercator (UTM) coordinates for a number of spheroids,
m.u2ll and *m.region.ll*	- convert Universal Transverse Mercator (UTM) coordinates falling within the current geographic region to geographic (latitude/longitude) coordinates,
m.gc2ll	- converts geocentric to geographic coordinates for a number of possible spheroids,
m.ll2gc	- converts geographic coordinates to geocentric.

The use of geographic coordinates in GRASS is still rather restricted.

Display and printout It is not so easy to create the good-quality printed maps in GRASS that look professional. There is no automatic way to create legend with user-specified options, bar scale, north arrow. The *p.map* script file has to be created in advance in order to create a postscript file and then a map can be printed. The other possibility is to use any *screendump* or *grab* procedure, which is available in a number of packages, and then to add additional features using these tools. Some new capabilities in the map printing program are designed now.

Special hydrological support programs There are several programs in GRASS, which provide support for hydrological modelling. The program *r.watershed* is the main tool for delineation of basin and sub-basin boundaries based on DEM, and for calculating the LS (slope length and steepness) and S (slope steepness) factors of the Revised Universal Soil Loss Equation (RUSLE) (see more detailed description in 4.1.6). There are some more hydrologically-oriented programs in GRASS, like *r.basins.fill, r.cost, r.drain* as well as the useful interpolation tools.

The *r.basins.fill* program is similar to *r.watershed* but does not require DEM. It generates a raster map layer depicting sub-basins, based on two maps: 1) the coded stream network (each channel segment is „coded“ with a unique category value) and 2) the ridges within the given watershed (including the ridge which defines the perimeter of the watershed). The resulting output raster map layer codes the sub-basins with category values matching those of the channel segments passing through them.

The *r.cost* program determines the cumulative cost of moving to each cell on a cost surface (the input raster map) from other specified cell(s) whose locations are specified by their coordinates, and the *r.drain* program traces a flow through a least-cost path in an elevation model. The results for cells are similar to those obtained when using the *seg* version of the *r.watershed* program.

Interpolation programs There are two programs in GRASS for the interpolation from point data (*s.surf.idw* and *s.surf.tps*) and two programs for the interpolation from raster data (*r.surf.idw* and *r.surf.idw2*). The *s.surf.idw* fills a raster matrix with interpolated values generated from a set of irregularly spaced data points using numerical approximation (weighted averaging) techniques. The interpolated value of a cell is determined by values of nearby data points and the distance of the cell from those input points. In comparison with other methods, numerical approximation allows representation of more complex surfaces (particularly those with anomalous features), and restricts the spatial influence of any errors.

The *s.surf.tps* interpolates and computes topographic analysis from given site data (digitised contours, climatic stations, drill holes, etc.) to GRASS raster format using spline with tension. As an option, simultaneously with interpolation, topographic parameters like slope, aspect, profile curvature (measured in the direction of the steepest slope), tangential curvature (measured in the direction of a tangent to a contour line) or mean curvature are computed and saved as raster files. Topographic parameters are computed directly from the interpolation functions so that the important relationships between these parameters are preserved. The equations and their interpretation are described in Mitasova et al., 1996.

Two programs *r.surf.idw* and *r.surf.idw2* fill a grid cell (raster) matrix with interpolated values generated from a set of input layer data points or irregularly spaced data points. They use a numerical approximation technique based on distance squared weighting of the values of nearest data points. The number of nearest data points used to determine the interpolated value of a cell can be specified by the user (default: 12 nearest data points). Unlike *r.surf.idw2*, which processes all input data points in each interpolation cycle, *r.surf.idw* attempts to minimise the number of input data for which distances have to be calculated. Execution speed is therefore a function of the search effort and does not increase appreciably with the number of input data points. The r.surf.idw2 does not work with latitude/longitude data, in such a case the r.surf.idw should be used.

There are a number of useful GRASS commands, which are necessary for any SWIM user. They are needed for visualisation, recalculation, and reclassification of map layers. In the **Appendix I** the most useful GRASS commands are listed, which are needed for spatial data preparation.

4.1.6 Map Export from ARC/INFO to ASCII Format

Raster Data in ARC/INFO A raster data set in ARC/INFO is called a "Grid". All operations on grids are performed in the module with the same name. The resolution (or cell size) of any existing grid can be changed using the resample function, which offers different algorithms for categorial and continuous data. Conversion from vector to raster data in ARC/INFO can be either done on the Arc prompt, or within Grid. Both procedures are similar and can be performed with polygon, line or point input data. The user has to define the desired cell size, because one coverage can be gridded using different resolutions. By defining the coordinates of a lower left corner and a desired number of rows and columns, the processing can be focussed on a certain part of the coverage, if necessary. As GRASS version 4.2 does not yet support the NODATA data format, it is recommended to select ARC/INFO's ZERO option using "0" as NODATA (or background) value.

Data Exchange between ARC/INFO and GRASS As neither GRASS 4.2 can import ARC/INFO grids, nor ARC/INFO can read GRASS raster maps directly, the data exchange between both systems should be performed using ASCII format. Both systems can produce and read ASCII files containing the data as a continuous stream of values separated by blanks. The information about how to produce a raster map for the system is stored in a header section containing the coordinates of the corner (or north, south, east west coordinates) and the number of rows and columns. ARC/INFO's header format looks like

NCOLS xxx
NROWS xxx
XLLCORNER xxx
YLLCORNER xxx
CELLSIZE xxx
NODATA_VALUE xxx,

whereas GRASS uses the following header:

north: xxx
south: xxx
east: xxx
west: xxx
rows: xxx
cols: xxx

An example of data conversion Let us assume that we want to grid a polygon coverage called "lupoly" containing land use information (item lu-code) with cell size 50 and a line coverage "fgw" containing the stream network of the same region. The necessary commands are listed below (the comments are between **).

Step 1:
Usage: POLYGRID <in_cover> <out_grid> {value_item} {lookup_table} {weight_table}
Arc: POLYGRID lupoly lugrd lu-code

Converting polygons from lupoly to grid lugrd
Cell Size (square cell): 50
Convert the Entire Coverage? (Y/N): y
Number of Rows = 648 ** the value is calculated by the program**
Number of Columns = 604 ** the value is calculated by the program**

Step 2:
Usage: LINEGRID <in_cover> <out_grid> {value_item} {lookup_table} {weight_table}
Arc: LINEGRID fgw fgwgrd

Converting arcs from fgw to grid fgwgrd
Cell Size (square cell): 50
Convert the Entire Coverage(Y/N)?: y
Enter background value (NODATA | ZERO): zero
Number of Rows = 493 ** the value is calculated by the program**
Number of Columns = 553 ** the value is calculated by the program**

An example of changing the cellsize of an existing grid Let us assume that we want to change the cell size of lugrd from its original size of 50 cells to 100 cells using the nearest-neighbour assignment as default option. (N.B.: This of course could be done earlier when prompted during POLYGRID).

Arc: grid ** starts the grid module**

Grid: lugrd2 = resample(lugrd,100)
Resample ...
Grid: quit   ** leaves the grid module**

An example of export to ASCII file Let us assume that now we want to export lugrd and fgwgrd to ASCII files.

Usage: GRIDASCII <in_grid> <out_ascii_file> {item}
Arc: GRIDASCII lugrd lugrd.txt
Arc: GRIDASCII fgwgrd fgwgrd.txt

The header of lugrd.txt is:

```
ncols         604
nrows         648
xllcorner     4492676.68
yllcorner     5884875.398
cellsize      50
NODATA_value  -9999
```

The header of fgwgrd.txt is:

```
ncols         553
nrows         493
xllcorner     4494452.5
yllcorner     5886652
cellsize      50
NODATA_value  -9999
```

It is obvious that although both grids have the same cell size, they do not match, because their llcorners' coordinates' difference is not a multiple of their cell size. In such a case it is recommended to use the coordinates of lugrd as an input to LINEGRID as shown in the following example.

An example of producing matching grids The following commands should be done:

Usage: DESCRIBE <geo_dataset>
Arc: DESCRIBE lugrd

```
        Description of Grid LUGRD
 Cell Size =  50.000                 Data Type: Integer
Number of Rows  =  648               Number of Values =  14
Number of Columns = 604              Attribute Data (bytes) =  8

         BOUNDARY                        STATISTICS
 Xmin =  4492676.680        Minimum Value =  111.000
Xmax =  4522876.680         Maximum Value =  512.000
Ymin =  5884875.398         Mean  =  225.421
Ymax =  5917275.398         Standard Deviation =  42.130
```

Arc: LINEGRID fgw fgwgrd
Converting arcs from fgw to grid fgwgrd
Cell Size (square cell): 50

Convert the Entire Coverage(Y/N)?: n **in Example 1 we entered y **
Grid Origin (x, y): 4492676.680,5884875.398 **values taken from lugrd **
Grid Size (nrows, ncolumns): 648,604 **values taken from lugrd **

Enter background value (NODATA | ZERO): zero
Number of Rows = 648
Number of Columns = 604
Arc: GRIDASCII fgwgrd fgwgrd.txt

Now fgwgrd.txt's header looks as follows:

```
ncols        604
nrows        648
xllcorner    4492676.68
yllcorner    5884875.398
cellsize     50
NODATA_value  -9999
```

After the header information has been changed, both ASCII files are almost ready to be imported to GRASS running r.in.ascii (after changing the header).

An example of changing the header information The map exported from ARC/INFO in ASCII format has the heading, which consists of six lines, describing coordinates of the lower left corner, number of columns and rows, and the cell size, e.g.:

```
ncols        349
nrows        542
xllcorner    69367.3
yllcorner    37980.7
cellsize     1000
NODATA_value  -9999
```

However GRASS requires slightly different format for its *r.in.ascii* program, describing the coordinates of north, south, east and west, and the number of rows and columns, like:

```
north:579980.7
south: 37980.7
east: 418367.3
west: 69367.3
rows: 542
cols: 349
```

The ARC/INFO export file in ASCII format can be transformed to GRASS input ASCII format using the program arc2grass, which is included in the SWIM model package.

4.1.7 Watershed Analysis Program r.watershed

Delineation of watersheds from the Digital Elevation Model (DEM) is the first necessary step in many hydrological applications. A procedure that has become a standard one is based on the eight-direction basis in which each grid cell is connected to one of its eight neighbour cells according to the direction of steepest descent. Another possibility is to use the four-direction procedure for watershed delineation.

Based on an elevation grid, a grid of flow direction is built, and then a map of flow accumulation is derived from the flow direction map, counting the number of cells upstream of a given cell. Streams are identified as lines of cells whose flow accumulation exceeds a specified threshold number of cells and thus a specified upstream drainage area. This threshold number must be specified in advance. Watershed is delineated as the set of all cells draining through a given cell.

GRASS program *r.watershed* is the main tool for delineation of basin and sub-basin boundaries and calculating the LS (slope length and steepness) and S (slope steepness) factors of the Revised Universal Soil Loss Equation (RUSLE) in GRASS.

There are two versions of this program available in GRASS: *ram* and *seg*. Which of them is run depends on whether the -m flag is set or not. The *ram* version uses virtual memory managed by the operating system to store data and is much faster than the *seg* version. The *seg* version (with the -m flag) uses the memory on disk which allows larger maps to be processed but is considerably slower.

The *seg* version uses the AT least-cost search algorithm (Ehlschlaeger, 1989) to determine the flow of water over the landscape and is more reliable than *ram*. In addition to the elevation map, maps of depressions in the landscape and blocking terrain can be provided to assure more reliable watershed boundaries.

Due to memory requirements of both *seg* and *ram* versions of the program, it is quite easy to run out of memory. If the resolution of the current region cannot be increased, more memory needs to be added to the computer. GRASS Reference Manual provides recommendations on how to use the coarser resolution. Masking out unimportant areas is another means to reduce processing time significantly if the watershed of interest occupies only a part of the overall area. According to our experience, the *seg* version of the program is much more reliable. Our recommendation is to use only this version for watershed delineation (using the -m flag).

After the watersheds are delineated for a certain region, an analysis of output maps has to be done in order to identify the basin under study and its sub-basins. For this purpose the basin, accumulation, and streams output maps are needed, as well as any available digitised maps of the basin boundaries or river network. Comparison of digitised and calculated rivers, digitised and calculated watershed boundaries can be very helpful in order to find some mistakes or inconsistencies in the DEM. An example of resulted sub-basin map with the river network is given in **Fig. 4.3.**

After correction of the DEM the procedure *r.watershed* can be repeated. It is also quite difficult to find an appropriate threshold value from the very beginning. Usually, it is necessary to repeat the procedure several times with different thresholds. The user has to remember that LS and S factors are multiplied by 100 for the GRASS output map layer, since they are usually small numbers.

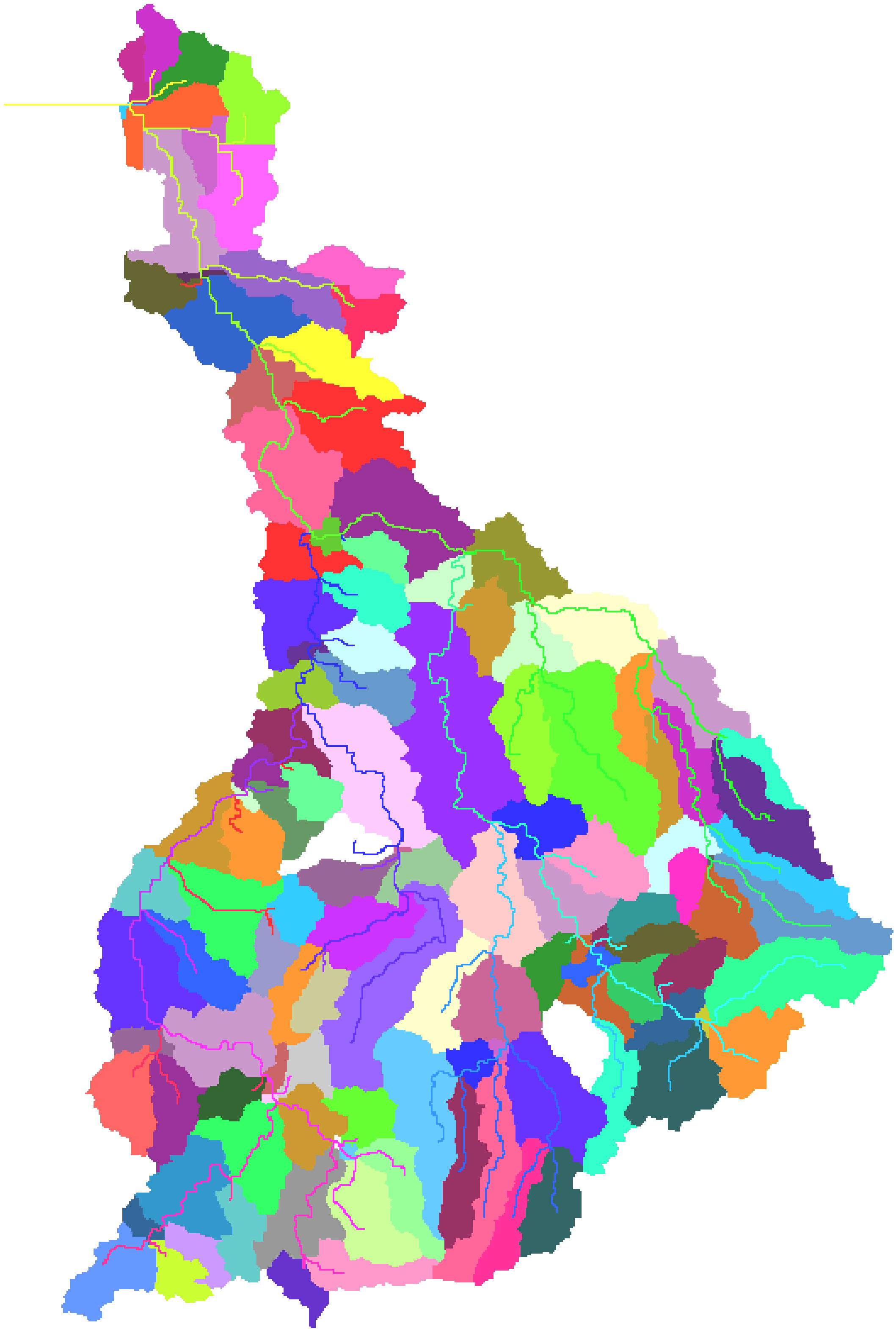


Fig. 4.3 Virtual subbasins obtained by applying r.watershed function in GRASS for the Mulde river basin

4.1.8 DEMO Data Set

Here the DEMO data set for spatial data preparation is described. The maps for the Glonn basin in Bavaria (drainage area 392 km^2) were used for that.

Input data in ASCII format The exemplary export files in ASCII format produced in ARC/INFO are located in the directory */grassdata*. They are: the Digital Elevation Model map in the file

glonn160-dem.asc,

and the soil map in the file

glonn160-soil.asc.

The program *arc2grass* can be used for converting the ARC/INFO export files to GRASS format. The resulting ASCII files for these two and other maps, which are ready for GRASS import, are located in the same directory

- glonn160-dem.txt - DEM map,
- glonn160-lus.txt - land use map,
- glonn160-soil.txt - soil map,
- glonn160-fluss.txt - a river map,
- glonn160-rivnet.txt - a more detailed river map,
- glonn160-pegel.txt - gage station map,
- glonn160-clst.txt - climate stations map
- glonn160-prst.txt - precipitation stations map
- glonn160-clst-this.txt - a map with Thiessen polygons for climate stations,
- glonn160-prst-this.txt - a map with Thiessen polygons for precipitation stations.

Geographic location Let us assume that the geographic location with the name *glonn160* is created by the user *usern* in the directory */usern/databases*. Here 160 indicates the resolution of maps in this location (which was chosen in accordance with the resolution of available DEM map). The directory */usern/databases* contains at least two subdirectories: */PERMANENT* and */usern*. The directory */PERMANENT* describes the name (file *MYNAME*) and coordinates (file *WIND*) of the geographic location. In our case the file *WIND* looks as following:

proj:	0
zone:	0
north:	6098669
south	6064429
east:	123951
west:	73871
cols:	313
rows:	214
e-w resol:	160
n-s resol:	160

The directory */usern/databases/glonn160/usern* is designated for all GRASS files in this geographic location, which will be stored under subdirectories: *cats, catts_dig, cell, cell_misc, cellhd, colr, dig, dig_ascii, dig_att, dig_cats, hist*. Here the user name *usern* corresponds to the name of MAPSET, which is asked always when starting GRASS session. All files from this directory can be copied by any other user and used independently.

Map input to GRASS As a first step, a number of maps can be created by introducing data in ASCII format to GRASS using *r.in.ascii* command. For example, the following maps listed in **Tab. 4.2** can be introduced from available ASCII data:

Table 4.2 List of source ASCII files and the corresponding maps in GRASS

GRASS map	*Map description*	*The corresponding source ASCII file*
dem	DEM	glonn160-dem.txt
lus	Land use	glonn160-lus.txt
soil	Soil	glonn160-soil.txt
fluss	River network	glonn160-fluss.txt
flussnet	Detailed river network	glonn160-rivnet.txt
pegel	Gage station	glonn160-pegel.txt
clst	Climate stations	glonn160-clst.txt
prst	Precipitation stations	glonn160-prst.txt
clstthis	Thiessen polygons for climate stations	glonn160-clst-this.txt
prstthis	Thiessen polygons for precipitation stations	glonn160-prst-this.txt

Program r.watershed After that the program *r.watershed* can be applied to the Digital Elevation Model *dem* in order to create sub-basin maps. Let us assume that we applied this program six times (always with a flag *–m*) with different thresholds. The threshold is defined as a minimum size of the exterior watershed basin. As a result, a number of sub-basin maps (*basN*) and stream network maps (*rivN*) will be created as listed in **Tab. 4.3**:

Table 4.3 Maps created with *r.watershed* using different thresholds

Threshold (number of cells)	*Corresponding area, km^2*	*Created maps*
3600	92.16	bas1, riv1
1800	46.08	bas2, riv2
900	23.04	bas3, riv3
200	5.12	bas4, riv4
100	2.56	bas5, riv5
50	1.26	bas6, riv6

We can compare the average, minimum and maximum sub-basin area for three different sub-basin maps *bas3, bas4,* and *bas6*, created with different thresholds (see **Fig. 4.4** and **Tab. 4.4**).

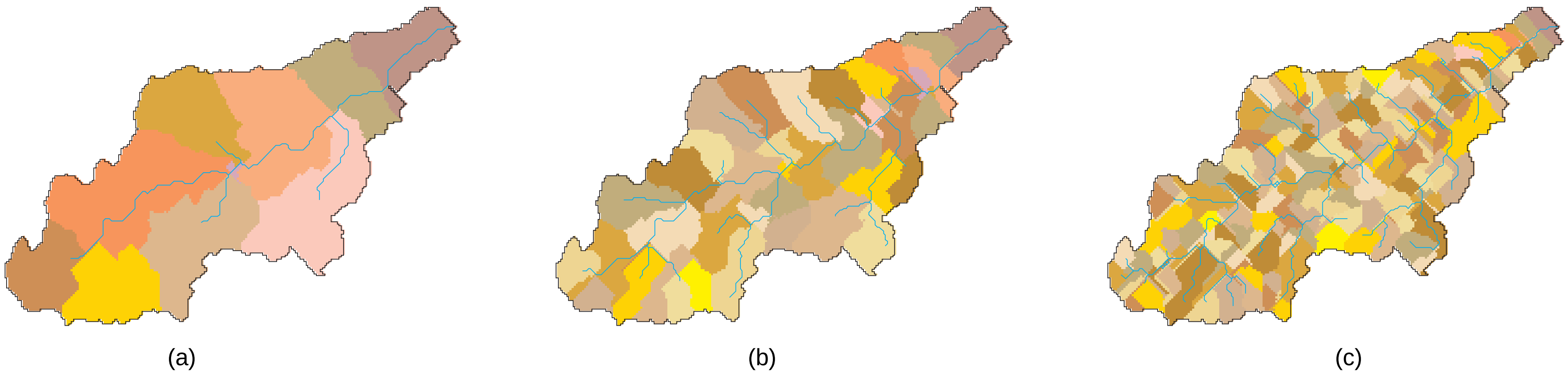


Fig 4.4 A set of sub-basin and river network maps produced with *r. watershed* using different thresholds: 900 (a), 200 (b) and 50 (c)

Table 4.4 Comparison of three sub-basin maps created with different thresholds

Raster map name	*Number of sub-basins*	*Average sub-basin area, km²*	*Minimum sub-basin area, km²*	*Maximum sub-basin area, km²*
bas3	10	40.6	1.02	72.2
bas4	42	9.7	0.36	19.1
bas6	162	2.5	0.05	11.2

As we can see, 10 sub-basins with an average area of 40.6 km^2 were created with threshold 900 cells, or 23.04 km^2, 42 sub-basins with an average area of 9.7 km^2 were created with threshold 200 cells, or 5.12 km^2, and 162 sub-basins with an average area of 2.5 km^2 were created with threshold 50 cells, or 1.26 km^2. In other words, the threshold corresponds approximately to ½ of the average area of created sub-basins. This has to be taken into account when estimating the threshold values. Finally, the three sub-basin maps: bas36, bas44 and bas64 were chosen for model application.

Reclassification and analysis The original land use map *lus* has to be reclassified to SWIM land use categories. The latter one, as well as the *dem* and *soil* maps have to be clipped using a mask (e.g. corresponding to the *bas3* map), to get the final maps *dem3, lus3, soil3*, which can be used by Interface. Finally, the four maps (e.g. *dem3, lus3, soil3* and *bas3*) are ready for SWIM/GRASS interface.

The programs *r.stats* and *r.report* (see **Appendix I**) are useful for the analysis of obtained maps. For example, using the function *r.report* as

```
r.report -z map=soil3 units=k,p output=gl160-soil.rep
```

we can get the following report about the soil map soil, indicating areal distribution of soil categories (in km^2 and in percent). For example, **Tab. 4.5** includes GRASS report about the soil map soil3, indicating areal distribution of soil types.

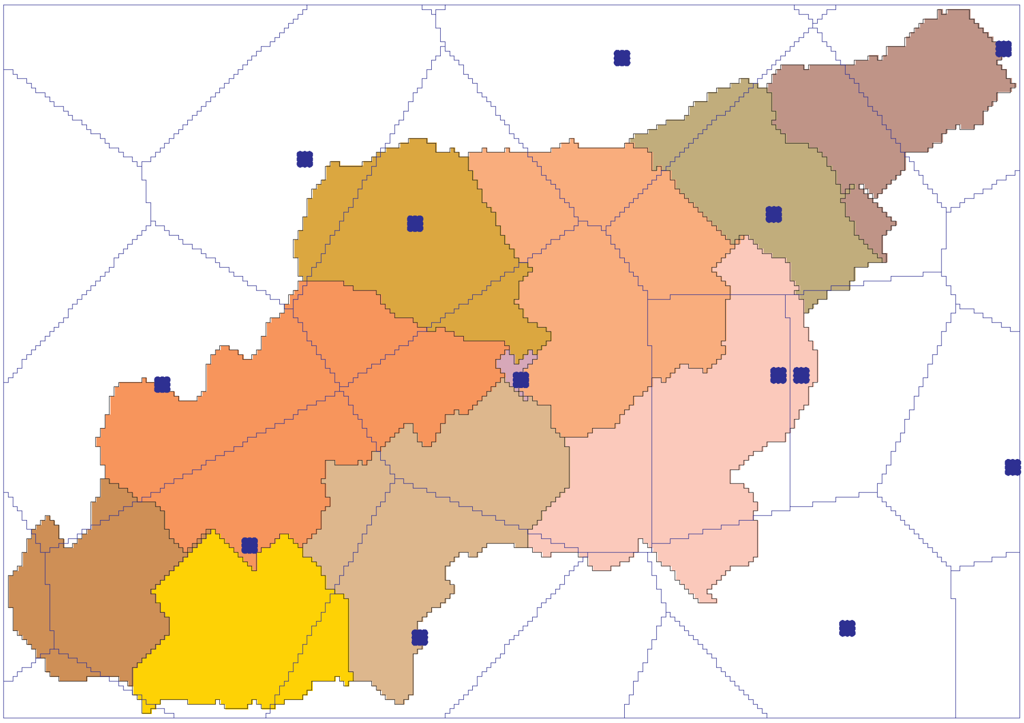
Fig. 4.5 demonstrates an overlay of sub-basins (bas3), precipitation stations (prst2), and Thiessen polygons for precipitation stations. The report about two of these maps:

```
r.report -z map=bas3,prstthis units=k,p output=glonn-bas36-prstthis.rep
```

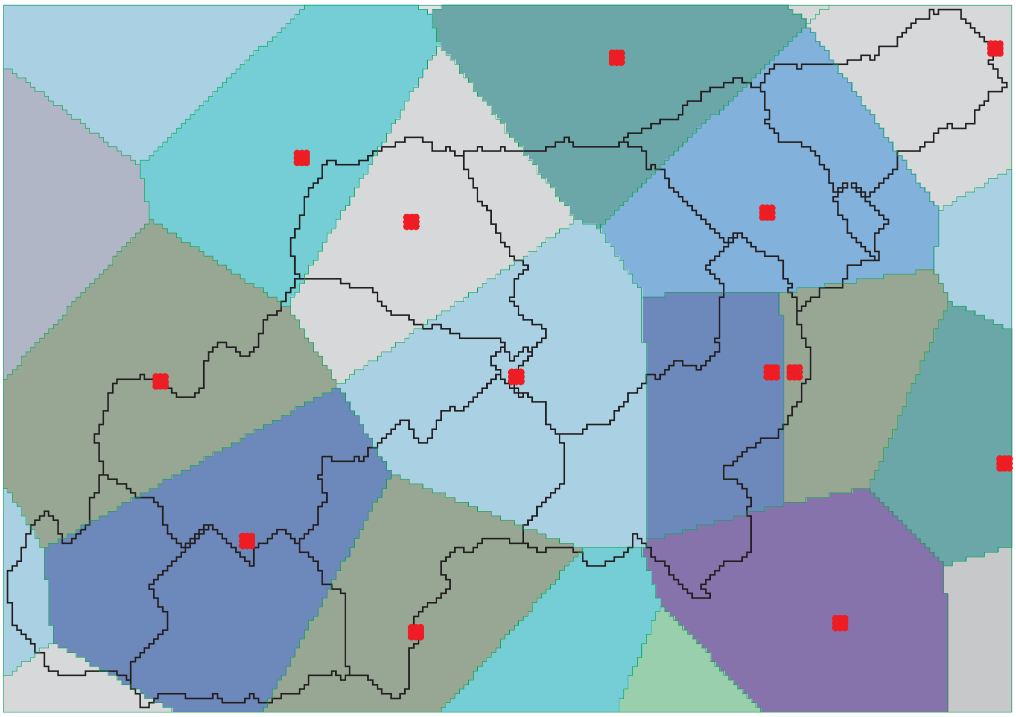
is given in **Tab. 4.6**.Such a report can be very helpful in establishing the connection between sub-basins and precipitation stations (weighting coefficients).

Table 4.5 GRASS report about the soil map soil3, indicating areal distribution of soil types

```
+-----------------------------------------------------------------------------+
|                         RASTER MAP CATEGORY REPORT                          |
|LOCATION: glonn160                                   Tue Apr 20 12:09:32 1999|
|-----------------------------------------------------------------------------|
|          north: 6092269    east: 113711                                     |
|REGION    south: 6067469    west:  78351                                     |
|          res:       160    res:     160                                     |
|-----------------------------------------------------------------------------|
|                     Category Information                |  square   |   %  |
|  #|description                                         |kilometers| cover |
|-----------------------------------------------------------------------------|
| 33| . . . . . . . . . . . . . . . . . . . . . . . . . . | 49.433600| 12.24|
| 34| . . . . . . . . . . . . . . . . . . . . . . . . . . |  6.809600|  1.69|
| 36| . . . . . . . . . . . . . . . . . . . . . . . . . . |  6.604800|  1.64|
| 39| . . . . . . . . . . . . . . . . . . . . . . . . . . | 31.308800|  7.75|
| 47| . . . . . . . . . . . . . . . . . . . . . . . . . . |  4.940800|  1.22|
| 49| . . . . . . . . . . . . . . . . . . . . . . . . . . | 11.468800|  2.84|
| 56| . . . . . . . . . . . . . . . . . . . . . . . . . . |  1.536000|  0.38|
| 77| . . . . . . . . . . . . . . . . . . . . . . . . . . |  0.307200|  0.08|
| 81| . . . . . . . . . . . . . . . . . . . . . . . . . . |  2.355200|  0.58|
| 82| . . . . . . . . . . . . . . . . . . . . . . . . . . | 11.878400|  2.94|
|105| . . . . . . . . . . . . . . . . . . . . . . . . . . |  1.382400|  0.34|
|115| . . . . . . . . . . . . . . . . . . . . . . . . . . |  4.377600|  1.08|
|116| . . . . . . . . . . . . . . . . . . . . . . . . . . | 47.462400| 11.75|
|117| . . . . . . . . . . . . . . . . . . . . . . . . . . | 27.750400|  6.87|
|124| . . . . . . . . . . . . . . . . . . . . . . . . . . |  0.358400|  0.09|
|133| . . . . . . . . . . . . . . . . . . . . . . . . . . | 87.782400| 21.73|
|134| . . . . . . . . . . . . . . . . . . . . . . . . . . | 23.680000|  5.86|
|135| . . . . . . . . . . . . . . . . . . . . . . . . . . |  2.611200|  0.65|
|159| . . . . . . . . . . . . . . . . . . . . . . . . . . | 14.054400|  3.48|
|161| . . . . . . . . . . . . . . . . . . . . . . . . . . |  3.430400|  0.85|
|167| . . . . . . . . . . . . . . . . . . . . . . . . . . | 43.264000| 10.71|
|168| . . . . . . . . . . . . . . . . . . . . . . . . . . | 11.648000|  2.88|
|207| . . . . . . . . . . . . . . . . . . . . . . . . . . |  6.707200|  1.66|
|209| . . . . . . . . . . . . . . . . . . . . . . . . . . |  0.128000|  0.03|
|210| . . . . . . . . . . . . . . . . . . . . . . . . . . |  2.662400|  0.66|
|-----------------------------------------------------------------------------|
|TOTAL                                                   |403.942400|100.00|
+-----------------------------------------------------------------------------+
```



(a)



(b)

Fig 4.5 An overlay of the sub-basin map, the precipitation station map and the Thiessen polygon map for the Clonn basin (a, b)

Table 4.6 GRASS report about sub-basin map bas3 and the map of Thiessen polygons for precipitation stations

RASTER MAP CATEGORY REPORT

LOCATION: glonn160 Thu Apr 1 10:07:56 1999

REGION	north: 6093229	east: 114831
	south: 6067469	west: 78351
	res: 160	res: 160

#	description (Category Information)	square kilometers	% cover
1		32.256000	3.43
	92164	15.308800	47.46
	92165	16.947200	52.54
2		30.771200	3.27
	90661	4.096000	13.31
	92156	0.537600	1.75
	92164	26.137600	84.94
3		60.851200	6.48
	90661	8.217600	13.50
	92160	25.292800	41.56
	92162	8.627200	14.18
	92164	11.929600	19.60
	92169	6.784000	11.15
4		39.040000	4.15
	90634	5.017600	12.85
	92160	5.939200	15.21
	92162	28.083200	71.93
5		1.024000	0.11
	92160	1.024000	100.00
6		72.192000	7.68
	90625	25.318400	35.07
	92160	14.361600	19.89
	92161	23.040000	31.91
	92162	9.472000	13.12
7		28.211200	3.00
	90624	4.300800	15.25
	90625	2.252800	7.99
	92135	1.305600	4.63
	92161	20.352000	72.14
8		33.920000	3.61
	92141	5.094400	15.02
	92161	28.825600	84.98
9		50.508800	5.37
	92141	23.168000	45.87
	92160	19.865600	39.33
	92161	7.475200	14.80
10		57.292800	6.10
	92141	1.536000	2.68
	92142	5.785600	10.10
	92156	3.046400	5.32
	92160	14.771200	25.78
	92164	3.788800	6.61
	92169	28.364800	49.51
TOTAL		939.724800	100.00

4.2 SWIM/GRASS Interface

Throughout SWIM/GRASS, two primary types of interface input are used:

1) Text input that can be completed by hitting the RETURN key. In most cases, if no text was entered, the given question or operation is cancelled. Most often the text input will consist of the name of a new or existing map or project name, in which case entering the word "list" will provide a list of currently used names.

2) Text or menu options that can be completed by hitting the ESC (escape) key. This type of interface is used for menus or for entering tables of parameters. All menus have a default answer of Exit (0), so that by simply hitting ESC one may leave the program's menus.

The following **Tab. 4.7** provides a keystroke guide, which is helpful when using the parameter entry worksheets that use this interface:

Table 4.7 Keystroke guide for using the interface

key	*the function*
<RETURN>	moves the cursor to next prompt field
<CTRL-K>	moves the cursor to previous prompt field
<CTRL-H>	moves the cursor backward non-destructively within the field
<CTRL-L>	moves the cursor forward non-destructively within the field
<CTRL-A>	copies the screen to a file named "visual_ask" in the users home directory
<CTRL-C>	where indicated (on the bottom line of the screen) can be used to cancel operation

Starting GRASS and SWIM_INPUT Before running SWIM/GRASS interface, GRASS has to be started. For that, the user has to start GRASS:

```
grass4.2.1
```

The following information window will appear:

```
GRASS 4.2.1

LOCATION: This is the name of an available geographic location.
           spearfish is the sample data base for which all tutorials
           are written.

MAPSET:   Every GRASS session runs under the name of a MAPSET.
           Associated with each MAPSET is a rectangular COORDINATE
           REGION and a list of any new maps created.

DATABASE: This is the unix directory containing the geographic
           databases

           The REGION defaults to the entire area of the chosen
           LOCATION. You may change it later with the command: g.region
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

LOCATION:   glonn160______      (enter list for a list of locations)
MAPSET:     usern_________      (or mapsets within a location)

DATABASE:   usern/databases________________



              AFTER COMPLETING ALL ANSWERS, HIT <ESC> TO CONTINUE
                             (OR <Ctrl-C> TO CANCEL)
```

The Location and Database names are the last entered. If you need another ones, please change the names. After entering GRASS, the user can open the monitor with the command *d.mon*. After that SWIM/GRASS interface can be started:

```
cd  usern/swiminput
swim_input
```

The following window will appear:

```
SWIM / GRASS Project Manager

  This program is designed to help you use information in
  GRASS raster layers to create an input file to run on a
  standard version of the SWIM basin simulation program.
  All steps of this process are recorded in data files
  stored under a project name in your GRASS database.

                   Choose desired option:

                  0.  Exit
                  1.  Create new project
                  2.  Work on an existing project
                  3.  Copy an existing project
                  4.  Remove an existing project

          Option: 0_

              AFTER COMPLETING ALL ANSWERS, HIT <ESC> TO CONTINUE
                              (OR <Ctrl-C> TO EXIT)
```

Options of the main menu The user can use option 1 to create a new project, or option 2 to continue working on an existing project. If you want to create a new project, choose the option 1. After that you have to enter the project name. The name should correspond to the basin name, but it has to be not too long (maximum 8 letters), for example, we choose ‚gl':

```
Enter project name:

Enter 'list' for a list of existing SWIM / GRASS project files
Hit RETURN to cancel request
> gl
```

Then the following Data Extraction Menu will appear:

```
SWIM / GRASS Project Data Extraction Menu
    Project Name:  gl

                   Choose desired option:
        0   Quit
        1   Extract data from layers
        2   Display Raster, Vector and/or Site Maps
run     3   Extract Basin Attributes
run     4   Extract Hydrotop Structure
run     5   Extract Topographic Attributes
run     6   Extract Groundwater Attributes
run     7   Compute Routing Structure and Create .fig file
run     8   Extract Climate Station
run     9   Extract Precipitation Station


 Option: 0__
              AFTER COMPLETING ALL ANSWERS, HIT <ESC> TO CONTINUE
                             (OR <Ctrl-C> TO EXIT)
```

Data Extraction Steps 3 to 7 have to be run one after another, after that option 0 has to be chosen. Steps 8 and 9 are not up to date, they have to be modified.

When the option 3 is chosen to extract basin attributes, the name of the basin and sub-basin map is asked. Assuming that we use the maps described in the previous section, the name ‚bas36' has to be entered:

```
Basin and Subbasin Map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> bas36
```

When the option 4 is chosen to extract the hydrotope structure, the names of three maps: 1) basin and sub-basin, 2) land use and 3) soil are asked:

```
Basin and Subbasin Map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> bas36
<bas36>
```

```
Landuse Map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> lus36
<lus36>

Soil Map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> soil36
```

When the option 5 is chosen to extract topographic attributes, the name of the elevation map has to be entered:

```
Elevation Map
Enter 'list' for a list of existing raster files
Enter 'list -f' for a list with titles
Hit RETURN to cancel request
> dem36
```

When the option 6 is chosen to extract groundwater attributes, the name of the groundwater alpha map is asked. If the user does not have such a map, an option ‚n‘ has to chosen:

```
Do you have groundwater alpha parameter map?(y/n) [y]
n
```

The next step is to choose 7 in order to compute routing structure of the basin. If the routing structure is calculated without problems, the user gets a message about the outlet sub-basin, like:

```
outlet subbasin number is 1
```

Please note that the outlet sub-basin has to numbered with 1, otherwise the user has to recode the output. After that the user has to choose ‚0‘ to quit the SWIM/GRASS interface. The results will be stored in the directory:

```
in usern/databases/glonn160/usern/swim/gl,
```

which corresponds to the DATABASE/LOCATION/MAPSET/swim/projectname. In our case the full list of resulting files is the following:

```
file.cio  gl.str gl.fig gl.proj str.cio  gl.cod gl.bsn
gl0.sub gl0.gw gl0.rte
gl1.sub gl1.gw gl1.rte gl2.sub gl2.gw gl2.rte
gl3.sub gl3.gw gl3.rte gl4.sub gl4.gw gl4.rte
gl5.sub gl5.gw gl5.rte gl6.sub gl6.gw gl6.rte
gl7.sub gl7.gw gl7.rte gl8.sub gl8.gw gl8.rte
gl9.sub gl9.gw gl9.rte
```

,where the number n corresponds to the sub-basin number n+1.

Possible problem In some cases, option 7 runs not so smoothly, and the message like

```
Start checking the aspect through each subbasin
More than one outlet from subbasins 1 and 40
More than one outlet found from subbasins 40 1
Do you agree with this?(y/n) [y]
```

can appear. If the user chooses ‚y', the routing structure file will be created, but without sub-basin 40. In such a situation ‚n' has to be chosen in order to edit aspect. After choosing ‚n', the programs asks:

```
Would you like to continue?(y/n) [y]
```

When the user answers: ‚y', the following Sub-basin Aspect Editing menu will appear:

```
Subbasin Aspect Editing/Error Checking Menu
   Project Name:  gl

                   Choose desired option:
        0   Return to Previous Menu
        1   Check for Errors in Subbasin Aspect
        2   Edit Subbasin Aspect Using Key board
        3   Edit Subbasin Aspect Using Graphic Monitor
        4   Display Subbasin Number on the Graphic Monitor
```

Please choose the option 3, and point on two sub-basins sequentially. For example, if you know that stream in sub-basin 40 flows to sub-basin 38, then point two sub-basins: first sub-basin 40, then sub-basin 38. After that click on non-basin area to finish.

Working on existing project If the user wants to continue working on an existing project, he/she can start from that point, where the project was stopped the former time.

4.3 Relational Data Preparation

4.3.1 An Overview of Relational Data

The full list of necessary relational data is the following:
1. Climate data: average, minimum and maximum daily air temperature, daily precipitation, and daily solar radiation,
2. soil geophysical and geochemical parameters,
3. crop types, crop rotation and crop management,
4. river discharge at the basin outlet,
5. water quality parameters (N, P, suspended solids) at the basin outlet,
6. river cross-sections or mean river width and depth,
7. rainfall intensity parameters.

The climate and soil data (1-4) are absolutely necessary to run the model.

Information about crop types in the basin, crop rotation and crop management (dates of planting and harvesting, dates and rates of fertilization) (5) is needed to initialise the model. If detailed information about crop management is not available for the studied basin, at least expert knowledge should be used in this case.

Measured river discharge and water quality parameters (6-7) are necessary for model validation.

River cross-sections (8) or mean river width and depth in several points of a basin (approximately one per sub-basin) can facilitate the model verification, especially for lateral processes (water and chemicals routing). The other way is to use the default stream width and depth parameters extracted from DEM by SWIM/GRASS interface.

Rainfall intensity parameters (9), which include
- ten years frequency of I_{30} - the maximum annual half-an-hour rainfall,
- ten years frequency of I_{360} - the maximum annual six-hours rainfall, and
- long-term monthly maximum of the half-an-hour rainfall,

are necessary for erosion modelling.

In the following sections specific data requirements for climate, soil, crops, curve numbers are considered with some more detail.

4.3.2 Climate Data

The climate parameters necessary to drive the model are daily precipitation, air temperature (maximum, average, and minimum), and solar radiation. Usually, the climate data must be taken from meteorological and precipitation stations. This is absolutely necessary in the case of model validation for a specific basin. Note that the climate data have to be corrected, no missing values in form of –999 are allowed.

Usually, climate input is considered to be homogeneous at the level of sub-basins. The precipitation data has to be provided for as many stations as possible (approximately 1 station per 100 km^2 area), while this is less important for the air temperature and solar radiation parameters.

According to our experience, the best is to use data from all available climate stations (parameters 1-3), located inside and close to the basin, in a combination with precipitation data from all available precipitation stations, also located inside the basin and close to it.

The following **Tables 4.8, 4.9 and 4.10** demonstrate the format of temperature, precipitation, and radiation data for SWIM. The other possibility is to put all climate data in one file, if the number of stations is not too large.

Table 4.8 Format of temperature data

YYYY	MON	DAY	4116tmx	4116tav	4116tmn
1981	1	1	3.5	0.4	-1.7
1981	1	2	1.0	0.5	-1.3
1981	1	3	5.8	3.9	0.7
1981	1	4	4.0	1.4	0.4
1981	1	5	0.5	-1.6	-3.5
1981	1	6	-1.3	-3.0	-3.6
1981	1	7	-3.4	-6.8	-10.5
1981	1	8	-5.8	-15.5	-21.4
1981	1	9	-4.8	-7.8	-21.8
1981	1	10	-0.2	-2.8	-6.6
1981	1	11	-1.2	-2.6	-4.3
1981	1	12	-2.0	-3.9	-4.6
....	..	..	...	...	....

Table 4.9 Format of precipitation data

YYYY	MON	DAY	90625	90661	92141	92160	92161	92162
1981	1	1	12.2	12.4	7.6	10.4	7.6	8.5
1981	1	2	7.7	8.0	4.2	8.5	4.2	9.1
1981	1	3	7.8	4.5	8.3	5.4	8.3	6.2
1981	1	4	8.8	6.6	6.8	7.1	6.8	8.8
1981	1	5	9.0	6.0	6.2	7.8	6.2	5.6
1981	1	6	3.2	3.3	2.4	3.4	2.4	3.0
1981	1	7	1.7	2.1	1.4	1.4	1.4	1.5
1981	1	8	0.6	0.0	0.3	0.4	0.3	0.3
1981	1	9	0.0	1.4	0.4	0.0	0.4	0.9
1981	1	10	1.2	1.4	0.4	0.2	0.4	0.9
1981	1	11	0.0	0.0	0.0	0.0	0.0	0.0
1981	1	12	0.0	0.0	0.0	0.0	0.0	0.0
....	..	..	...	...	...	...	...	...

Table 4.10 Format of radiation data

YYY	MON	DAY	4117rad
1981	1	1	171.0
1981	1	2	173.0
1981	1	3	186.6
1981	1	4	178.0
1981	1	5	173.0
1981	1	6	174.0
1981	1	7	241.0
1981	1	8	485.8
1981	1	9	170.0
1981	1	10	183.0
1981	1	11	171.0
1981	1	12	479.0
....	..	..	.....

Climate input in the model is not fully automatised at the moment. Therefore, the subroutine cliread() has to be recompiled for new applications to take into account specific climate input: number of climate and precipitation stations, and their ‘attachment’ to sub-basins with specific weighting coefficients. Later, this routine has to be rearranged to allow fully automatised climate data input.

The other way is to use weather generator instead of actual climate parameters. The weather generator is attached to the model and can be initialised using monthly statistical data for the station(s) (see, e.g., **Tab. 4.11**):

- average monthly maximum temperature (e.g., line 3 in **Tab.4.11**),
- average monthly minimum temperature (line 4),
- coefficient of variation for monthly temperature (line 5),
- average monthly solar radiation (line 6),
- monthly maximum 0.5 hour rain for period of record (line 7),
- monthly probability of wet day after dry (line 8),
- monthly probability of wet day after wet (line 9),
- monthly days with precipitation in a month (line 10) (can be used instead of monthly probabilities),
- monthly mean event rainfall (line 11),
- monthly standard deviation of rainfall (line 12),
- monthly skew coefficient of daily rainfall (line 13).

Table 4.11 Format of monthly statistics for climate stations

SYTHETIC WEATHER DATA FOR ST41017												TITLE
45.000	66.000	54.000	51.000									I_{30},I_{360},N_{yr},Lat
1.80	3.00	8.10	13.40	19.10	22.10	23.70	23.00	19.30	13.30	6.70	2.90	Av Mo Max Temp
-3.30	-2.90	-0.20	3.40	7.90	11.20	13.20	12.70	9.60	5.50	1.30	-1.70	Av Mo Min Temp
0.18	0.14	0.11	0.10	0.09	0.08	0.07	0.07	0.08	0.10	0.13	0.15	Co Var Mo Temp
56.	104.	213.	267.	512.	471.	417.	351.	282.	152.	74.	42.	Av Mo Sol Rad
7.	7.	9.	9.	10.	10.	10.	10.	9.	9.	7.	7.	Mo Max .5h rain
0.37	0.34	0.35	0.33	0.32	0.29	0.35	0.41	0.51	0.55	0.56	0.38	Mo Prob W aft D
0.69	0.67	0.69	0.64	0.64	0.61	0.65	0.70	0.72	0.78	0.79	0.45	Mo Prob W aft W
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Mo days of prec
2.7	2.6	2.7	3.2	4.2	5.0	4.9	5.0	3.7	3.2	3.0	3.0	Mo mean ev rain
3.3	3.05	2.54	2.79	2.54	3.30	5.08	5.84	4.57	4.57	3.81	3.05	Mo st dev rain
2.86	4.07	3.49	2.19	1.70	2.02	2.51	1.84	2.00	2.90	2.14	2.04	Mo skew of rain

4.3.3. Soil Data

In addition, data for soils have to be provided. The soil data should include the following parameters for each of a maximum of ten soil layers:

- depth of the layer (mm),
- clay, silt and sand content (%),
- bulk density (g/cm^3),
- porosity (Vol. %),
- available water capacity (Vol. %),
- field capacity (Vol. %),
- organic carbon content (%),
- organic N content (%),
- saturated conductivity (mm/hr).

According to the model requirements, the depth of the first soil layer should be always 10 mm. The format of soil parameters presentation in the soil database is shown in **Tab. 4.12**. Format inside lines is free, the right column with parameter names is not needed. The read and recalculation of soil parameters is fully automatised.

Table 4.12 Format of soil parameters for SWIM

26	5				SoilNum, Layers
Fahlerde aus sandigen Deckschichten über Geschiebelehm					SoilName
Ap	Ap	Ael	Bt	Cc	Horizon
Sl3	Sl3	Sl2	Ls4	Sl4	Type
10.	240.	400.	800.	1300.	Depth, mm
10.	10.	5.	20.	15.	Clay, %
7.	7.	5.	12.	15.	Silt, %
83.	83.	90.	68.	70.	Sand, %
1.30	1.30	1.45	1.75	1.60	Bulk density,g/cm3
51.	51.	43.	40.	42.	Porosity, Vol. %
23.	23.	18.	16.	16.	AWC, Vol. %
32.	32.	24.	31.	28.	FC, Vol. %
0.6	0.6	0.	0.	0.	C, %
0.07	0.07	0.	0.	0.	N, %
0.25					Erodibility factor
83.4	83.4	29.2	4.2	29.2	SC, mm/h

Saturated conductivity can be either read from the file (like **Tab. 4.12**), or, In case if it is not available (zeros in the soil parameter files), it can be estimated in the model using the method of Rawls & Brakensiek et al. (1985) as dependent on soil texture and porosity:

$$
\begin{aligned}
SC &= 24.\cdot \exp(x_1 + x_2 + x_3 + x_4),\\
x_1 &= 19.52348\cdot PV - 8.96847 - 0.028212\cdot CL\\
x_2 &= 0.00018107\cdot SN^2 - 0.0094125\cdot CL^2 - 8.395215\cdot PV^2 + 0.077718\cdot SN\cdot PV \qquad (3.1)\\
x_3 &= 0.0000173\cdot SN^2\cdot CL + 0.02733\cdot CL^2\cdot PV + 0.001434\cdot SN^2\cdot PV - 0.0000035\cdot CL^2\cdot SN\\
x_4 &= -0.00298\cdot SN^2\cdot PV^2 - 0.019492\cdot CL^2\cdot PV^2
\end{aligned}
$$

where PV is porosity in m3/m3, CL – clay content in %, and SN – sand content in %. In principle, also the methods of Cosby (1984)

$$
\begin{aligned}
SC &= 60.96\cdot 10^a,\\
a &= -0.6 + 0.0126\cdot SN - 0.0064\cdot CL
\end{aligned}
$$

(4.2)

and Vereecken et al., (1989)

$$SC = \exp\left[20.62 - 0.96\cdot \ln(CL) - 0.66\cdot \ln(SN) - 0.46\cdot \ln(OM) - 8.43\cdot BD\right] \qquad (4.3)$$

where *OM* – organic matter content, and *BD* – bulk density in g/cm^3, can be used.

The results produced by three methods may be quite different. The comparison of estimates of saturated conductivity by three methods is given in **Fig. 4.6.** As we can see, usually they produce quite different values of saturated conductivity.

For German soils (BÜK 1000), the estimation of saturated conductivity SC in mm/h can be done using the following **Tab. 4.13** or **Tab. 4.14**.

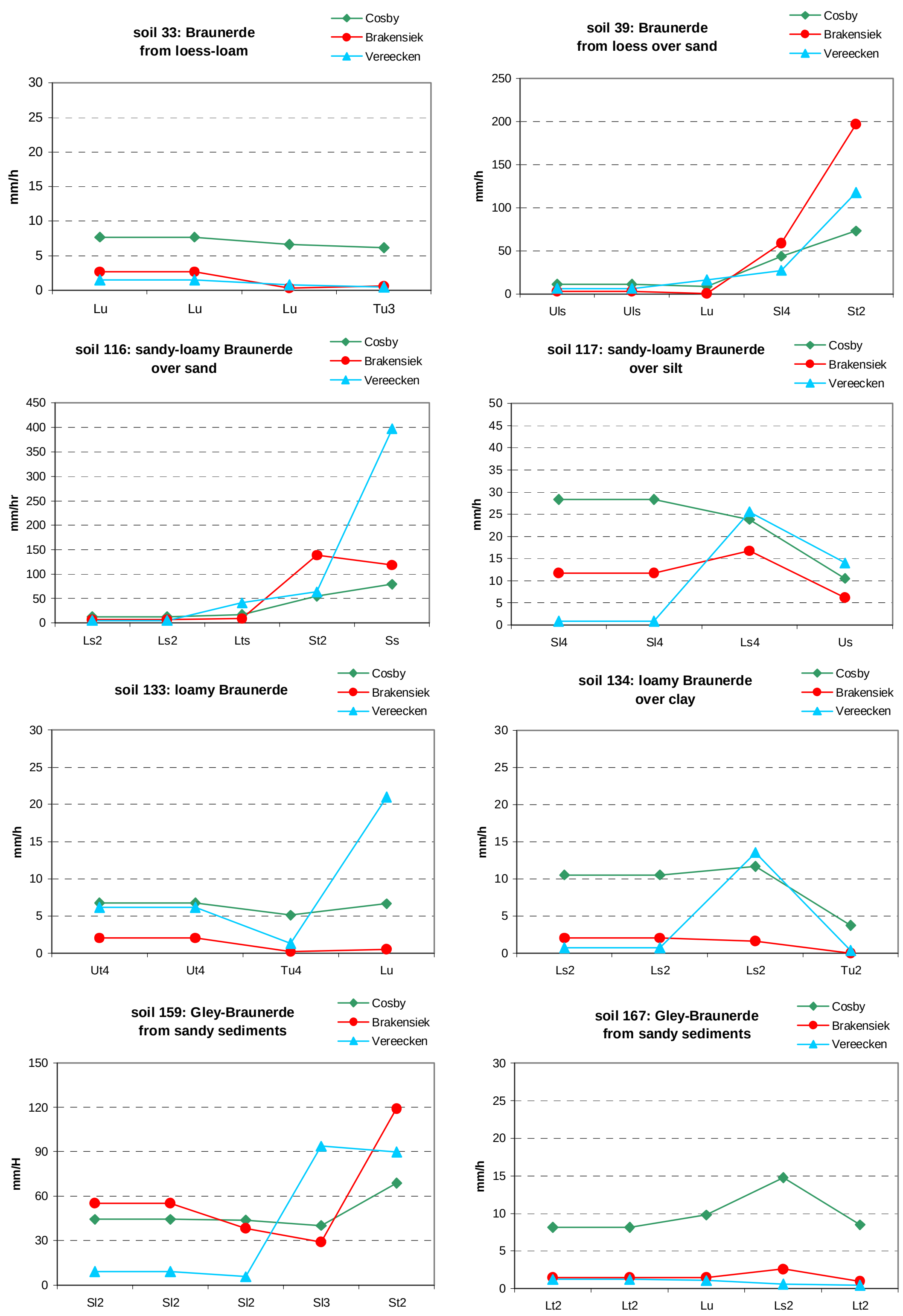


Fig. 4.6 Estimation of saturated conductivity using three different methods for dominant soils in the Glonn basin

Table 4.13 Estimation of saturated conductivity based on soil texture class and bulk density (based on Bodenkundliche Kartieranleitung, 3.)

Bulk density ***Texture class***	***1.3***	***1.4***	***1.5 – 1.6***	***1.7 – 1.75***	***1.8 – 1.9***	***2.0 – 2.1***	***2.3 – 2.4***
mS	200	125	125	83.4	83.4	42	
fS	83.4	42	29	16.7	10	4.2	
Su,Slu	29	16.7	10.4	4.2	2.3	0.4	
Sl2	83.4	42	29.2	16.7	10.4	4.2	
Sl3,Sl4,St2	83.4	42	29.2	16.7	10.4	2.3	
St3	29.2	16.7	10.4	4.2	2.3	0.4	
U,Us,Uls,Ul2, Ul3,Ut2,Ut3	29.2	16.7	10.4	4.2	2.3	0.2	
Ul4,Ut4	42	16.7	10.4	4.2	2.3	0.2	
Ls2,Ls3,Ls4	83.4	41.7	16.7	4.2	2.3	0.2	
Lu	29.2	16.7	10.4	4.2	2.3	0.2	
Ltu	83.4	42	16.7	4.2	2.3	0.2	
Lts,Lt2,Lt3	42	16.7	10.4	4.2	2.3	0.2	
Tu3,Tu4,Tl,Tu2,T	42	16.7	10.4	4.2	2.3	0.2	0.1
Hh	83.4	16.7	10.4	4.2	2.3	0.2	
Hn	125	42	29.2	16.7	10.4	4.2	

Table 4.14 Estimation of saturated conductivity based on soil texture class and bulk density (based on Bodenkundliche Kartieranleitung, 4.)

Soil texture class	Bulk density <1.6 mm/h	Bulk density = 1.6-1.8 SC mm/h	Bulk density >1.8 mm/h
Ss	145.4	95.4	52.5
Sl2	45.4	20.4	15.0
Sl3	19.6	13.8	6.3
Sl4	17.9	8.8	5.0
Slu	17.1	4.6	3.3
St2	37.9	32.9	15.4
St3	11.6	7.1	2.9
Su2	65.4	36.7	15.0
Su3	31.3	13.3	7.1
Su4	17.1	10.0	8.3
Ls2	17.1	8.3	5.4
Ls3	5.4	2.9	2.5
Ls4	8.3	5.8	2.5
Lt2	5.4	3.8	1.7
Lt3	4.2	4.2	2.9
Lts	5.0	2.5	1.3
Lu	10.8	7.5	2.5
Uu	6.7	2.9	1.2
Uls	14.6	5.8	2.1
Us	9.2	4.2	1.6
Ut2	12.5	2.9	1.7
Ut3	15.8	3.3	1.3
Ut4	12.9	3.8	1.7
Tt	2.9	0.8	0.4
Tl	4.2	1.3	0.4
Tu2	8.3	2.1	0.4
Tu3	11.3	5.4	2.5
Tu4	14.2	11.7	3.3
gSfs	153.8	54.2	20.8
mS	272.1	177.9	79.1
mSgs	242.1	117.1	29.1
mSfs	129.6	92.1	54.1
fS	71.7	44.2	16.6
fSms	101.7	70.4	25.0
Hhz1	83.3	10.4	2.1
Hhz2	83.3	10.4	2.1
Hhz3	10.4	2.1	0.2
Hhz4	2.1	0.2	0.0
Hhz5	2.1	0.2	0.0
nHv	83.7	10.8	2.5
nHm	83.7	10.8	2.5
nHa	83.7	10.8	2.5
nHt	83.7	10.8	2.5
nHr	83.7	10.8	2.5

4.3.4 Crop Parameters and Crop Management Data

Crop parameters file **crop.dat** has to be included in the model input. It is a standard input file for SWIM. The full description of this data is given in Section 3.3.6.

Crop management data include description of agricultural activities:
- day of operation,
- operation code (planting, harvesting),
- crop number (from the available crop data base, which also include some aggregated categories),
- days of fertilisation,
- amount of N and P in kg applied per hectare.

Cop management input in the model is not fully automatised at the moment. Therefore, the subroutine initcrop() has to be recompiled for new applications to take into account crop rotation and crop management. Three options are available for crop rotation now:
- one crop in cropland,
- 10-11 years rotation scheme, including six crop types and set aside,
- three different rotation schemes for three soil groups (poor, intermediate and high quality soils) with a stochastic crop distributor, so that crop rotation is the same within the soil group, but it is not synchronised for different ‘fields’ (starting year is chosen stochastically for the ‘fields’).

Later, this routine has to be rearranged to allow fully automatised climate data input.

4.2.5 Hydrological and water quality data

Additionally, river discharge and concentrations of nitrogen, phosphorus and suspended solids in the basin outlet are needed for model validation. River discharge has to be included in the model input (see format in **Tab. 4.15**), while the measured water quality data can be compared with the model output outside the model. A number of criteria of fit are included in the model, like the Nash & Sutcliffe efficiency (Nash and Sutcliffe, 1970).

Table 4.15 Format of water discharge data for SWIM

YYYY	MON	DAY	Q,m3/s
1981	1	1	3.10
1981	1	2	3.45
1981	1	3	7.92
1981	1	4	13.80
1981	1	5	6.81
1981	1	6	5.39
1981	1	7	4.86
1981	1	8	4.53
1981	1	9	4.13
1981	1	10	4.09
1981	1	11	3.97
1981	1	12	4.06
1981	1	13	3.91
1981	1	14	3.92
1981	1	15	4.17
...	..	..	....

4.4 Model Run

4.4.1. Collect all input data

All input files necessary for the model application were listed in Section 3.3 and described in **Tab. 3.10**. Their preparation is described in Sections 4.1 – 4.3. Here a summary is given on how to collect all prepared data before running SWIM.

The working directory (later called 'main working directory') is usually named by the basin name, It must have the following subdirectories:

- **/Code** – for the model code
- **/Sub** – for sub-basin parameter files
- **/Soil** – for soil data files,
- **/Struc** – for sub-basin structure files,
- **/Res** – for general model results,
- **/Flo** – for specific results on water and nutrient flows,
- **/GIS** – for specific results in GRASS GIS format,
- **/Clim** – for climate and hydrological data files.

After that all prepared files have to be copied in appropriate subdirectories as described below.

Step1. Files created by SWIM/GRASS interface The four files created by SWIM/GRASS interface in the user GRASS directory DATABASE/LOCATION/MAPSET/swim/projectname

- **file.cio**,
- **str.cio**,
- **xxx.fig** ,
- **xxx.str**

have to be copied to the main working directory.

The sub-basin files created by SWIM/GRASS interface in the user GRASS directory DATABASE/LOCATION/MAPSET/swim/projectname

- **xxxNN.sub** – M files, where M is the number of sub-basins,
- **xxxNN.gw** – M files, where M is the number of sub-basins,
- **xxxNN.rte** – M files, where M is the number of sub-basins

have to be copied in the directory **/Sub.**

Step 2. Climate and hydrological data Climate and hydrological data have to be copied to the main working directory: either one file

- **clim.dat**,

which includes all climate and hydrological data (see Sections 4.2.2 and 4.2.5), or four files

- **prec.dat**
- **temp.dat**,
- **radi.dat**
- **runoff.dat**,

which include separately precipitation, temperature, radiation, and runoff data, respectively. The directory /Clim may be used for original climate data sets and for climate data modification (e.g. to prepare two separate climate data sets for the calibration and validation periods).

In the case of large number of sub-basins and direct correspondence '1 sub-basin – 1 precipitation station', the file

sub2prst.dat

may be prepared, which indicates the correspondence between sub-basins and precipitation stations. If necessary, this file may contain weighting coefficients for precipitation stations. This file has to be placed in the main working directory.

Usually the climate read part is organised specifically for the basin under study by user (file cliread.f in the directory /Code), who can specify whether the data are read from one file clim.dat, or from several files, and how the correspondence between sub-basins and precipitation/climate stations is established.

Step. 3 Soil data The user has either use available soil database BÜK-1000 supplied with the model or to prepare all soil data in the same format as described in Section 4.3.3. Soil data

soil04.dat,

soil05.dat, etc

Have to be copied in the directory **/Soil**. In addition, the file

soil.cio,

which includes a list of all soil data file names, has to be copied to the main working directory or prepared.

Step 4. Crop data The standard crop database contained in the file

crop.dat,

which is supplied with the model, has to be copied to the main working directory.

Step 5. Files .cod and .bsn An example program codes file

xxx.cod,

which includes program codes for printing, is supplied with the model. The user has to specify the desired period of simulation (parameters nbyr, iyr, idaf, idal), which has to be in correspondence with climate and hydrological data, and the number of sub-basins (parameter lu). The print codes have to established by user, if the hydrotope printout, sub-basin printout, process printout, or special printout are necessary. This file has to be placed in the main working directory.

An example basin parameters file

xxx.bsn,

which includes a set of basin parameters and a set of calibration parameters, is supplied with the model. The user has to introduce the correct basin area (parameter da), which can be taken from .bsn file produced by SWIM/GRASS interface. This file has to be placed in the main working directory.

Step 6. File wstor.dat An example file

wstor.dat,

which includes initial water storages for the reaches is supplied with the model. Here all initial storages may be put to 0, then initial period (1-2 weeks) of simulation has to be ignored. The other option is to take water storage at the end of the first year from the test model run. This file has to be placed in the main working directory.

Step 7. File wgen.dat An example file with monthly statistical climate data

wgen.dat,

is used to run weather generator. Besides this file is needed to establish rain intensity parameters (tp5, tp6, tp24), latitude (parameter ylt), and average monthly maximum and minimum temperature (vectors obmx, obmn). It is assumed that these parameters are basin-specific. The vectors obmx, obmn can be calculated using an additional program *wgenpar* from the available climate data, taking as long time series of climate for the basin as possible. Then the calculated average monthly maximum and minimum temperatures have to be substituted into the example wgen.dat file. The file wgen.dat has to be placed in the main working directory.

4.4.2 Modification of the code to adjust for specific input data

When all input data are ready, the user has to copy the source code files

```
clicon.f            gwat.f              readcrp.f
cliread.f           hydrotop.f          readsol.f
common.f            init.f              readsub.f
compar.f            initcrop.f          readwet.f
crop.f              main.f              route.f
cropyld.f           ncycle.f            routfun.f
curn.f              open.f              solt.f
eros.f              pcycle.f            stat.f
evap.f              perc.f              subbasin.f
flohyd.f            readbas.f           veget.f
genres.f            readcod.f           vegfun.f
```

and the Makefile from the supplied model package. Some files, which provide initialisation of the model, may be corrected. The correction may be needed in

- climate data read part (files **open.f,** and **cliread.f),**
- crop initialization part (file **initcrop.f**),
- soil parameter read part (file **readsol.f**),
- global model parameter part (file **compar.f**).

As soon as a certain flexibility is allowed regarding the climate data input, the corresponding changes may be necessary in files

open.f, and
cliread.f

Different options are possible: from the simplest variant, when all climate and hydrological data are put in one file **clim.dat**, to another variant, when precipitation, temperature, radiation, and water discharge are put in four different files

prec.dat
temp.dat,
radi.dat
runoff.dat.

Correspondingly, the assignment of precipitation stations to sub-basins may be done differently. Examples are given in **cliread.f.variants** file located in **/Codevar** directory (supplied with the model).

Crop management is initialised in the file

initcrop.f.

Different options are possible in initialisation of crop management:

- single crop on the total cropland area,
- different crop rotations and fertilization schemes,
- crop generator.

The first two options may be used by including desired version of initcrop() subroutine. Examples are given in **initrcrop.f.rotNferN** and **initcrop.f.single** files located in **/Codevar** directory (supplied with the model). They can be used directly by opening the desired variant of initcrop() and closing the others. The user has to keep in mind that winter crops may start only from the second year of simulation (planting in autumn). That is why the single crop variants with winter crops include summer barley for the first year of simulation.

The third option (crop generator) is usually applied only for regional studies. It requires more changes in the code, and is supplied as a separate model version.

The user may either use the available soil database BÜK-1000, or another soil parameters. In principle, the format should be the same, then no changes are needed in the **readsol.f** file. In case if a new format is used, the corresponding changes have to be made in the file

readsol.f

Two examples: **readsol.f.elbe** and **readsol.f.glonn** are given in the /Codevar directory for the Elbe and Glonn basins, respectively.

Besides, the user may changes global model parameters, like maximum number of sub-basins, *mb*, and maximum number of hydrotopes, *meap*, in the file

compar.f

This is necessary if the maximum number of sub-basins/hydrotopes for the case study basin is larger than in the code, and it is also useful if the maximum number of sub-basins/hydrotopes for the case study basin is significantly smaller than in the code (saves compilation time!).

4.4.3 Sensitivity of the simulated river discharge to model parameters

Sensitivity of the simulated river discharge to model parameters described in this Section is one of the most important sensitivity studies with SWIM as an ecohydrological model. It can be extended by sensitivity analysis of the crop yield or nitrogen flow components to model parameters. The results of the sensitivity analysis are partly basin-specific, because they depend on the basin structure (land use, soil, etc.).

The sensitivity analysis described here was done for the Stepenitz basin (gauge station Wolfshagen, drainage area 575 km^2) for the six years period 1983 - 1988. Most of parameters used for the sensitivity analysis are from the *.bsn* file (see Section 3.4.3). The results are summarised in **Tab. 4.16** and depicted in **Figs 4.7 – 4.24**.

Saturated Conductivity is a very important model parameter. However, it is rarely available in soil databases, and its estimation using pedo-transfer functions or other methods is problematic and often leads to contrasting estimates (see e.g. **Fig. 4.6** in Section 4.3.3). In SWIM the saturated conductivity *sc* can be either read from the database connected to the model (if the parameter *isc* = 0), or calculated using the Rawls & Brakensiek method (if *isc* = 1). The comparison of the effect of the both methods on the simulated river discharge is shown in **Fig. 4.7**. If the parameter *sc* is read, the peaks are higher, and the level of lowflow is lower, the total water discharge for the six years simulation period is 6% higher.

Due to uncertainties in the estimation of saturated conductivity, it is allowed to correct the parameter *sc* in the model globally for all soils and soil layers, using the correction factor *sccor*. The results of model sensitivity to the correction of the parameter *sc* are shown in **Figs. 4.8 and 4.9**. As one can see, the decrease in the sc (sccor = 0.8) leads to a slight increase in peaks and lowering the level (compare with **Fig. 4.7**). The difference in the total water discharge is rather small. The graphs on the right hand side show changes for shorter periods of several months.

Soil depth Usually there is an uncertainty in the establishing of soil depth in the models. In some models the soil depth is limited by 1 m, in others by 2 m or by the maximum root depth. In our soil database based on BÜK 1000 (Hartwich et al., 1995) the soil depth is limited by the maximum rooting depth defined for the leading soil profile in dry years. This defines the reference case in **Tab. 4.16**. The sensitivity of the model to soil depth is depicted in **Fig. 4.10**, which compares the reference case with the variant, when soil depth is increased by 50%. In the both cases the actual root depth is restricted by the parameter *rdmx* (see **Tab. 3.13**) and the actual soil depth. The increase in soil depth leads to a quite significant decrease (-10.1 %) in the total water discharge (due to higher evapo-transpiration), and lowering of the peaks and the level.

Assignment of hydrological soil groups The analysis of the model sensitivity to the assignment of hydrological soil groups is shown in **Fig. 4.11**. As could be expected, shifting of the soil groups to the higher ones, like A → B, B → C, and C → D leads to the increase in peaks (more explicitly visible in two graphs on the right hand side), but rather small changes in the total water discharge.

Curve Number method The Curve Number method in SWIM ca be used in two different modes: a) in the original mode, differentiating CN parameter for soil types and land use categories, and b) in the other mode, not differentiating for land use and soil types, and putting CN parameter for conditions 1 equal to cnum1, and for conditions 3 equal to cnum3 (cnum1 is not equal to cnum3) for all land use categories and all soil types. The comparison of the reference case (icn = 0) and a number of variants corresponding to the mode b) are given in **Tab. 4.16** and **Figs. 4.12 – 4.14**. When CN is not differentiated, small peaks disappear, and the hydrograph becomes smoother. Though the high peaks can be lower (**Fig. 4.12**), or higher (**Fig. 4.13**), the total discharge is always lower by 5 – 5.5 %.

Baseflow factor for return flow travel time The influence of the baseflow factor *bff* on water discharge is shown in **Figs. 4.15 and 4.16**. When *bff* is decreased from 1.0 to 0.2, the peaks are lower, the level of lowflow is higher, and the total discharge is 3.4% lower. The increase of *bff* leads to the opposite effect.

Groundwater recession rate Alpha factor for groundwater, or groundwater recession rate, which characterises the rate at which groundwater flow is returned to the stream, has quite significant influence on hydrograph, especially in the period of high flow (winter – spring) (**Figs. 4.17 – 4.18**). When the alpha factor *abf0* is higher, peaks in winter and early spring are also higher, while the decrease in *abf0* leads to the 3.5% decrease in the total discharge and the lowering of winter peaks.

Initial conditions The initial conditions in SWIM may be changed by establishing the initial groundwater contribution to streamflow (parameter *gwq0*) and the initial water storage (parameter *stinco*). This influences the hydrograph during the first 3-6 months, as one can see in **Figs. 4.19 – 4.20**.

Routing coefficients Initial estimation of the storage time constants for the reach, *xkm*, in the model is based on the channel length and celerity, which, in their turn, are estimated based on the DEM. This preliminary estimation can be corrected during the model calibration using parameters *roc2* and *roc4*. The increase in these coefficients leads to the lowering of peaks and the smoothing of the dynamics in general (**Figs. 4.21 – 4.22**).

However, the total water discharge does not change significantly. It is recommended to check these parameters always during the model calibration.

Crop type Water discharge is also sensitive to crop types due to their different seasonality and other characteristics (e.g. maximum LAI). Regarding the crop distribution on arable land, SWIM can be applied either

a) with one crop on the whole arable land every year, or
b) applying a predefined crop rotation scheme for the whole arable land, or
c) with crop generator, which distributes different crop types in the basin or region under study in accordance with several predefined crop rotation schemes.

In our sensitivity analysis the simplest option a) was used in order to check the influence of crop types on the simulated hydrograph. Though the change in the total water discharge is rather small (**Tab. 4.16**), there are obvious differences in the discharge dynamics (see **Figs. 4.23 – 4.24**). This confirms the importance of using reliable information on actual crop distribution for the initial parametrisation of the model.

The sensitivity study like one described in this Section can be recommended for inexperienced users in order to gain better understanding of the model performance.

Table 4.16 Results of sensitivity analysis for the Stepenitz basin

method to define saturated conductivity sc	**Reference**: sc calculated (Rawls & Brakensiek method)	sc read from database
Model parameter used	isc = 1	isc = 0
Change in total water discharge		+ 6.0%
Change in peaks		Peaks ↑↑
Change in level		Level ↓↓

Correction of saturated conductivity sc, if sc is read (isc = 0)		**Reference**:	
Model parameter used	sccor =1.2	sccor = 1.	sccor = 0.8
Change in total water discharge	-1.3 %		+1.6 %
Change in peaks	Peaks ↓		Peaks ↑
Change in level			

Correction of saturated conductivity sc, if sc is calculated (isc = 1)		**Reference**:	
Model parameter used	sccor =1.2	sccor = 1.	sccor = 0.8
Change in total water discharge	-1.0 %		+1.2 %
Change in peaks	Peaks ↓		Peaks ↑
Change in level	Level ↑		Level ↓

Soil depth	**Reference**: Soil depth is established according to maximum root depth	Soil depth is established according to maximum root depth + 50%
Change in total water discharge		-10.1 %
Change in peaks		Peaks ↓↓
Change in level		Level ↓↓

Hydrological soil groups	**Reference**: soil groups A, B, C, D	A→ B, B → C, C → D, D = D	A → C, B → C, C → D, D = D
Model parameter used	nsolgr = 1, 2, 3, 4	nsolgr = 2, 3, 4, 4	nsolgr = 3, 3, 4, 4
Change in total water discharge		+0.3 %	+0.9 %
Change in peaks		Peaks ↑	Peaks ↑↑
Change in level		Level ↓	Level ↓

Curve number method: differentiate on land use and soil or not	**Reference**: CN different, icn = 0	icn = 1	icn = 1	icn = 1	icn = 1	icn = 1	icn = 1	icn = 1
Model parameter used: cnum1, cnum3		30, 70	40, 80	50, 90	30, 80	40, 90	40, 70	50, 80
Change in total water discharge		- 5.5 %	- 5.5 %	- 5.0 %	- 5.5 %	- 5.1%	- 5.5 %	- 5.5 %
Change in peaks		Peaks ↓ no small peaks	Peaks ↓ no small peaks	Peaks ↑ no small peaks	Peaks ↓ no small peaks	Peaks ↑ no small peaks	Peaks ↓ no small peaks	Peaks ↓ no small peaks
Change in level		no	no	no	no	no	no	no

Baseflow factor for return flow travel time	**Reference**					
Model parameter used: bff	bff = 1.	bff = 1.5	bff = 2.	bff = 3.	bff = 0.5	bff = 0.2
Change in total water discharge		+ 1.%	+1.6 %	+2.3 %	-1. 5 %	-3.4 %
Change in peaks				Peaks ↑		Peaks ↓
Change in level				Level ↓		Level ↑

Alpha factor for groundwater	**Reference**				
Model parameter used: abf0	abf0 = 0.048	abf0 = 0.1	abf0 = 0.3	abf0 = 0.024	abf0 = 0.012
Change in total water discharge		+ 1 %	+ 1.7 %	- 1.4 %	- 3.5 %
Change in peaks			Peaks ↑ in winter-spring		Peaks ↓ in winter-spring
Change in level			Level ↑ in winter-spring		Level ↓ in winter-spring

Initial groundwater contribution to flow	**Reference**		
Model parameter used: gwq0	gwq0 = 0.5	gwq0 = 0.2	gwq0 = 1.
Change in total water discharge		- 5.1 %	+ 8.4 %
Change in peaks & level		Initial peaks and level ↓	Initial peaks and level ↑

Initial soil water storage	**Reference**		
Model parameter used: stinco	stinco = 0.7	stinco = 0.4	stinco = 1.0
Change in total water discharge		- 3.4 %	+ 3.1 %
Change in peaks & level		Initial peaks and level ↓	Initial peaks and level ↑

Routing coefficients							

Model parameter used: roc2, roc4	3, 3	6, 6	12, 12	24, 24	48, 48	6, 48	96, 96
Change in total water discharge		0 %	- 0.2 %	- 0.6 %	- 1.2 %	- 1 %	- 2.2 %
Change in peaks		Peaks ↓, dynamics - smoother	Peaks ↓, dynamics - smoother	Peaks ↓, dynamics - smoother	Peaks ↓, dynamics - smoother	Peaks ↓, dynamics - smoother	Peaks ↓, dynamics - smoother

Crop type (in the case if only one crop type on cropland)	**Reference:** winter rye	winter wheat	winter barley	summer barley	maize	potatoes
Model parameter used: ncrp	ncrp =iwr	ncrp =iww	ncrp =iwb	ncrp =isba	ncrp =imai	ncrp =ipo
Change in total water discharge		- 3.0 %	- 2.2 %	+ 0.4 %	- 0.9 %	+ 1.2 %
Change in peaks		some peaks - different	some peaks - different	some peaks - different	some peaks - different	some peaks - different

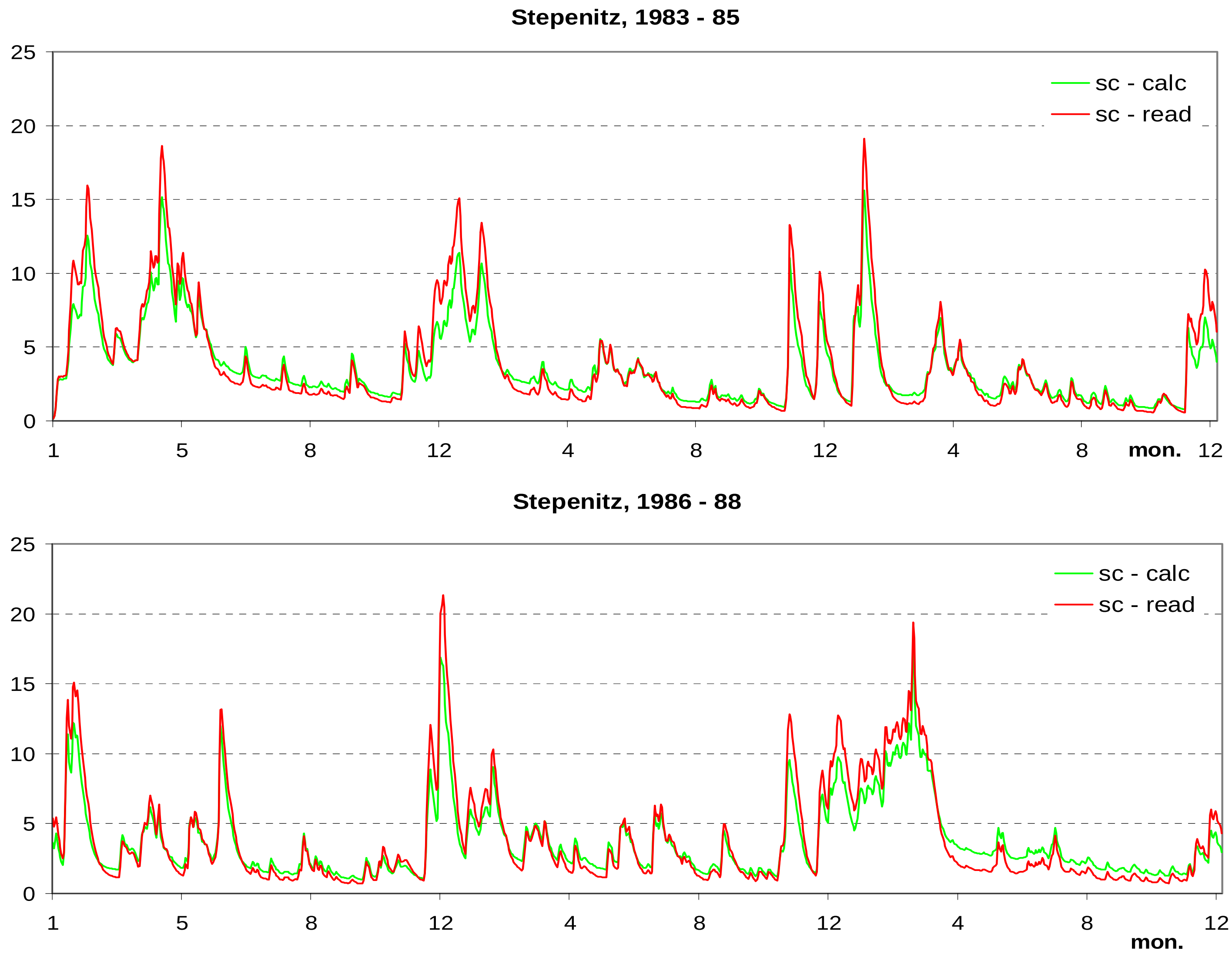
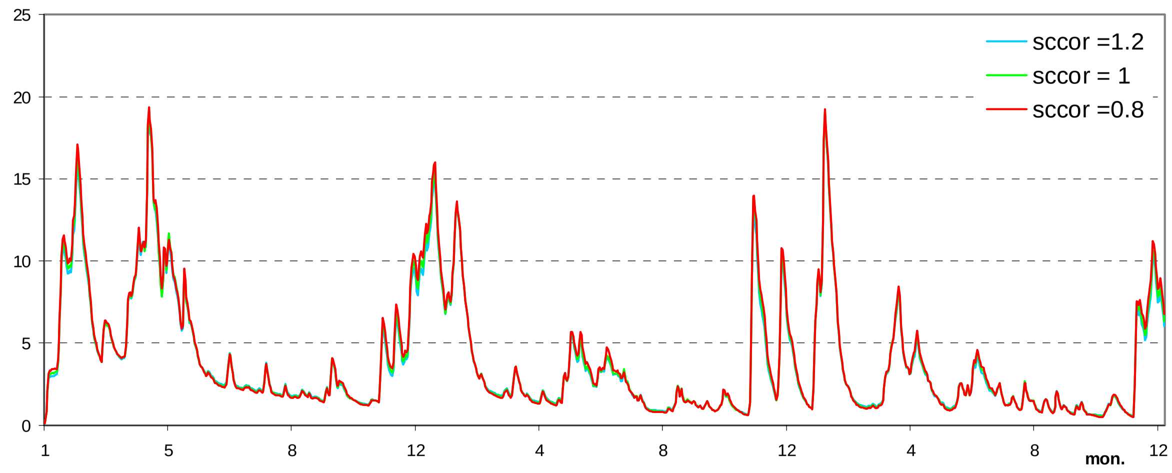


Fig. 4.7 Sensitivity to the method of estimation of saturated conductivity

Stepenitz, 1983 - 85



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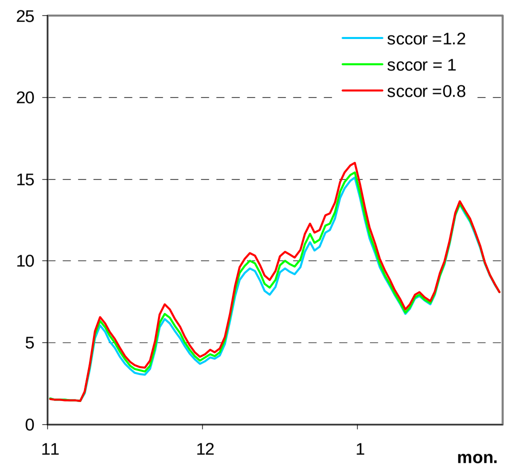
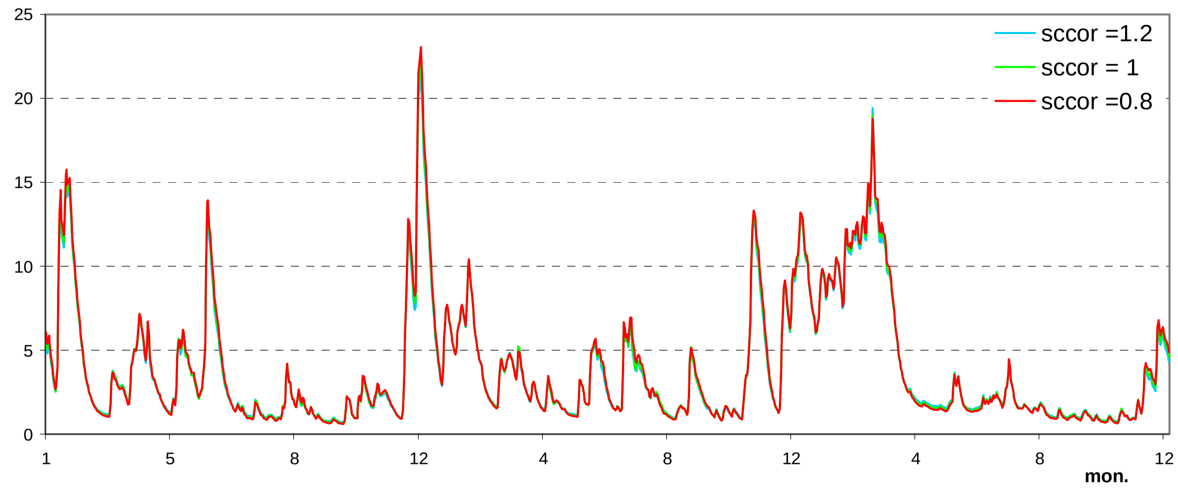


Stepenitz, 1986 - 88



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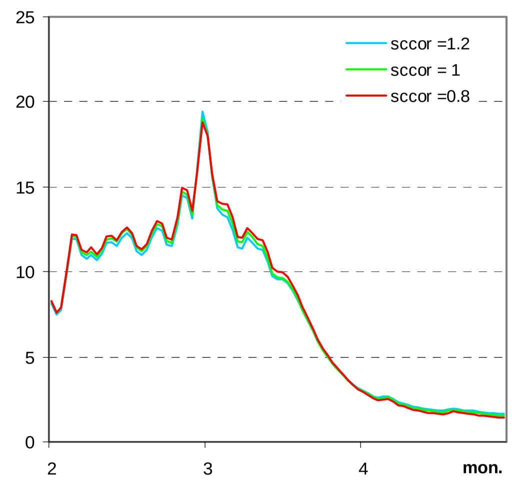

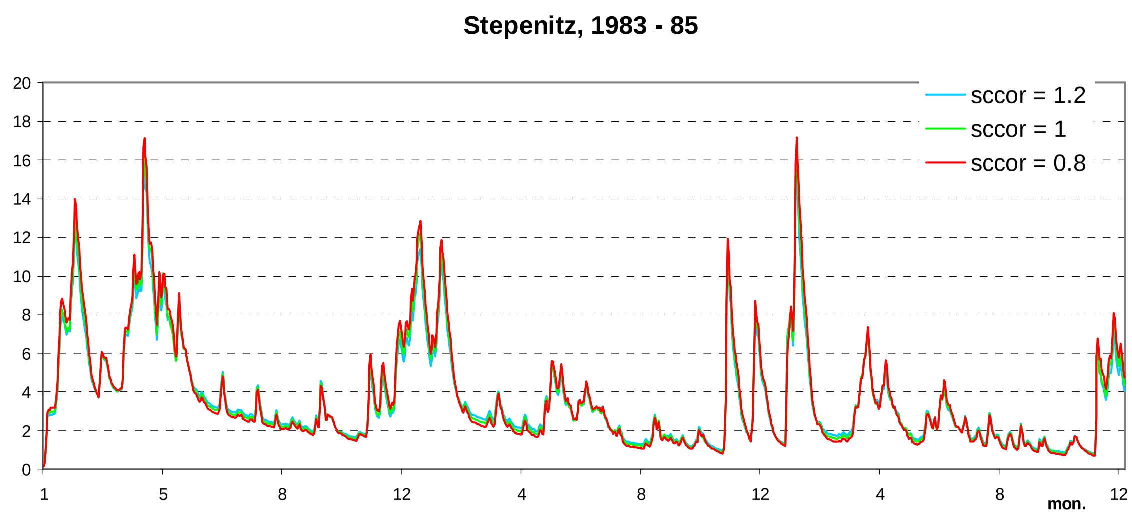
Stepenitz, 1983 - 85
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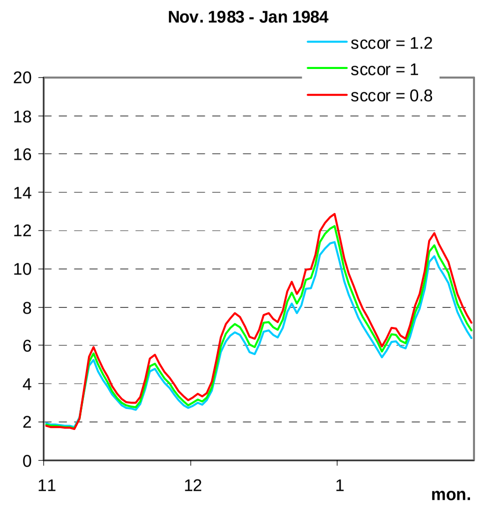
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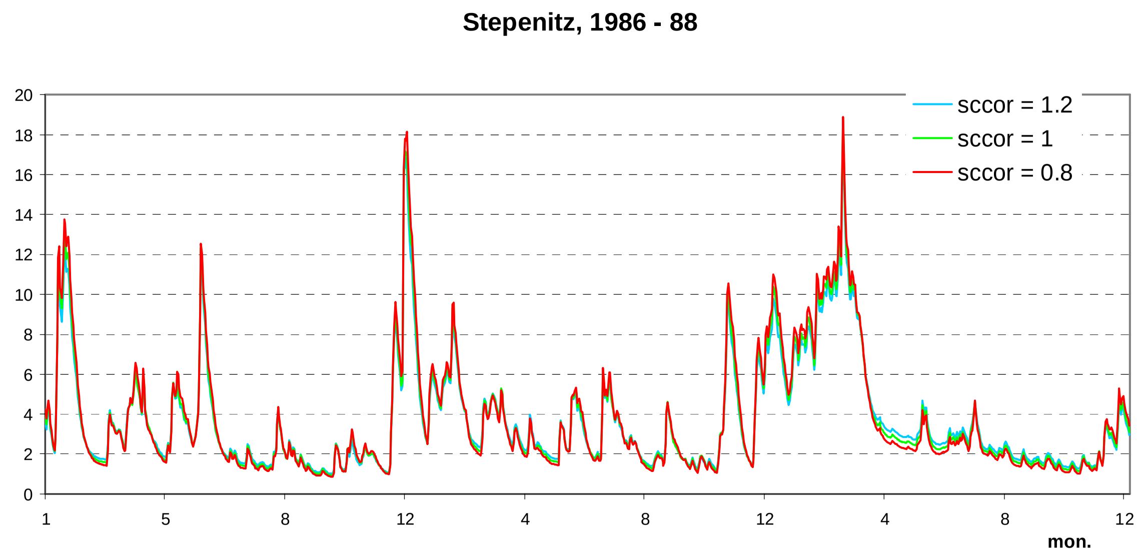
Stepenitz, 1986 - 88
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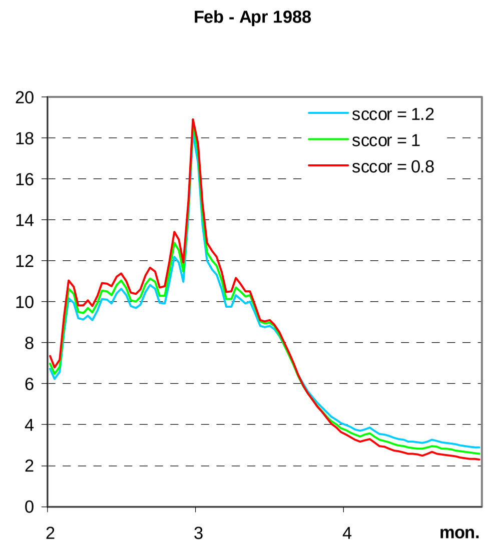
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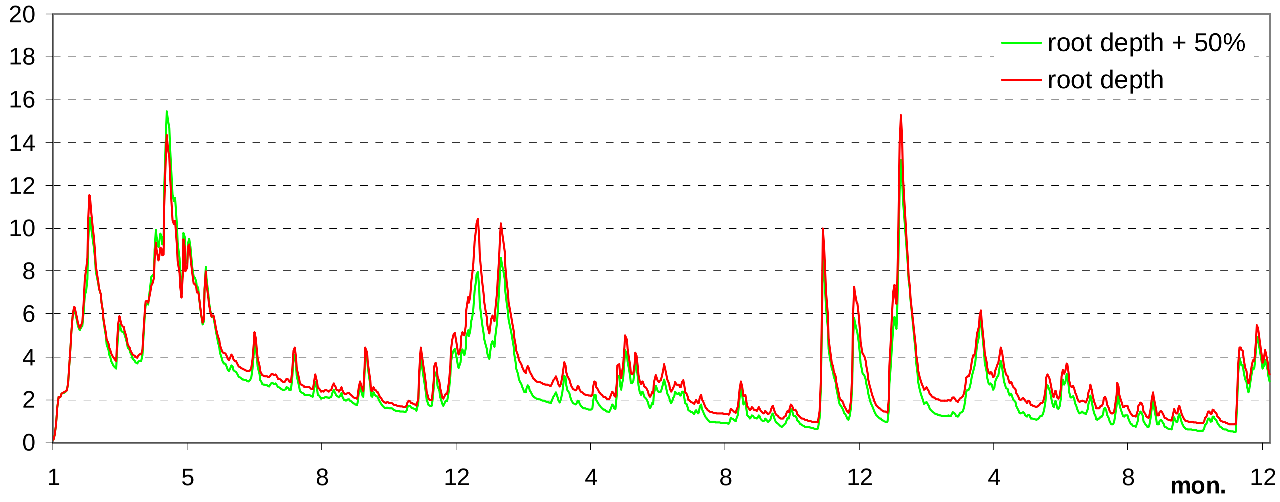
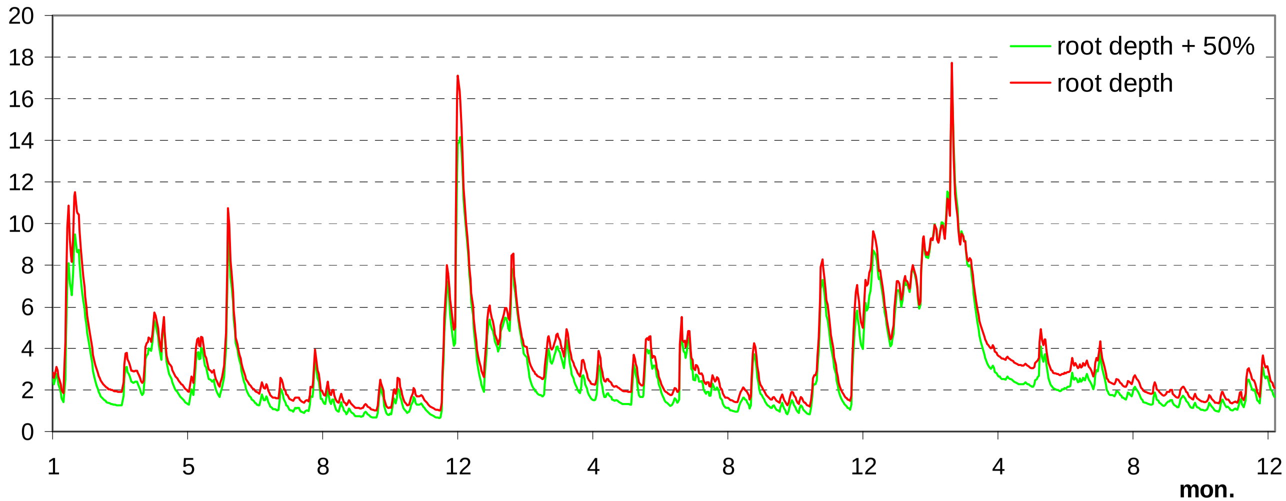
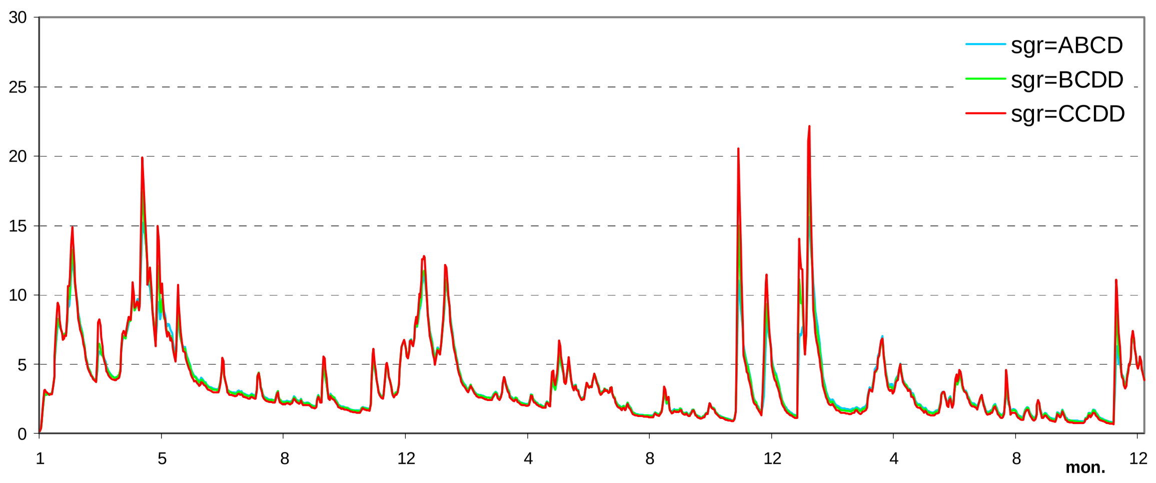
Stepenitz, 1983 - 85



Stepenitz, 1986 - 88



Stepenitz, 1983 - 85



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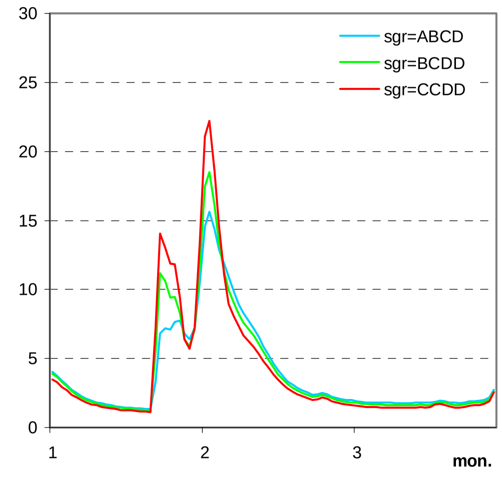
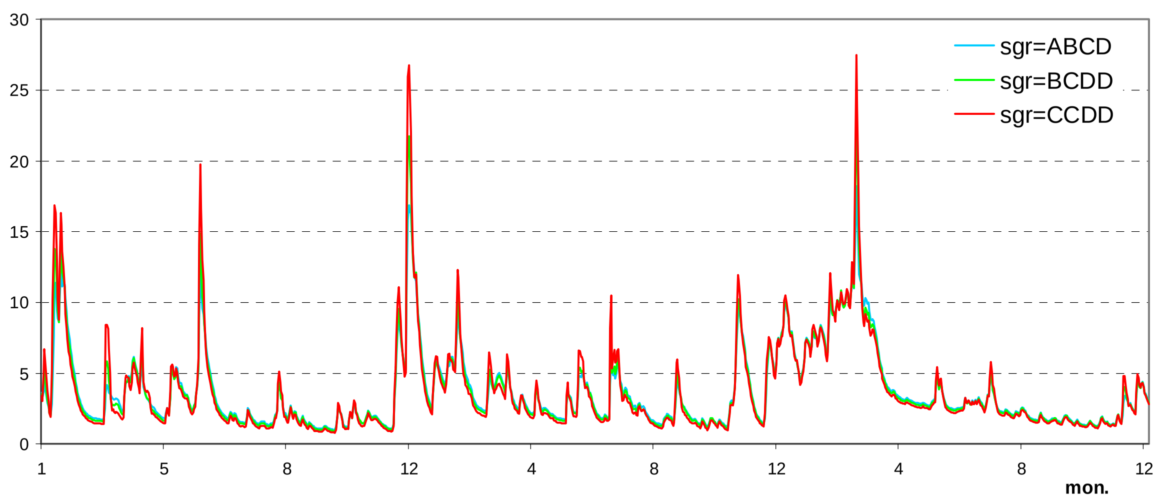


Stepenitz, 1986 - 88



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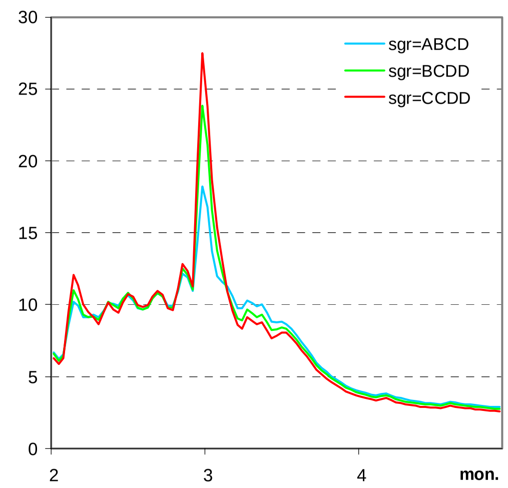

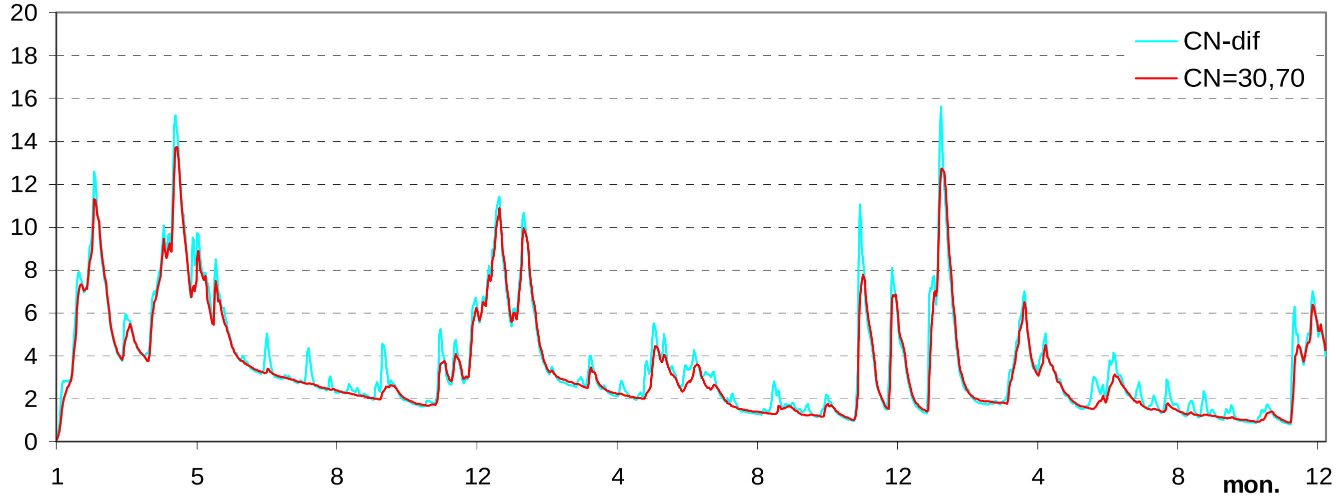
Stepenitz, 1983 - 85
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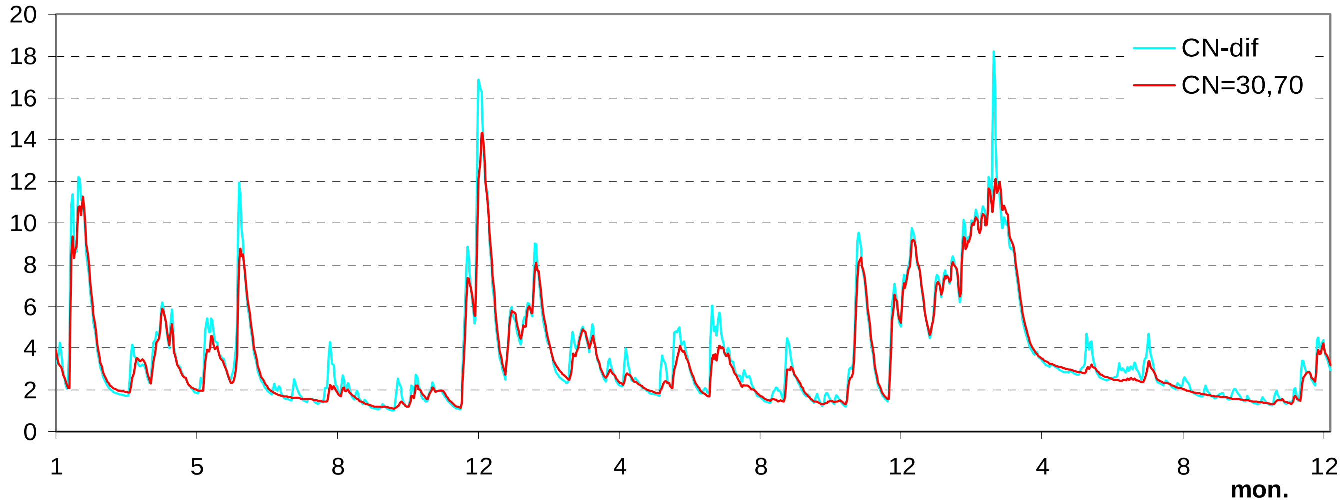
Stepenitz, 1986 - 88
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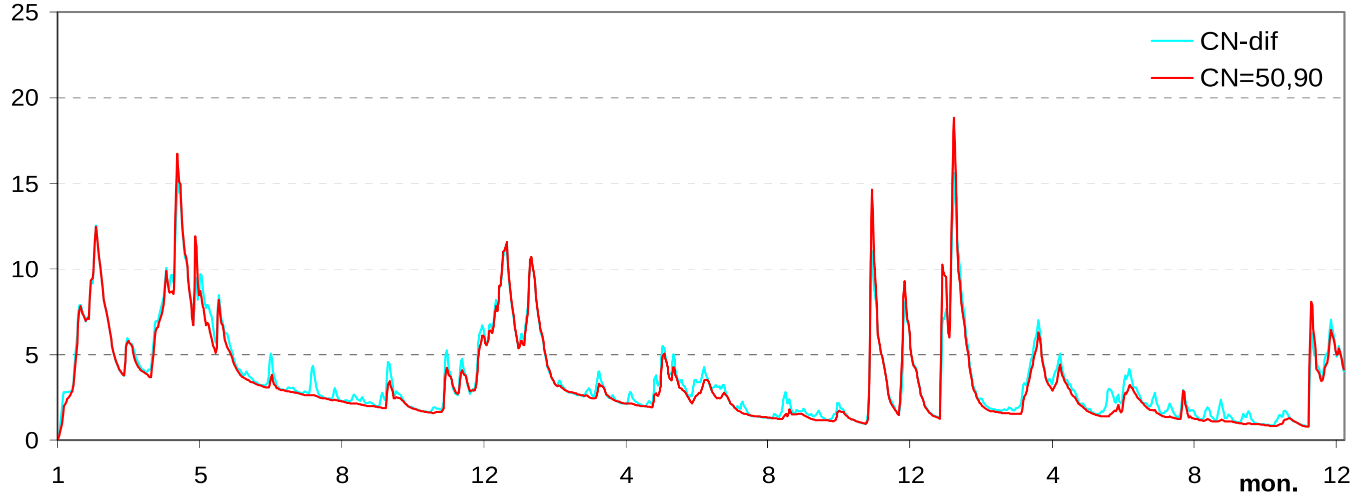
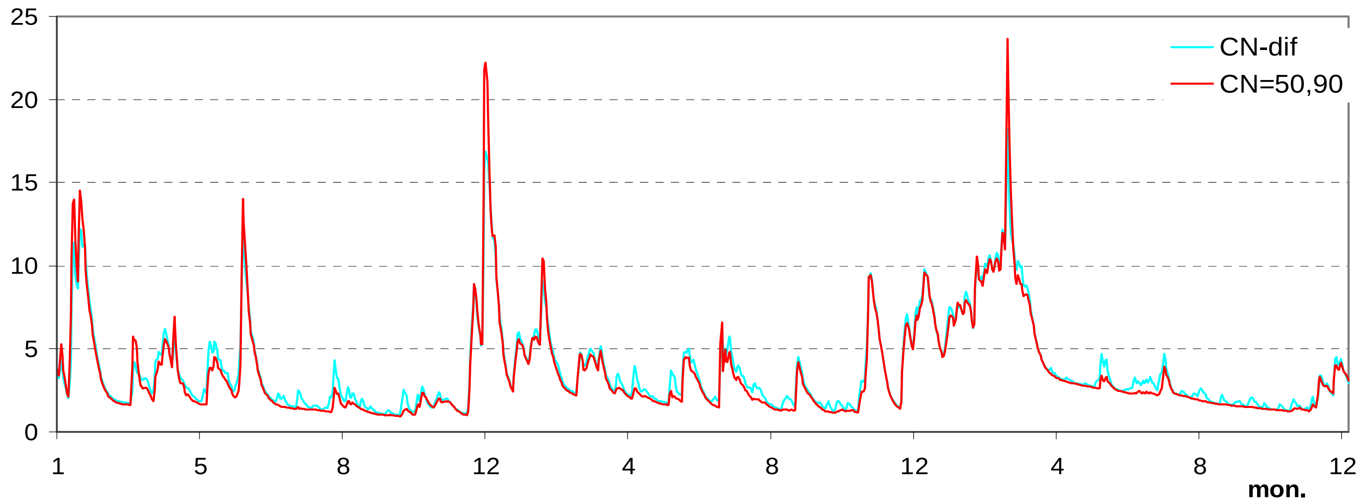
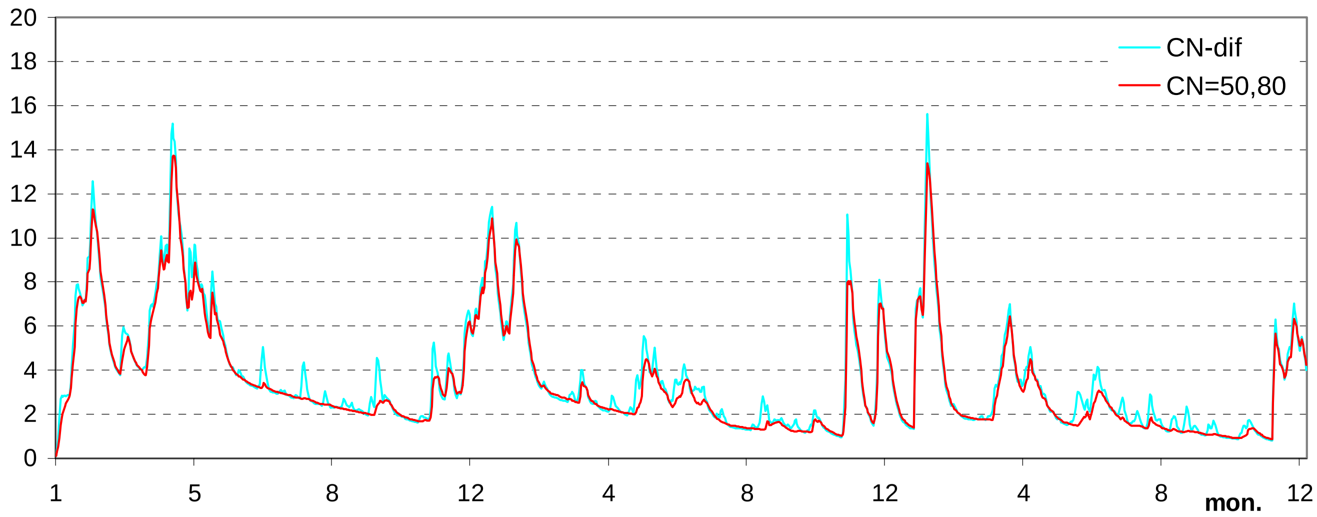
Stepenitz, 1983 - 85



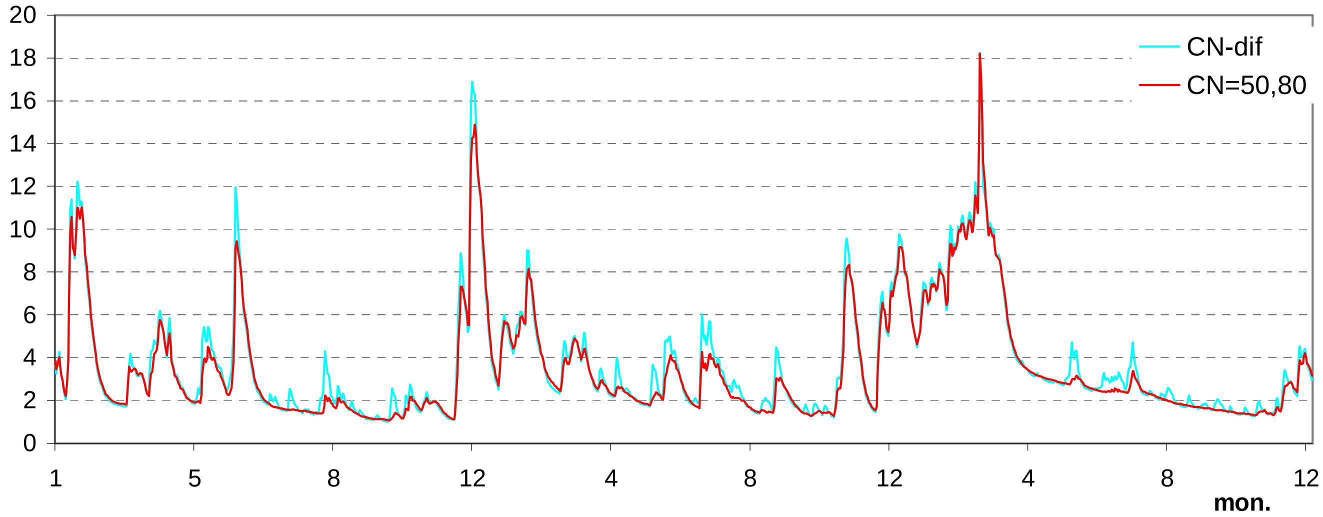
Stepenitz, 1986 - 88

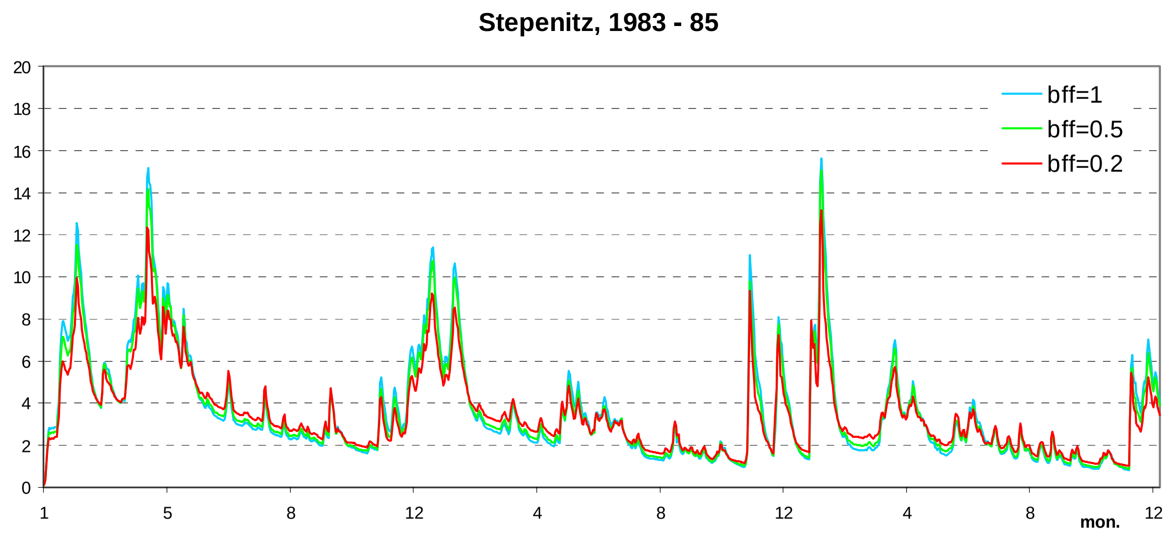


Stepenitz, 1983 - 85



Stepenitz, 1986 - 88




Stepenitz, 1983 - 85
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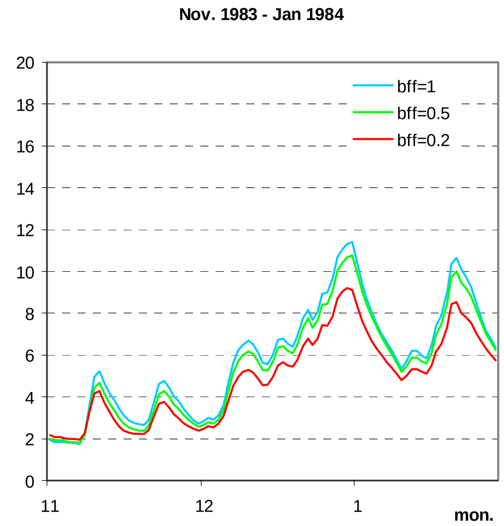
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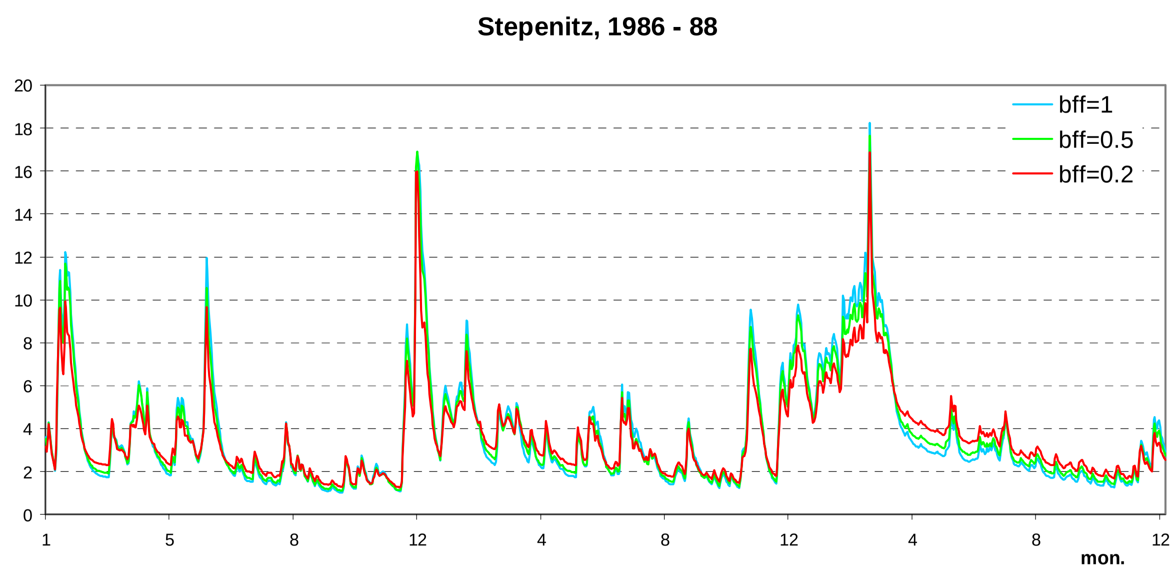
Stepenitz, 1986 - 88
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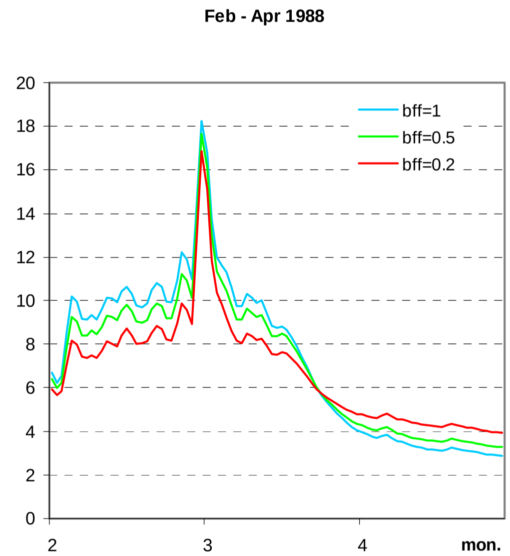
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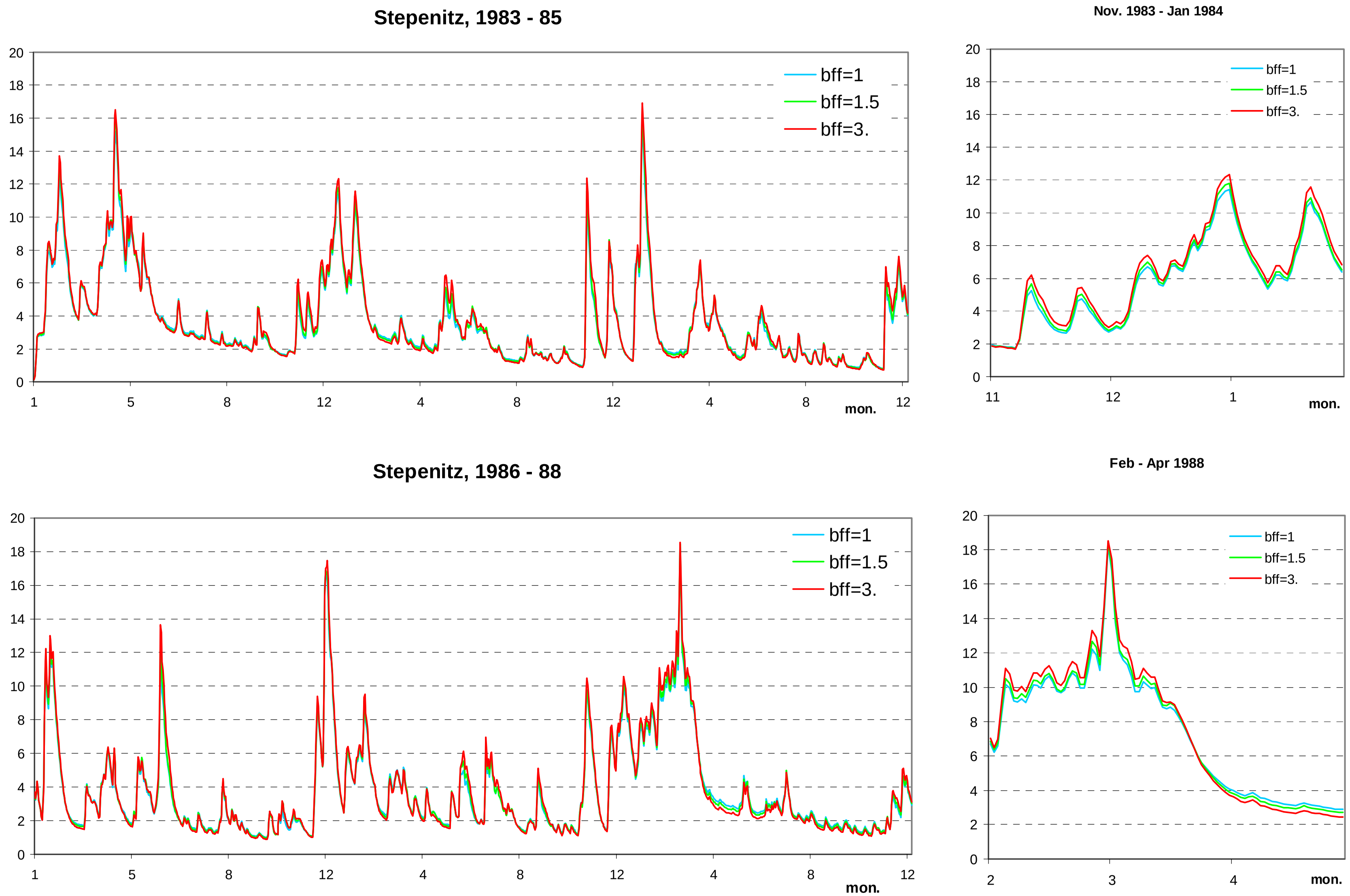
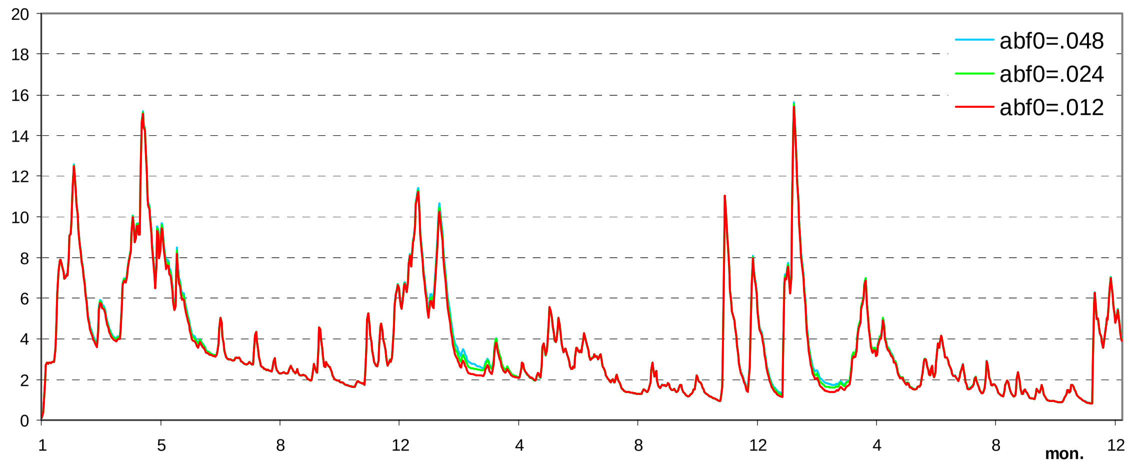
Fig. 4.15 Sensitivity to the baseflow factor (bff = 1; 0.5; 0.3)



Stepenitz, 1983 - 85



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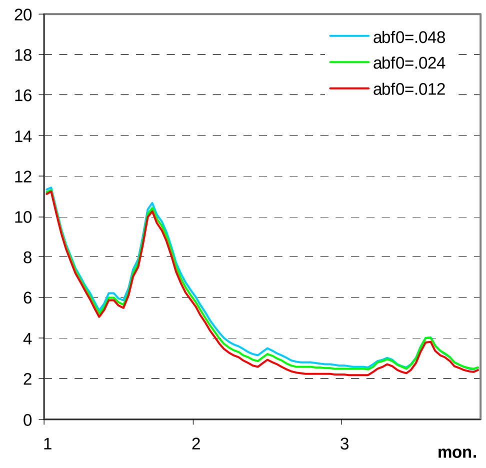
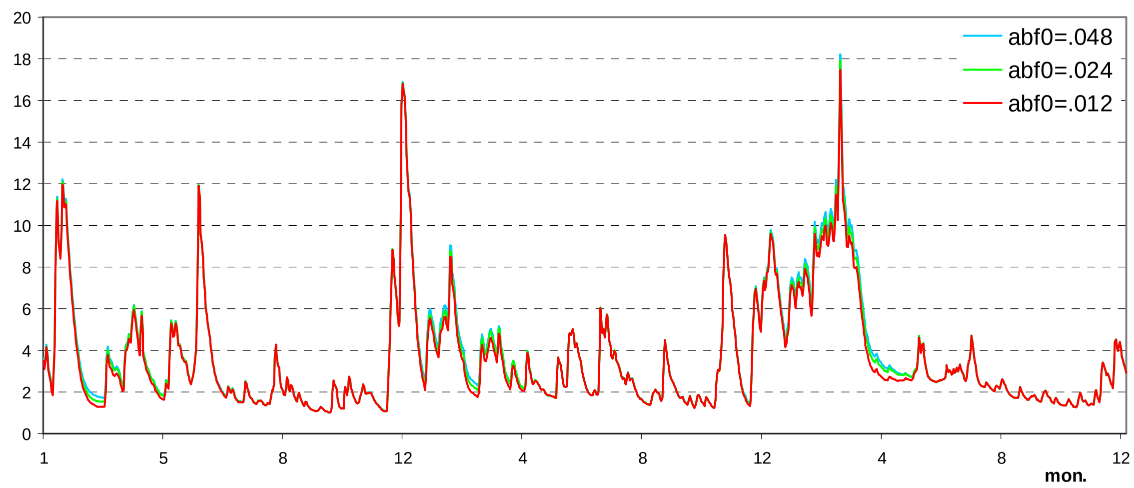


Stepenitz, 1986 - 88



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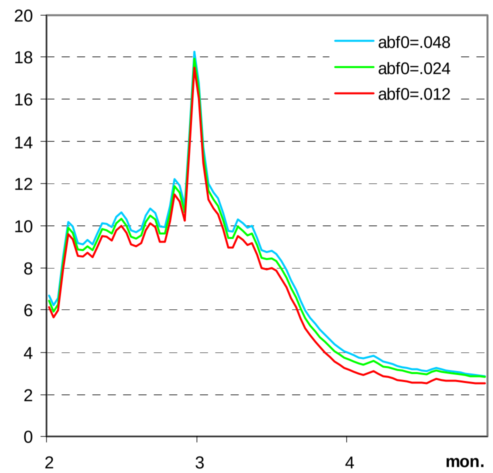
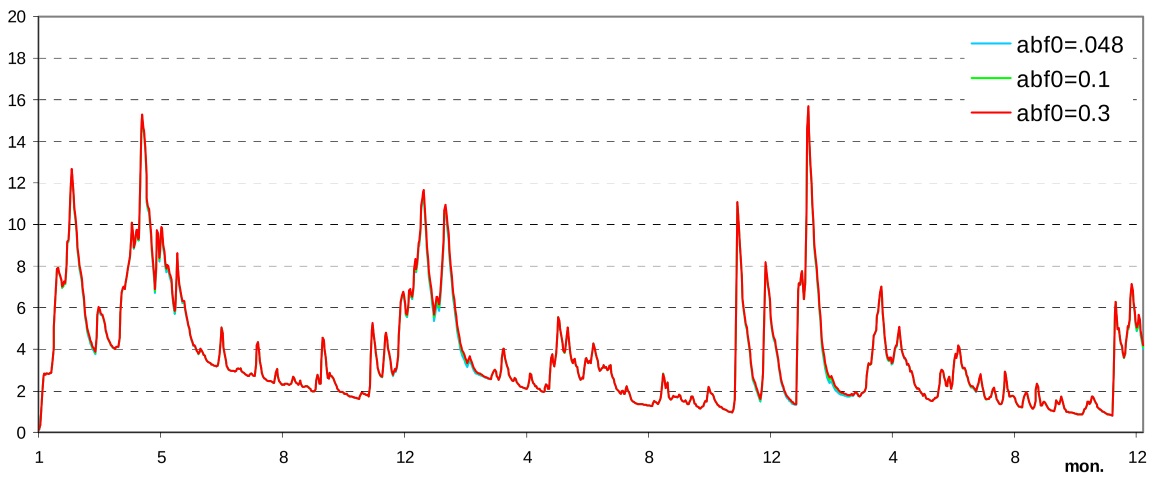
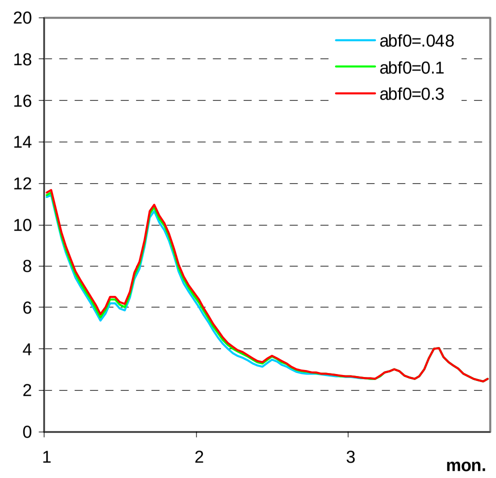


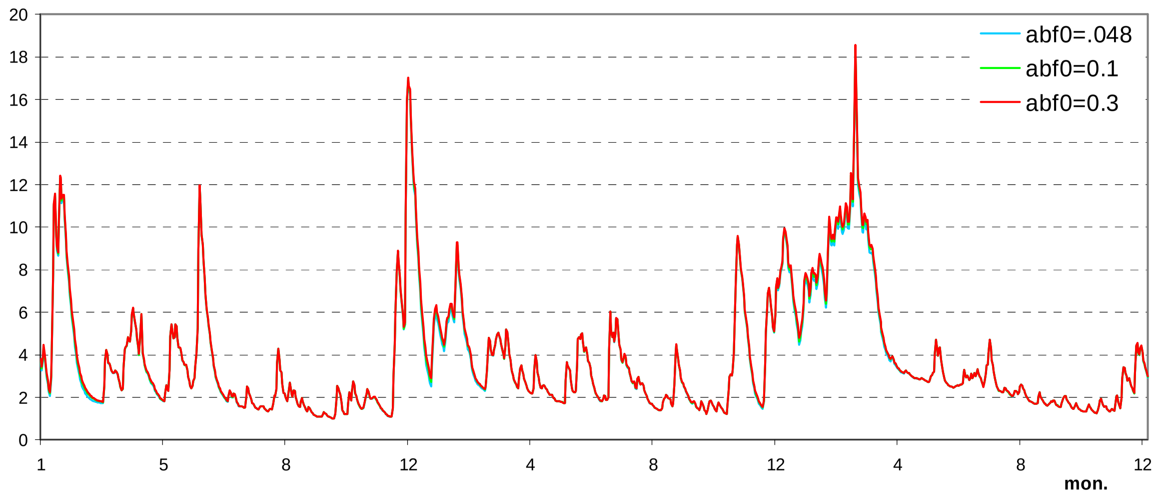
Stepenitz, 1983 - 85



Jan. - Mar. 1984



Stepenitz, 1986 - 88



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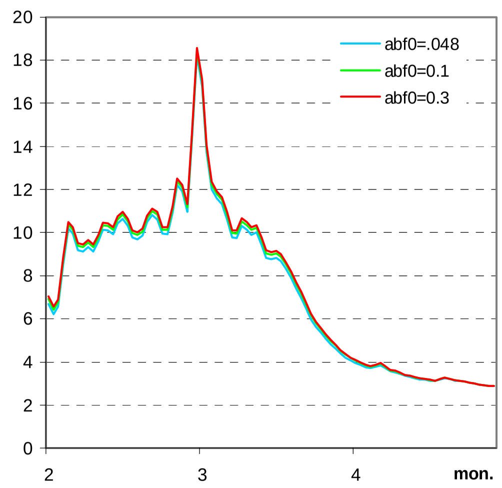
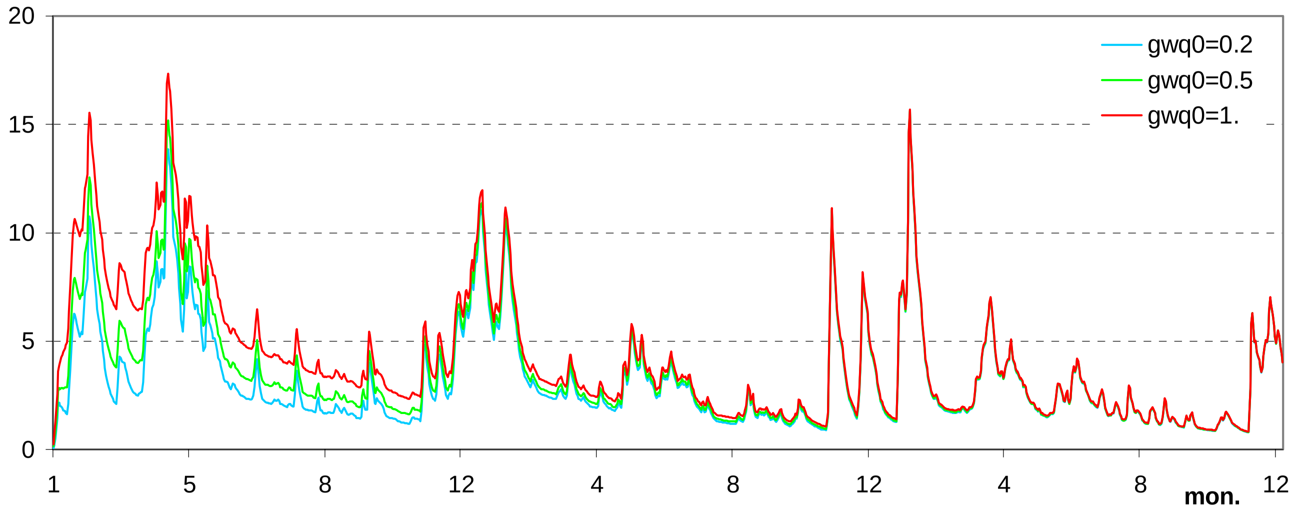
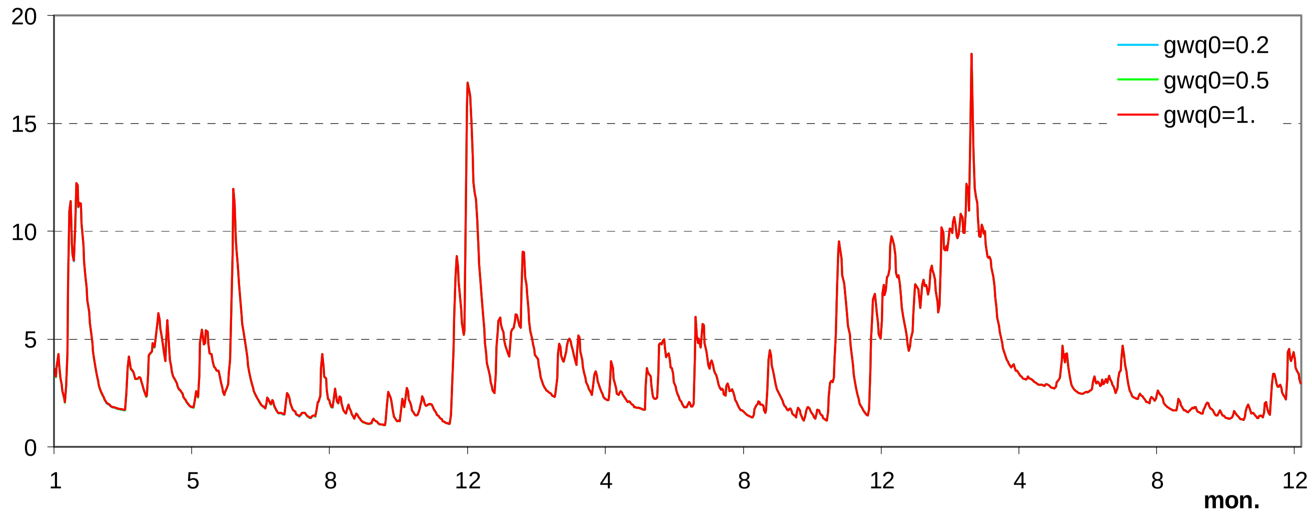


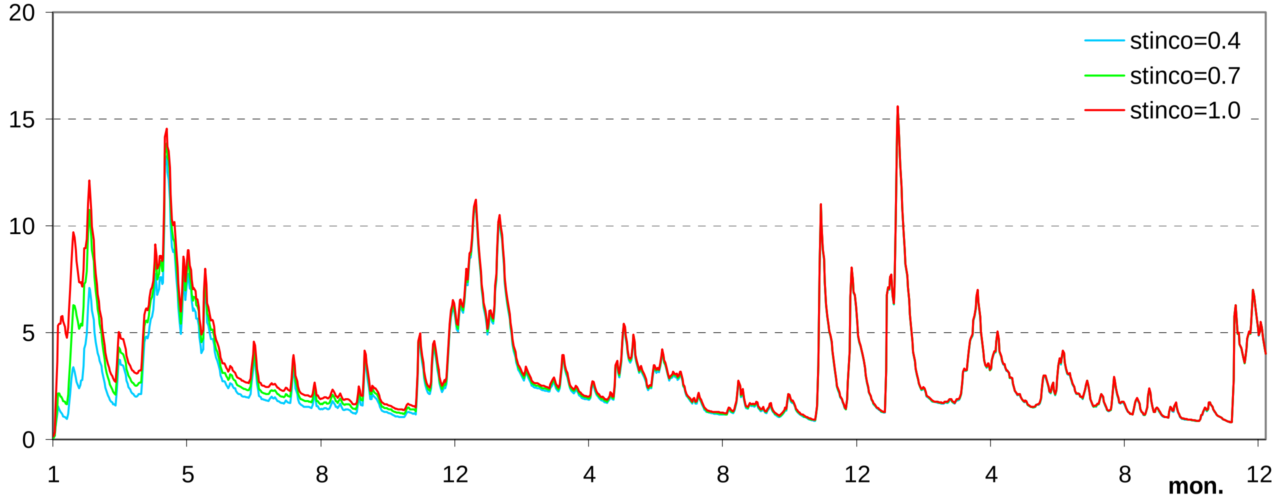
Stepenitz, 1983 - 85



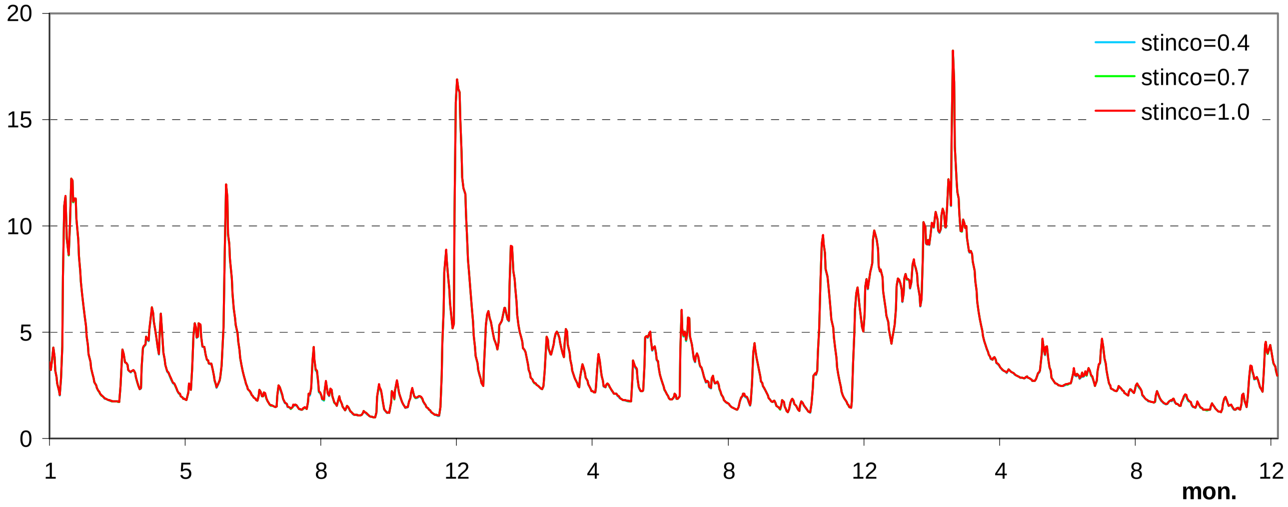
Stepenitz, 1986 - 88



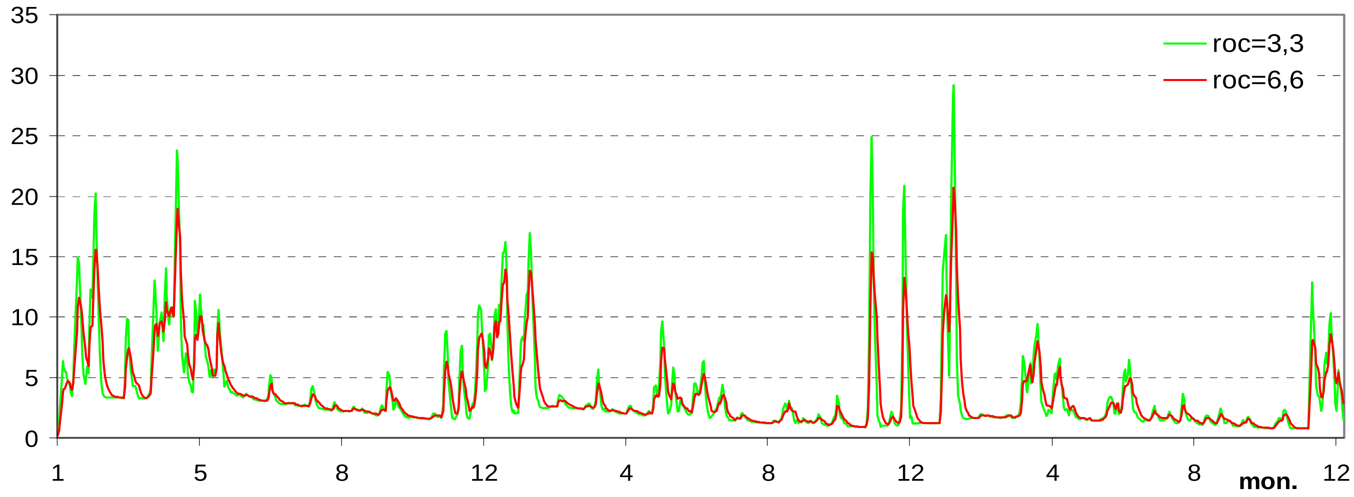
Stepenitz, 1983 - 85



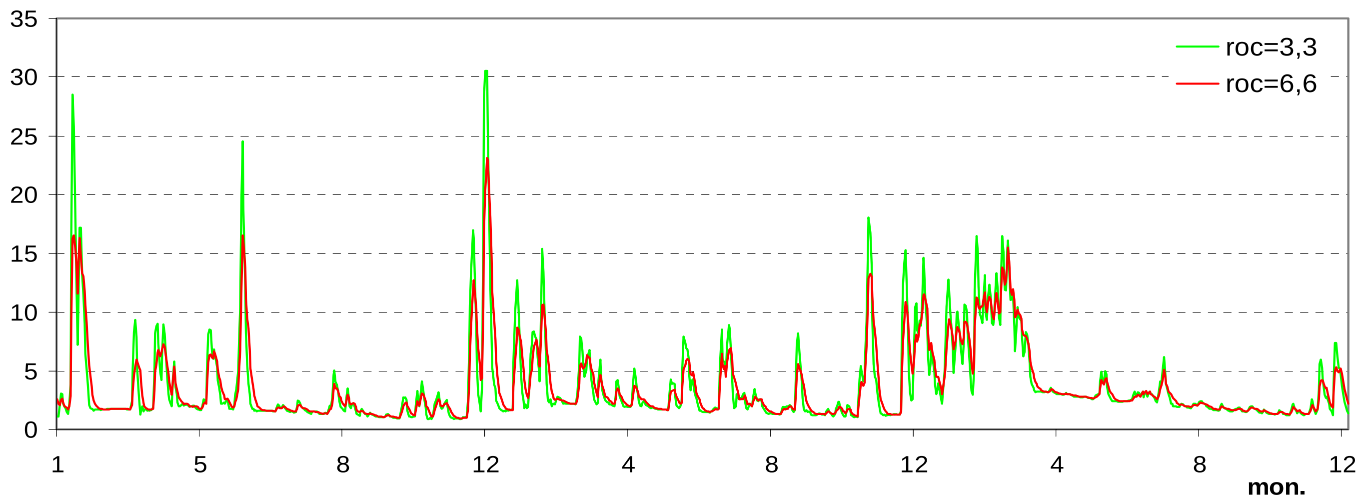
Stepenitz, 1986 - 88



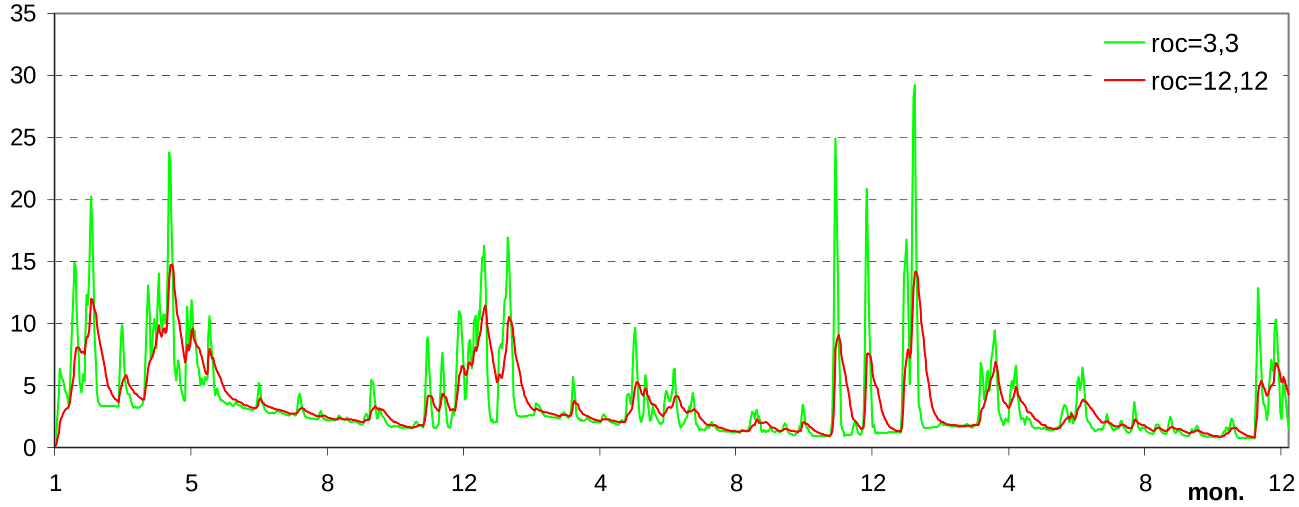
Stepenitz, 1983 - 85



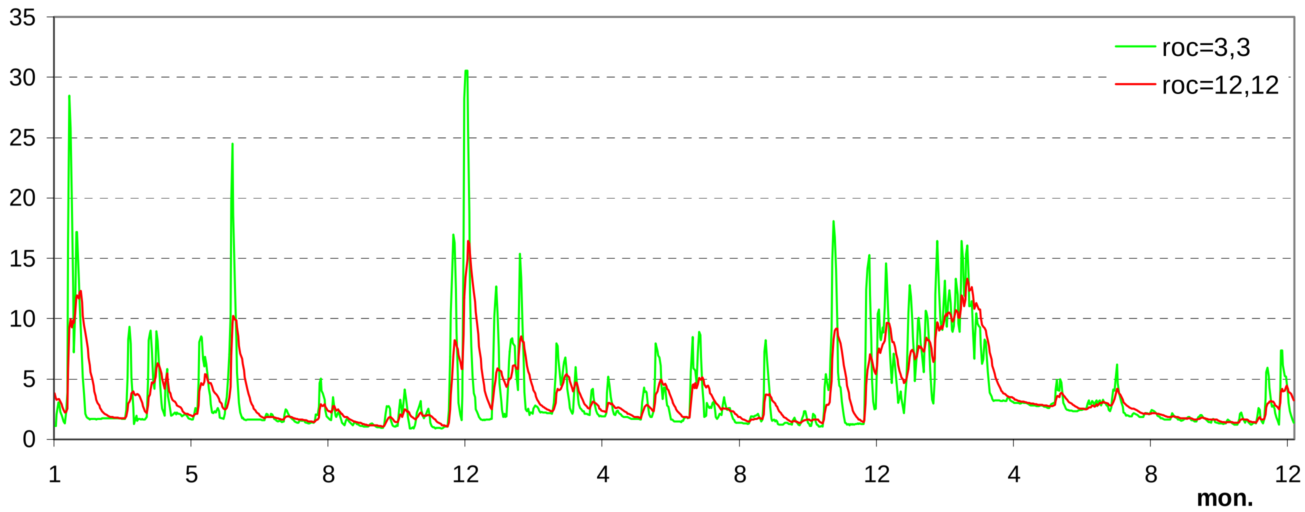
Stepenitz, 1986 - 88



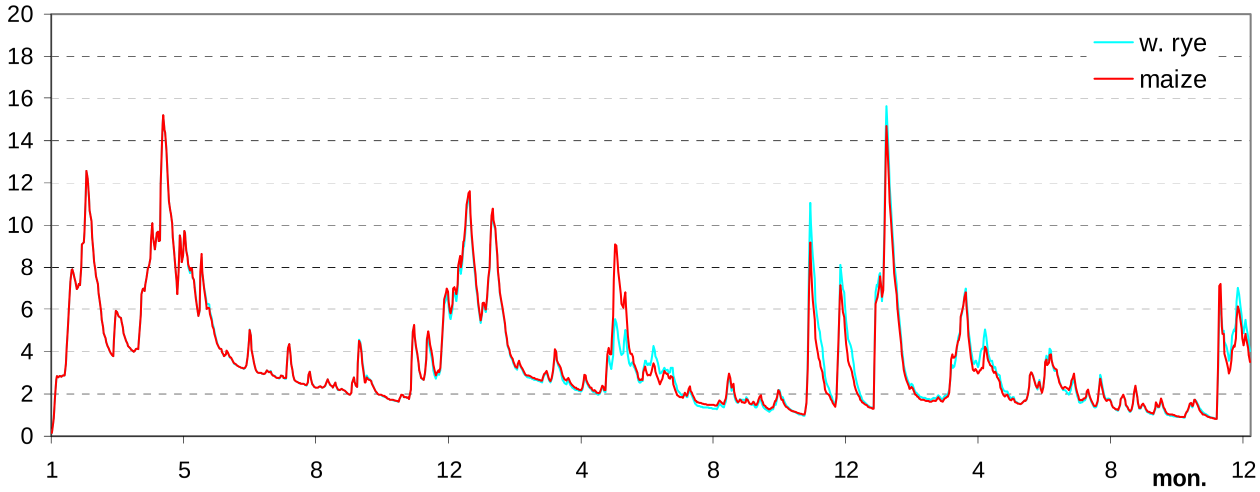
Stepenitz, 1983 - 85



Stepenitz, 1986 - 88



Stepenitz, 1983 - 85



Stepenitz, 1986 - 88

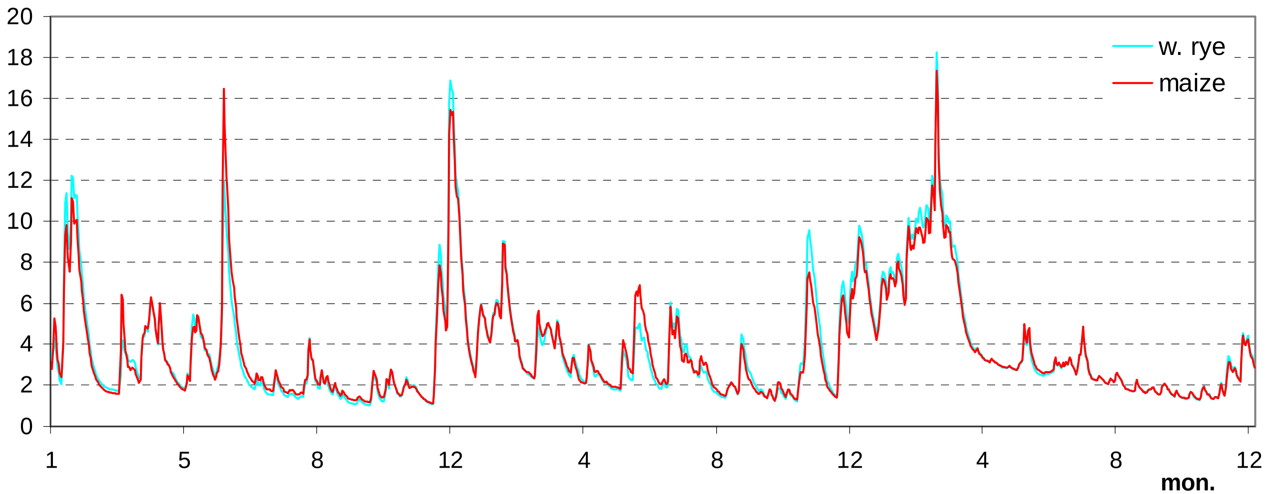
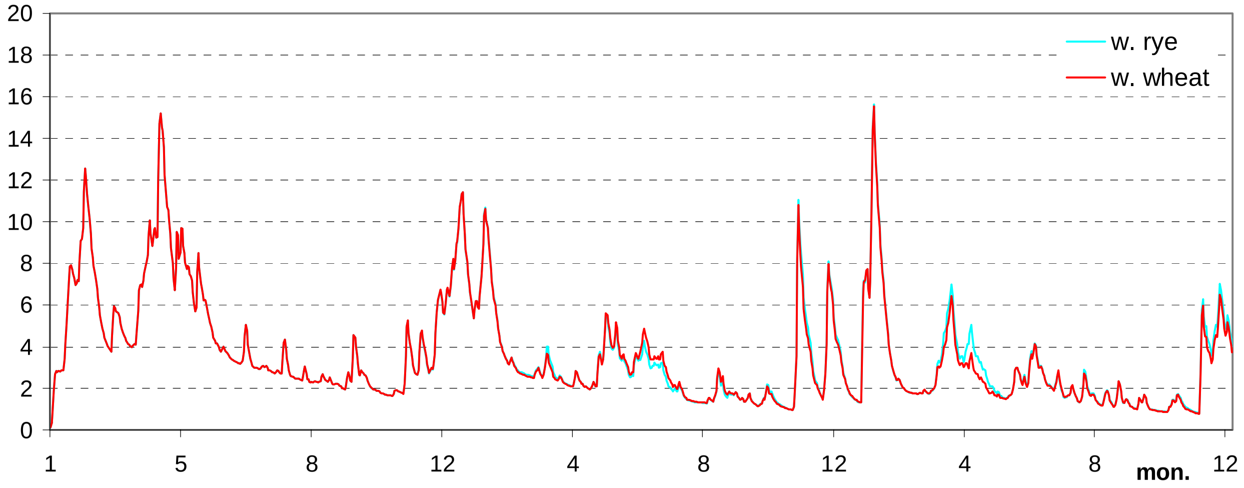


Fig. 4.23 Sensitivity to the crop type: winter rye and maize

Stepenitz, 1983 - 85



Stepenitz, 1986 - 88

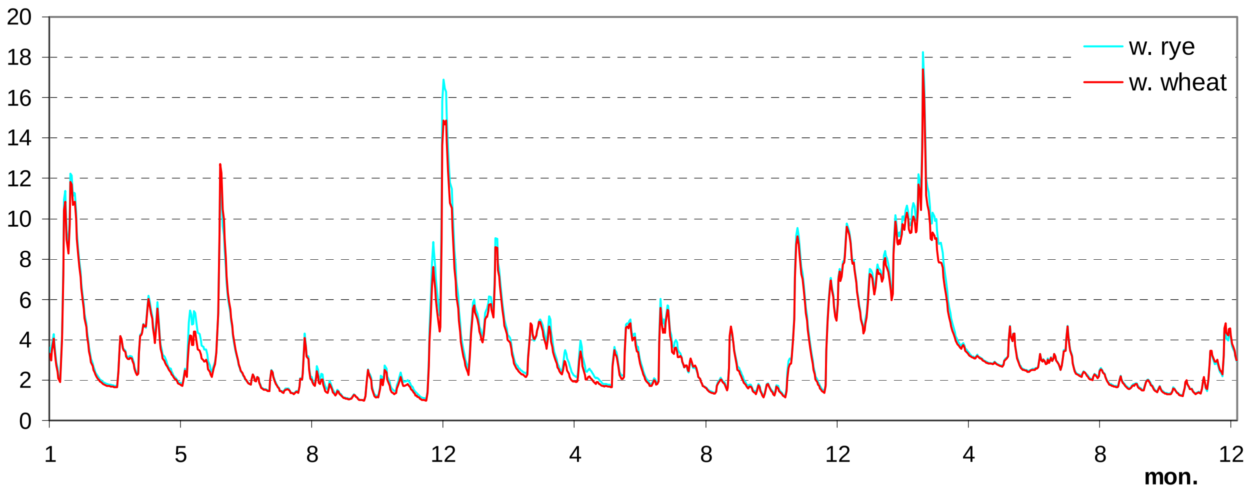


Fig. 4.24 Sensitivity to the crop type:winter rye and winter wheat

4.4.4 Overview of SWIM applications

Model validation SWIM was tested and validated sequentially for hydrological processes, for nitrogen dynamics, crop growth and erosion. First validation for hydrological processes performed for several mesoscale river basins is described in Krysanova *et al.*, 1998a. Preliminary validation of the model for nitrogen dynamics and crop growth is described in Krysanova *et al.*, 1998a. First test for erosion processes was performed for the Mulde basin (area 6171 km^2), and it is described in Krysanova *et al.*, 1998b.

More detailed validation of the model for hydrological processes and nitrogen dynamics in the lowland and mountainous sub-regions of the Elbe was done for the Stepenitz and the Zschopau basins (Krysanova *et al.*, 1999a & b). These two papers include also the analysis of factors affecting nitrogen export from diffuse agricultural sources of pollution.

More elaborate validation of the erosion processes in SWIM was done for the Glonn basin in Bavaria (392 km^2, Krysanova *et al.*, 2001), where more detailed data than for the Mulde basin were available. Results of the model validation are quite satisfactory.

Further development is foreseen for some processes, like nutrient retention in river basins. Besides the validation studies, the model was applied for the land use change and climate change impact studies, which are described below.

Land use change impact study was performed for the state of Brandenburg, Germany. Besides general vulnerability against water stress due to natural conditions, water resources in Brandenburg are strongly affected by brown coal mining, which took place in the south-east of the federal state in the last decades. Now the mining activities are significantly shortened. This results in decreasing river discharge, in particular in the Spree river, and may lead to general shortages in water availability. Land use change is one possible option to counteract this development.

As regards land use change trends, a tendency towards deintensification in the use of agricultural land is observed in Brandenburg during the last decade. The increase in a temporary set-aside within crop rotations was the main measure used to decrease the intensification level on arable land. Another effective way to deintensify crop production and, at the same time, to protect environmentally sensitive areas, is to create buffer zones along river courses (river corridors) by converting the arable land there into grassland or forest (permanent “set-aside”). Besides, the latter is an efficient way to reduce nitrate pollution and sediment load in rivers and to improve water quality.

Therefore, the primary objective of our study was to analyse the effects of these two alternatives of deintensification in the use of arable land on water resources in Brandenburg. Three types of land use change scenarios were developed and applied:
- **modification of the basic rotation scheme by increasing the portion of temporary “set-aside”;**
- introducing river corridors (150 and 500m width) in the original land use map and converting cropland within them into meadows (permanent “set-aside”);
- combinations of temporary and permanent set-aside schemes described above.

Two opposite tendencies were established in our simulation study. The temporary “set-aside” within a crop rotation scheme would result in decreasing evapotranspiration and increasing runoff and groundwater recharge in the region, whereas the permanent set-aside within river corridors would reduce runoff and increase evapotranspiration.

Therefore, land use changes in terms of deintensification may compensate for the expected decrease of discharge in the river Spree over the coming period, only if these changes assume increases in the portion of temporary set-aside areas, and do not include conversion of arable land into meadows (or forests). Runoff increases might be even greater with a decreasing production intensity on the remaining area for arable crops, due to reduction in regional transpiration as consequence of the lowered leaf area index. The land use change impact study is described in Krysanova et al, 1999d, and Wechsung *et al*., 2000.

Climate change impact The analysis of climate change impacts on hydrology and crop yield was performed also for the state of Brandenburg, applying two transient 1.5 K scenarios of climate change. In advance, hydrological validation was performed in three representative mesoscale river basins in the area, and the crop module was validated regionally for Brandenburg, using crop yield data for districts. The CO_2 fertilization effect was studied in two options, considering:

a) adjustment of the potential growth rate per unit of intercepted PAR by a temperature dependent correction factor alpha based on experimental data for C3 and C4 crops;
b) assuming a CO_2 influence on transpiration at the regional scale as the beta factor, which is coupled to the factor alpha.

Two transient 1.5 K scenarios of climate change for Brandenburg were developed in PIK: wet scenario W15 and dry scenario D15. Three periods were compared: 1981 - 1992 (control period A), 2022 - 2030 (period B), and 2042 - 2050 (period C). The atmospheric CO_2 concentration for the reference period and two scenario periods were set to 346, 406 and 436 ppm, respectively. According to the scenario W15, precipitation is expected to increase in Brandenburg: +5.2% and +11.7% on average in periods B and C, respectively. According to the scenario D15, precipitation is expected to decrease slightly in the period B (-1.7%) and quite significantly in the period C (-11.3%).

Evapotranspiration is expected to increase quite significantly under changing climate for the scenario W15, and moderately for the scenario D15. Groundwater recharge is practically the same as that in the control period for scenario W15. On the opposite, the decrease of groundwater recharge is notable for scenario D15, down to -31.5% in the period C. According to scenario W15, runoff is increasing (up to +17.2% in the period C). However it decreases significantly in the period C for scenario D15 (-22.6%).

The crop yield was only slightly altered under the "climate change only" variant of the W15 scenario for barley and maize, and it was reduced for wheat. The D15 scenario lead to the reduced crop yield for all the crops.

The impact of higher atmospheric CO_2 (alpha factor) compensated fully or partly for climate-related crop yield losses, and resulted in an increased yield both for barley and maize in scenario W15 compared to the reference scenario. The negative changes were still preserved in scenario D15 for wheat and maize.

The assumption that in addition stomatal control of transpiration is taking place at the regional scale (beta factor coupled to alpha factor) lead to further increase in crop yield, which was larger for maize than for barley and wheat. A full description of the climate change impact study with scenario W15 is given in Krysanova *et al*. (1999c).

Conclusions **One of the major challenges for BAHC (Biospheric Aspects of Hydrological Cycle) research in the frame of the International Geosphere and Biosphere Program (IGBP) is**

the adequate description and modelling of the complex interactions between climate, hydrological and ecological processes at different scales. SWIM has been developed as a tool to serve this purpose at the mesoscale and regional scale.

Model applications in a number of river basins in the range of about 100 to 24000 km^2 drainage area have shown that the model is capable to describe realistically the basic ecohydrological processes under different environmental conditions, including a) the spatial and temporal variability of main water balance components (evapotranspiration, groundwater recharge, runoff generation), b) the cycling of nutrients in soil and their transport with water considering the dynamics of the controlling climate and hydrological conditions, c) vegetation/crop growth and related phenomena, d) the dynamical features of soil erosion and sediment transport, and e) the effect of changes in climate and land use on all these interrelated processes and characteristics.

APPENDIX I

GRASS commands useful for the spatial data preparation for SWIM

Command format	*Flags and Parameters*	*Command description*
d.colors [map=name]	**Parameters:** map raster map name	To interactively change the color table of a raster map layer
d.display		A menu-driven display program for viewing maps
d.erase [color=name]	**Parameters:** color color to erase with	Erases the contents of the active display frame on the user's monitor
d.frame [-cepsD] [frame=name] [at=bottom,top,left,right]	**Flags**: -c Create a new frame -e Remove all frames and erase the screen -p Print name of current frame -s Select a frame -D Debugging output **Parameters:** frame frame to be created/selected at where to place the frame	Manages display frames on the user's monitor
d.histogram [-zq] map=name [color=name] [style=name]	**Flags**: -z Display zero-data information -q Gather the histogram quietly **Parameters:** map raster map for which histogram will be displayed color color for legend and title options: red, orange, yellow, green, blue, indigo, white, black, brown, magenta, aqua, gray, grey style indicate if a pie or bar chart is desired	Displays a histogram in the form of a pie or bar chart for a user-specified raster file
d.legend map=name [color=name] [lines=value]	**Parameters:** map name of raster map color sets the legend's text color lines number of text lines (useful for truncating long legends)	Displays a legend for a raster map layer in the active frame on the graphics monitor
d.mon [-lLprs] [start=name] [stop=name] [select=name] [unlock=name]	**Flags**: -l List all monitors -L List all monitors (with current status) -p Print name of currently selected monitor -r Release currently selected monitor -s Do not automatically select when starting **Parameters:** start name of graphic monitor to start stop name of graphic monitor to stop select name of graphic monitor to select unlock name of graphic monitor to unlock	To establish and control the use of a graphics display monitor

d.rast [-o] map=name	**Flags**: -o Overlay (non-zero values only) **Parameters:** map name of raster map to be displayed	Displays and overlays raster map layers in the active display frame on the graphics monitor
d.vect [-m] map=name [color=name]	**Flags**: -m Use less memory **Parameters:** map name of vector map to be displayed color color desired for drawing map	Displays vector data in the active frame on the graphics monitor
d.what.rast [-1t] [map=name[,name,...]] [fs=name]	**Flags**: -1 Identify just one location -t Terse output. For parsing by programs. **Parameters:** map name of raster map(s) fs field separator (terse mode only), default: :	Allows the user to interactively query the category contents of multiple raster map layers at user-specified locations within the current geographic region
d.what.vect [-1] map=name	**Flags**: -1 Identify just one location **Parameters:** map name of existing vector map	Allows the user to interactively query the category contents of a (binary) vector map layer at user-specified locations within the current geographic region
d.where [-1] [spheroid=name]	**Flags**: -1 one mouse click only **Parameters:** spheroid name of a spheroid for lat/lon coordinate conversion, options: australian, bessel, clark66, everest, international, wgs72, wgs84	Identifies the geographic coordinates associated with point locations in the active frame on the graphics monitor
d.zoom [-q] [action=name]	**Flags**: -q Quiet **Parameters:** action type of zoom (for latitude/longitude databases only) options: zoom, rotate	Allows the user to change the current geographic region settings interactively, with a mouse
r.average [-c] base=name cover=name output=name	**Flags**: -c cover values extracted from the category labels of the cover map **Parameters:** base base raster map cover cover raster map output resultant raster map	Finds the average of values in a cover map within areas assigned the same category values in a user-specified base map
r.buffer [-q] input=name output=name distances=value[,value,...] [units=name]	**Flags**: -q Quiet **Parameters:** input name of input map output name of output map distances distance zone(s) units units of distance, options: meters, kilometers, feet, miles, default: meters	Creates a raster map layer showing buffer zones surrounding cells that contain non-zero category values

r.cats map=name [cats=range[,range,...]] [fs=character|space|tab]	**Parameters:** map name of a raster map cats category list: e.g. 1,3-8,14 fs output separator character, default: tab	Prints category values and labels associated with user-specified raster map layer
r.coin [-qw] map1=name map2=name units=name	**Flags**: -q Quiet -w Wide report, 132 columns (default: 80) **Parameters:** map1 name of first raster map map2 name of second raster map units unit of measure, options: c,p,x,y,a,h,k,m	Tabulates the mutual occurrence (coincidence) of categories for two raster map layers
r.colors [-wq] map=name color=type	**Flags**: -w Don't overwrite existing color table -q Quietly **Parameters**: map raster map name color type of color table options: aspect, grey, grey.eq, gyr, rainbow, ramp, random, ryg, wave, rules **Where color type** is one of: aspect (aspect oriented grey colors) grey (linear grey scale) grey.eq (histogram equalized grey scale) gyr (green through yellow to red) rainbow (rainbow color table) ramp (color ramp) ryg (red through yellow to green) random (random color table) wave (color wave) rules (create color table by rules) **Valid colors** are: white black red green blue yellow magenta cyan aqua grey gray orange brown purple violet indigo	Creates/modifies the color table associated with a raster map layer
r.combine [-s]	**Flags**: -s Use symbols (instead of graphics)	Allows category values from several raster map layers to be combined
r.cross [-qz] input=name[,name,...] output=name	**Flags**: -q Quiet -z Non-zero data only **Parameters**: input names of 2-10 input raster maps output name of the resulting map	Creates a cross product of the category values from multiple raster map layers
r.describe [-1rqd] map=name	**Flags**: -1 Print the output one value per line -r Only print the range of the data -q Quiet -d Use the current region **Parameters**: map name of raster map	Prints terse list of category values found in a raster map layer

r.in.ascii input=name output=name [title="phrase"] [mult=value]	**Parameters**: input ascii raster file to be imported output name of resultant raster map title title for resultant raster map mult multiplier for ascii data, default: 1.	Convert an ASCII raster text file (e.g., from ARC/INFO) into a binary raster map layer
r.info map=name	**Parameters**: map name of raster map	Outputs basic information about a user-specified raster map layer
r.mapcalc [result=expression]		Raster map layer data calculator, performs arithmetic operations on several raster map layers
r.neighbors [-aq] input=name output=name method=name size=value [title="phrase"]	**Flags**: -a Do not align output with the input -q Run quietly **Parameters**: input name of existing raster file output name of the new raster file method neigborhood operation, options: average, median, mode, minimum, maximum, astdev., variance, diversity, interspersion size neigborhood size, options: 1,3,5,7,9,11,13,15,17,19,21,23,25 title title of the output raster file	Makes each cell category value a function of the category values assigned to the cells around it, and stores new cell values in an output raster map layer
r.out.ascii [-h] map=name [digits=value]	**Flags**: -l Smooth Corners	Converts a raster map layer into an ASCII text suitable for other computer systems
r.poly [-l] input=name output=name	**Flags**: -h Suppress printing of header information **Parameters**: map name of existing raster map digits the minimum number of digits per cell to be printed	Extracts area edges from a raster map layer and converts data to GRASS vector format
r.reclass input=name output=name [title=name]	**Parameters**: input raster map to be reclassified output name for the resulting raster map title title for the resulting raster map	Creates a new map layer with category values based upon the user's reclassification of cate-gories in an existing map
r.report [-hmfqez] map=name[,name,...] [units=name[,name,...]] [pl=value] [pw=value] [output=name]	**Flags**: -h suppress page headers -m report zero values due to mask -f use form feeds between pages -q quiet -e scientific format -z filter out zero category data **Parameters**: map raster map(s) to report on units mi(les), me(tres), k(ilometers), a(cres), h(ectares), c(cells), p(ercent) pl,pw page length, page width output name of an output file	Reports statistics for raster map layers

r.stats [-1aclmqzgx] input=name[,name,...] [fs=character|space] [output=name]	**Flags**: -1 One cell per line -a Print area totals -c Print cell counts -l Print category labels -m Report zero values due to mask -q Quiet -z Non-zero data only will be output -g Print grid coordinates (east and north) (requires -1 flag) -x Print x and y (column and row) (requires -1 flag) **Parameters**: input raster maps(s) fs output field separator, default: space output output file name	Generates area statistics for raster map layers
r.watershed [-m4] elevation=name [depression=name] [flow=name] [disturbed.land=name] [blocking=name] [threshold=value] [max.slope.length=value] [accumulation=name] [drainage=name] [basin=name] [stream=name] [half.basin=name] [visual=name] [length.slope=name] [slope.steepness=name]	**Flags**: -m Enable extend memory option: Operation is slow -4 Allow only horizontal and vertical flow of water **Parameters**: **Input maps**: *elevation* Input map: elevation on which entire analysis is based *depression* Input map: locations of real depressions *flow* Input map: amount of overland flow per cell *disturbed.land* Input map or value: percent of disturbed land, for RUSLE *blocking* Input map: terrain blocking overland surface flow, for RUSLE *threshold* Input value: minimum size of exterior watershed basin *max.slope.length* Input value: maximum length of surface flow, for RUSLE **Output maps:** *accumulation* Output map: number of cells that drain through each cell *drainage* Output map: drainage direction *basin* Output map: unique label for each watershed basin *stream* Output map: stream segments *half.basin* Output map: each half-basin is given a unique value *visual* Output map: useful for visual display of results *length.slope* Output map: slope length and steepness (LS) factor for RUSLE *slope.steepness* Output map: slope steepness (S) factor for RUSLE	Watershed basin analysis program. It generates a set of maps indicating the location of sub-basins and streams, and the LS and S factors of the Revised Universal Soil Loss Equation (RUSLE)

g.remove [rast=name[,name,...]] [vect=name[,name,...]] [icon=name[,name,...]] [labels=name[,name,...]] [sites=name[,name,...]] [region=name[,name,...]] [group=name[,name,...]] [3dview=name[,name,...]]	**Parameters**: rast rast file(s) to be removed vect vect file(s) to be removed icon icon file(s) to be removed labels labels file(s) to be removed sites sites file(s) to be removed region region file(s) to be removed group group file(s) to be removed 3dview 3dview file(s) to be removed	Removes data base element files from the user's current mapset
g.rename [rast=old,new] [vect=old,new] [icon=old,new] [labels=old,new] [sites=old,new] [region=old,new] [group=old,new] [3dview=old,new]	**Parameters**: rast rast file(s) to be renamed vect vect file(s) to be renamed icon icon file(s) to be renamed labels labels file(s) to be renamed sites sites file(s) to be renamed region region file(s) to be renamed group group file(s) to be renamed 3dview 3dview file(s) to be renamed	To rename data base element files in the user's current mapset
p.map [input=name] [scale=mapscale]	**Parameters**: input file containing mapping instructions (or use input=- to enter from keyboard) scale scale of the output map, e.g. 1:25000 (default: 1panel)	Hardcopy color map output utility

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A short description of SWIM is available in the Register of Ecological Models, University of Kassel:

http//dino.wiz.uni-kassel.de/ecobas.html

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