STREAM SE Manual

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1. Introduction

1.1 Setup and Installation procedure

This manual describes how to setup a spatial hydrological model using the STREAM software. An existing model for the Ganges Brahmaputra Meghna basin in South Asia is used to demonstrate the capacity of the software as well as to prepare the input data.

Installation procedure

1. Copy all files from the Stream SE directory on cd to C:\Program Files\Stream SE\ **NOTE** If you choose another location, make sure to change the workspaces in the stream.mxl file;
2. Make sure none of the files is read only! Therefore, after copying all files, search for *.* in the new Stream SE directory and select all files (including sub-directories). Next, clear read only flag in properties);
3. Install all Stream ActiveX Components in the Install/RA Components directory by running Register.bat;
4. Install MapObjects Lite by running Setupex.exe in Install/System Components/MOLT directory;
5. Use IDRISI 32 to covert all Idrisi 16 bit files of the GBM model (*.doc and .img) to of a idrisi 32bit files (*.rdc and *.rst). Any new model should use Idrisi 32 bit files.

1.2 Checklist for running a new model

This paragraph provides an overview for installing a new model. It is recommended to copy all files of the GBM model, and replace each of these files with the files of the new model. Creating new files is described in chapter 2 to 6.

Check data input files

Running the STREAM model is fairly easy once you have all the input maps. If you want to run STREAM on a monthly basis, you need at least:

- Monthly (12) average precipitation (PRE);
- Monthly (12) average temperature (TMP);
- Monthly (12) daylight (day);
- Initial map for APWL;
- Initial map for GW;
- Initial map for SNOW;
- Initial map for SOILSTOR;
- Map for A;
- Map for HEAT;
- Map for C;
- Map for COVERmap;
- Map for MASK;
- Map for WHOLDN.

Put files in proper folder

You should place all data in the following directory structure:

..\\STREAM SE*name of your basin*\..

In this directory make the following directory structure:

```
..\Input\..
      ..\Climate\..
                  ..\Current\..
                  ..\Scenario\..
      ..\Discharge\..
      ..\Etc\..
      ..\Init\..
      ..\Palettes\..
      ..\Scripts\..
      ..\Shapefiles\..
..\Output\..
      ..\Current\..
..\Scenario\..
```

- Place under Climate\Current: all the TMP, PRE and DAY files;
- Place under Discharge: Qout3.dis file;
- Place under Etc: , HEAT, CROPF, WHOLDN, MASK, BPGLDD, C files;
- Place under Init: APWL, GW, SNOW, SOILSTOR files;
- Place under Palettes: the *.pal files (can be created using Idrisi);
- Place under scripts: the script files;
- Place under Shapefiles: the shapefiles. These are vector files (or other Idrisi files) that are available when viewing the output.

All the results will be placed in the output directory.

Check case text files

A text file is needed for every case (basin) named 'description.txt'. In this file, a short description of the case (basin) is given. For every new basin (case) you will need to create such a file in the root directory of the basin (i.e. in the directory ..\Case\..).

For every run (setup for a case) that you want to do, you also need to create 2 files: a *.run and a *.txt file. These are both normal text files. The *.txt file just contains a description of the run.

The *.run file contains the paths and information on the run. Once you have created such a file it is possible to adjust this within STREAM. It has the following structure:

```
[Stream SL Environment]
Landuse=
ShapefileDirectory=Input\Shapefiles\
DischargePoints=Input\Discharge\Qout3.dis
OutputDirectory=Output\Current\
ClimateChange=Input\Climate\Current\
CalculationScript=Case.csc
SimulationStart=1
SimulationTime=12
```

Set Initial parameters

Before running the model, set all the parameters for the case (these parameters are stored in the *.run file).

- In the STREAM program, go to the 'Current Case' tab;
- Select the appropriate case;
- Select the appropriate run;
- Set the appropriate directories and simulation start and end time;

- On the 'Calculation Script' tab select the appropriate script.;
- Go to the 'Run' tab and press 'Start Calculation';
- Go to the 'Output' tab and view the calculation results.

When you have all this data you also need the (BLAISE) script. In the next paragraph, an example script is presented.

Delete old IND file

On the basis of the flow direction map (See input data paragraph), STREAM produces a drain direction map with the ACCU function (See model script). The drain direction map has the name *.IND and is placed in the root of the '..Input\' directory. Please delete old *.IND files or delete this file if the model failed to accumulate water, because the model will NOT overwrite an existing DSCRH.IND map! Always first delete this file in case you intent to make a new model by replacing files from an old model, e.g. the GBM model.

Use Blaise

Make sure that under the tab 'Calculation scripts' you select Blaise v1.0 under 'languages'.

Check Stream.Meta file

A file named 'STREAM.Meta' exists in the root directory of STREAM SE. In case the program starts with showing the Interface, but it gives application errors try the following:
Open the stream.meta file in a notepad. Put a ' before the line CaseDirectory=\\server\OldProj\Stream\Stream_SE\Cases\ , So that is becomes: 'CaseDirectory=\\server\OldProj\Stream\Stream_SE\Cases\. Save the file in notepad.

2. STREAM model background information.

The STREAM model is a grid-based spatial water balance model for estimating runoff amounts in river basins. The model has been applied to many larger river basins, such as the Rhine, Krishna, Perfume, Zambezi, Nile, Niger and Yangtze Basins (Van Deursen and Kwadijk 1994; Aerts *et al.* 1999, Seyam 2000). It has also been applied for coastal areas to estimate salt intrusion (Aerts *et al.* 2000).

STREAM is based upon a 'multi – compartment' methodology where the hydrological cycle of a drainage basin is described as a series of storage compartments and flows. STREAM calculates per grid cell a water balance, which describes the transformation of input (precipitation) and output (runoff and evapotranspiration) through this cycle. Until now, STREAM applications mainly used the Thorntwaite and Mather (1957) approach. In this approach, the main water balance components and hence most important model parameters are: (see also Figure 1).

1. The amount of precipitation and its spatial distribution;
2. The temperature distribution in the catchment. This distribution forms the main control for the potential evapotranspiration in the catchment;
3. Soil moisture storage/shallow groundwater which gains water from the surplus precipitation and loses water to evapotranspiration, to seepage to the deeper groundwater and to direct runoff;
4. Deeper groundwater storage, which gains water from the soil seepage and loses water to the river base flow;
5. The distribution of land-cover and soil water storage capacity in the catchment, which control the actual evapotranspiration.

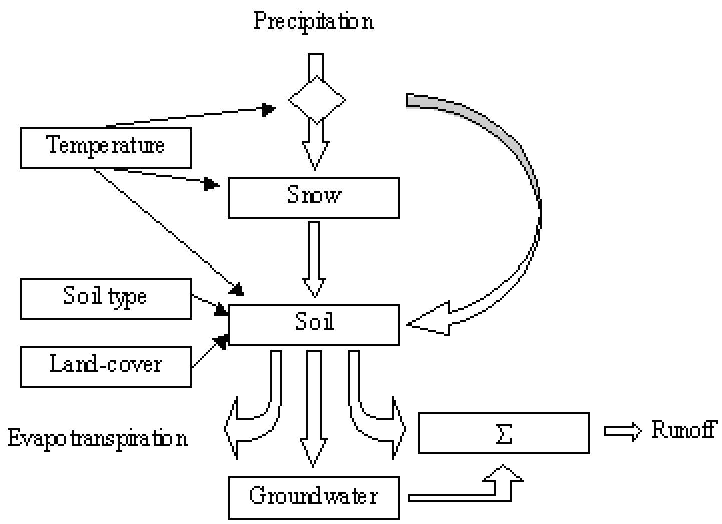

Figure 2.1 The water balance components of the STREAM model. (Aerts et al. 1999).

Potential evapotranspiration

To estimate the actual evapotranspiration ET_{act}, an estimate of a reference potential evapotranspiration is made. This is done by using the equation:

$$ET_{pot\,x,y,t} = ET_{ref\,x,y,t} \cdot k_{c\,x,y,t} \cdot F_{red} \tag{2.1}$$

where

ET_{pot} is the potential crop evapotranspiration,

ET_{ref} *is the reference evapotranspiration, both in millimetre.*

k_c *is a crop coefficient, and*

F_{red} *is a calibration parameter.*

The maximum crop coefficient depends on the characteristics of the vegetation, which for larger catchments can be reduced classifying the main land-cover.

Thornthwaite equation determines the reference evapotranspiration using temperature data, according to the equations below:

If $T \leq 26.5$ then

$$ET_{ref} = 16\left(10\frac{T}{H}\right)^{A} \tag{2.2}$$

,else

$$ET_{ref} = -415.85 + 32.24 \cdot T - 0.43 \cdot T^{2} \tag{2.3}$$

,where T is the average monthly temperature in degrees Centigrade, and

$$H = \sum_{jan}^{dec}\left(\frac{T_m}{5}\right)^{1.514} \tag{2.4}$$

,where T_m is the long term average monthly temperature from January to December, and

$$A = 0.49239 + 0.01792 \cdot H - 0.0000771771 \cdot H^{2} + 0.000000675 \cdot H^{3} \tag{2.5}$$

Actual evapotranspiration and soil water balance

Next, the actual evapotranspiration and the soil water balance are being calculated using the approach of Thornthwaite and Mather (1957). This is done for each month, depending on the accumulated water loss potential, using the equations below:

If $P_{x,y,t} \geq ET_{x,y,t}$ Then

$$AE_{x,y,t} = ET_{x,y,t} \tag{2.6}$$

,else

$$AE_{x,y,t} = P_{x,y,t} + MELT_{x,y,t} + \left(SS_{x,y,t-1} - S_{\max x,y}^{\left(-\frac{APWL_{x,y,t}}{S_{\max x,y}}\right)}\right) \tag{2.7}$$

where

P is the amount of monthly precipitation,

AE is the amount of actual evapotranspiration,

MELT is the amount of melt water,

SS is the soil storage (see below),

S_{max} is the maximum water holding capacity of the soil, and

APWL is the accumulated potential water loss, all in millimetre.

The **soil storage** *SS* is calculated using

$$SS_{x,y,t} = SS_{x,y,t-1} + SI_{x,y,t} - SO_{x,y,t} \quad (2.8)$$

,where $SI_{x,y,t} = P_{EFF\,x,y,t} + M_{x,y,t}$, with *Peff* being the effective precipitation, and *M* being the amount of melt water, and $SI_{x,y,t} = SP_{x,y,t} + AE_{x,y,t}$, with *SP* being the soil seepage (see below).

The ***APWL*** is calculated using the equation:

If $P_{x,y,t} > ET_{x,y,t}$ then $APWL_{x,y,t} = 0$, else

$$APWL_{x,y,t} = S_{\max} \cdot \ln\left(\frac{S_{\max x,y}}{SS_{x,y,t-1}}\right) - \left(P_{x,y,t} - ET_{xyt}\right) \quad (2.9)$$

Groundwater balance

The water balance of the groundwater is calculated for each grid cell using the equation:

$$GWS_{x,y,t} = GWS_{x,y,t} + SP_{x,y,t} - DER_{x,y,t} \quad (2.10)$$

where

GWS is the groundwater storage,

SP is the soil seepage, and

DER is the delayed runoff.

The **soil seepage** *SP*, the delayed runoff *DER*, and the direct runoff *DIR* are being calculated using the equations: If $P_{x,y,t} > ET_{x,y,t}$ then

$$(\,SP_{x,y,t} = (1-X)\cdot\left(SS_{x,y,t} - S_{\max x,y,t}\right) \quad (2.11)$$

,else $SP_{x,y,t} = 0$

where *X* is a factor to separate between **direct** and **delayed runoff**.

$$DER_{x,y,t} = \frac{GWS_{x,y,t}}{C} \tag{2.12}$$

where *C* is a calibration parameter (in moths), depending on the topography of the basin.

If $P_{x,y,t} > ET_{x,y,t}$ then $DIR_{x,y,t} = X \cdot \left(SS_{x,y,t} - S_{\max x,y,t}\right)$, else $DIR_{x,y,t} = 0$, (2.13)

Finally, the **total runoff** *TR* for each grid cell is:

$$TR_{x,y,t} = DER_{x,y,t} + DIR_{x,y,t} \tag{2.14}$$

3. Procedures used to create input maps for STREAM

The goal of this exercise is to prepare all data for a STREAM model. All data are in the form of digital maps, which are either in IDRISI or ARC INFO Ascii/Grid format. It is important that all data is of the same format! Please note that the newest version (STREAM SE) only reads IDRISI 32 maps. Hence, old Idrisi 16 bit maps should be converted to 32 bit before using in STREAM. All water balance calculations are made for each cell per month (however the time step of course vary according to the data which is available). Usually, the units used are mm water, °C and hours.

The model needs the following initial input data, which is provided with the source of the data. Iterative means that the data changes throughout the calculations.

The following maps need to be placed in the ‘ \Input\init ‘ directory’:

- APWL: the accumulated potential water loss (mm water). *Iterative*
- GW: the groundwater capacity. *Iterative*
- SNOW: the initial thickness (mm water) of the snow cover. *Iterative*
- SOILSTOR: the soil storage of water. From *Iterative*

The following maps need to be placed in the ‘ \Input\etc ‘ directory’

- A: parameter (constant) used to calculate PE. *Calculated from temperature data*
- HEAT: parameter (constant) used to calculate PE. *Calculated from temperature data*
- CROPF: crop parameter, which reflects the effect of crop on the PE. *From USGS land cover data (http://edcdaac.usgs.gov/glcc/glcc.html) in combination with table from Deursen and Kwadijk (1994)*
- WHOLDN: the water holding capacity of the soil. Use FAO soil map *Soil map in combination with table from Deursen and Kwadijk (1994)*
- MASK: 0-1 map of he whole basin. *For example from Hydro 1K: http://edcdaac.usgs.gov/gtopo30/hydro/*
- BPGLDD: discharge direction of cell. *From Hydro 1K: http://edcdaac.usgs.gov/gtopo30/hydro/. Or use DEM*
- Covermap: Not really necessary map. But sometimes used to mask the basin area. *From MASK (Hydro 1K)*
- C: a calibration parameter. Initial value = 3, or use DEM

The following maps need to be placed in the ‘ \Input\Climate\ ‘ directory’

* TMP: the temperature (average temperature in the month in °C). IPCC CD-ROM or http://ipcc-ddc.cru.uea.ac.uk/cru_data/datadownload/download_index.html
- PRE: the total precipitation in the month (mm)). IPCC CD-ROM
- DAYL: the length of a day (hours of sunshine). From Old data

Internally the following variables are used:

- SNOW1: the amount of snow fallen (mm water)
- SMELT: the amount of snowmelt (mm water)
- EVEN: temporary variable
- PE: the potential evapotranspiration (mm water)
- PEFF: the effective potential evapotranspiration (mm water), PRE - PE
- AE: the actual evapotranspiration
- TOGW: the flow to the groundwater
- SSTOR: the soil storage of water (available for evapotranspiration) (mm)
- RUNOFF: the quick flow; fast runoff (mm)
- SLOFLO: the slow flow; from the groundwater (mm)
- DSCHRG: the discharge for the cell (mm)
- DISMM: total discharge in the cell with discharge from all contributing cells (mm)
- DISQSEC: discharge in m3 per second
- DISTEMP: variable used to stretch DIS maps (if < 40 then 0)
- DISTEMP2: variable used to stretch DIS maps (if > 5000 then 5000)

The following maps are exported for each month:

- ARID: aridity index (actual evapotranspiration / potential evapotranspiration) (-)
- SNOW: the amount of snow (mm water)
- DISCHRG: the discharge for the cell (mm/month)
- DISQSEC: discharge map (m3/sec)
- TMP: Temperature map
- PRE: Precipitation map

All the parameters are exported for each month in graph form

As can be noted from above, all the initial input (except for the iteratively derived maps) and all the monthly climate data maps have to be created with the same projection, co-ordinates and resolution. It is recommended to use Lat Long projection for all input data

3.1 ETC DATA

Mask or COVERmap

The COVER map or MASK map has a value of 1 (basin) and 0 (outside basin).The extent of the basin can be derived from the Hydro 1K dataset (as_bas.shp), which is available on the Internet: *http://edcdaac.usgs.gov/gtopo30/hydro.*

Another option is to use ArcView for cutting out the appropriate basin from the study area. The following procedure is used: A shapefile outlining the basin is gridded to the same number of rows and collums used in the other maps (e.g. with the same output extent as the hydro 1K products). This results in a basin map with the same cellsize and position as the other data.

Flow direction: BPGLDD

The flow direction map provides the direction of flow per cell. For example, a ‘9’ means that the water flows to the North East. This map can be calculated from a DEM or can be directly derived from the HYDRO 1K flow direction map in case the model uses a 1x 1 km2 resolution. The latter data base is already in grid format.

HYDRO 1K

The HYDRO1k dataset in the Lambert Azimutal Equal Area projection system. This data is available online at http://edcdaac.usgs.gov/gtopo30/hydro/.

For example, for Asia, the following .zip files have to be extracted from the as_tar .zip file. :

- Basin outlines in Asia — as_bas.e00.gz
- Streams in Asia — as_str.e00.gz
- Digital elevation model (DEM) for Asia — as_dem.bil.gz
- Flow direction — as_fd.bil.gz

Flow Direction From DEM

Use a DEM, for instance the DEM available at the USGS internet site (1 x 1 km2 resolution). Next, fill the pits in the DEM using the ARCVIEW spatial analyst ‘pitt filling’ function or the pitt filling function in Idrisi 32. Then, cut out the basin extension using the previous made MASK map.

Important (1)

If you calculate the flow direction map in ARCVIEW, please note that ArcView uses a different flow direction scheme than STREAM. So the values must be reclassified according to the following scheme:

ArcView			Idrisi		
32	64	128	7	8	9
16		1	4	5	6
8	4	2	1	2	3

Important (2)

On the basis of this flow direction map, STREAM produces a drain direction map with the ACCU function (See model script). The drain direction map has the name DSCRH.IND and is placed in the root of the '..Input\' directory. Please delete this file if the model failed to accumulate water, because the model will NOT overwrite an existing DSCRH.IND map! Always first delete this file in case you intent to make a new model by replacing files from an old model, e.g. the GBM model.

Landuse: CropF

The CropF(actor)map is based on a land use map from the USGS site (http://edcdaac.usgs.gov/glcc/glcc.html) (International Geosphere Biosphere Program). These maps are in the same projection as the HYDRO 1K data. The data can be imported in ArcView and the appropriate area is selected with the mask (with analysis extent of the mask).

After importing the data in wither Idrisi or ArcView, the land cover units must be reclassed to CropF(actor) values according to the table used in Van Deursen and Kwadijk (1994). In the reclass procedure the data must be first multiplied by ten (as Idrisi can't reassign non-integer values) and thereafter divided by ten.

WHOLDN

The WHOLDN map is based on the FAO soil map of the world according to Table 3.2. In case there is no soil map, one can assume a very rough relationship between land use type and water holding capacity.

Also, Water holding capacity information can be found for the world with a resolution of 30 x 30', online at http://www.nrcs.usda.gov/technical/worldsoils/mapindx/whc.html.

C Map

The C map is a calibration parameter and reflects the duration of slow flow in months. Values between 1 and 3 are normal and can be derived by reclassing the slope map (derived from the DEM) in to values between 1 (shallow slopes) and 3 (Steep slopes).

Table 3.1 Land-cover classes and crop factors (after Van Deursen and Kwadijk, 1994).

	IGBP Land Cover Legend	CropF	Land use
1	Evergreen Needleleaf Forest	1.1	Forest
2	Evergreen Broadleaf Forest	1.1	Forest
3	Deciduous Needleleaf Forest	1.1	Forest
4	Deciduous Broadleaf Forest	1.1	Forest
5	Mixed Forest	1.1	Forest
6	Closed Shrublands	0.8	Expert guess
7	Open Shrublands	0.7	Expert guess
8	Woody Savannas	0.7	Expert guess
9	Savannas	0.6	Expert guess
10	Grasslands	0.8	Grasses
11	Permanent Wetlands	1.1	Swamps
12	Croplands	1.0	Plantations
13	Urban and Built-Up	0.8	Expert guess
14	Cropland/Natural Vegetation Mosaic	0.9	Expert guess
15	Snow and Ice	-	Glacier
16	Barren or Sparsely Vegetated	0.5	Expert guess
17	Water Bodies	0.3	Lakes

Table 3.2 Water holding capacity related to land-cover (after Van Deursen and Kwadijk, 1994).

	IGBP Land Cover Legend	S_{max} in mm/m (WHOLDN)	Corresponds to Soil type
1	1 Evergreen Needleleaf Forest	270	loam
2	2 Evergreen Broadleaf Forest	270	loam
3	3 Deciduous Needleleaf Forest	270	loam
4	4 Deciduous Broadleaf Forest	270	loam
5	5 Mixed Forest	270	loam
6	6 Closed Shrublands	180	Sandy loam
7	7 Open Shrublands	127	Loamy sand
8	8 Woody Savannas	280	Loam/Silt loam
9	9 Savannas	296	Silt loam
10	10 Grasslands	150	Loamy sand/sandy loam
11	11 Permanent Wetlands	-	
12	12 Croplands	246	Very fine sand loam
13	13 Urban and Built-Up	170	Sandy loam
14	14 Cropland/Natural Vegetation Mosaic	305	Clay loam
15	15 Snow and Ice	-	
16	16 Barren or Sparsely Vegetated	102	Sand
17	17 Water Bodies Also,	60	?

Climate data: precipitation and temperature

The Temperature (TMP) and precipitation (PRE) maps are derived from a monthly climate database. For the period 1901-2000, the CRU database is recommended. For climate change scenarios, the newest SRES scenarios are the most widely used data sets. All this data is available for the whole world in lat/long projection with a resolution of 0.5 degrees (i.e. approximately 45 * 55 km^2 in the centre of the area of interest).

Heat and A

The HEAT and A maps are derived from the processed TMP maps. HEAT is calculated using the equation:

$$H = HEAT = \sum_{jan}^{dec} \left(\frac{T_m}{5} \right)^{1.514}$$

The A map is calculated using:

$$A = 0.49239 + 0.01792 \cdot H - 0.0000771771 \cdot H^2 + 0.000000675 \cdot H^3$$

These formulas are used in the Thornthwaite equation for the calculation of the evapotranspiration.

Daylength

The DAYL data is based on a new calculation. The input maps need to reflect the potential amount of sunshine (in hours). Day length values are usually between 0 and 1. And example for the GBM model (South East Asia) is given in the following table:

January	0.88
February	0.93
March	1
April	1.07
May	1.12
June	1.16
July	1.14
August	1.1
September	1.03
October	0.96
November	0.9
December	0.87

3.2 Init data

The Init maps (APWL, GW, SNOW and SOILSTOR) are iteratively calculated during the running of the model. It is recommended to use the WHOLDN map and reclass this map into the four INIT maps using the initial values from the GBM model.
Next, run the model for a couple of years and then make an output of the same four INIT maps. To do this, run the model for a few years (say 60 months) until the model gets stable. You can know that by observing the TSummary of either GW or soil storage; if the cycle of peaks and low values is repeated each year without any difference, then it is stable. This check is valid only if the system (river basin) has a memory not more than one year, meaning there is no over year storage fluctuations. After you observed that the model is stable copy and rename the output (*.doc and *.img) for APWL, GW, SNOW and SOILSTOR to the Init directory.

4. Import, Export, Re-format Files

4.1 Importing and Exporting input data

Importing BIL Files

The .bil (Band Interleaved by Lines) files can immediately be read in **Arc/View**. Open the file in view by using View → Add Theme, select under Data Source Types the type Image Data Source and select the .bil files. Select Theme → Convert to Grid and choose a grid name.

Make sure the Spatial Analyst Package is switched on (see File → Extensions → Spatial Analyst, tick “default”). Select Analysis → Map Calculator and type the following formula:

([NwGrd1] >= 32768).Con ([NwGrd1] – 65536.AsGrid, [NwGrd1])

where NwGrd1 is the name of the gridfile generated by the function Convert to Grid. Select Theme → Save Data Set, select as a calculation (for example Calc1).

Select Analysis → Properties, click under Analysis Extent: Same As Kader.shp. Next, export the grid by clicking File → Export Data Source, select ASCII Raster and click OK. Select the appropriate Calculation file, and choose a name for the grid.

Importing E00 Files

Use the program **Import71** under the Start → Programs → ESRI → Arc/View folder to import the .e00 files. This programme creates a directory with files that can be opened in Arc/View. Select View → Add Theme and select under Data Source Types the type Feature Data Source, click on the directory of interest. In this way the basin outline and the stream locations can be displayed.

Click on the basin outline (activate) and click on the Select Feature tool. By holding down the shift button more than one sub-basin can be selected. Select Theme → Convert to Shapefile and choose a name for the basin outline and click “Yes” to add the theme.

Activate the theme, select Theme → Convert to Grid and choose a name for the grid. Select under Output Grid Extent the option Same as Kader.shp, cell size is 1000. The number of columns and rows should now change to 858 and 756 respectively. Choose “Level 1” under “Pick field for cell values” (this will return 0 and 1 for the grid values of the basin outline).

Deactivate the entire basin map. Select Analysis → Properties, click under Analysis Extent: Same As Kader.shp. Next, export the grid by clicking File → Export Data Source, select ASCII Raster and click OK and choose a name for the ascii-grid.

Importing Ascii files in IDRISI

Arc Info / Ascii files can be imported in Idrisi by replacing the header of the Arc Info / Ascii file with a GRASS header. This can be done by using WORDPAD. Save this file without an extension! The procedure works as follows:

1. The ARC View grids files need to be exported to ASCII format using the export option (export as ASCII);
2. Next, the ArcView header needs to be changed to a GRASS header in order to be able to import the data into Idrisi (the STREAM format). This is done by changing the header with WORDPAD.

ArcView header	**Idrisi header**
ncols 162	proj: 0
nrows 113	zone: 0
xllcorner 766500	North: -3061500
yllcorner –3174500	south: -3174500
cellsize 1000	east: 928500
nodata_value 0	west: 766500
	cols: 162
	rows: 113

Next, In Idrisi choose: Use File → Import/Export → Import → Software-Specific Formats → GRASSIDR. NOTE: Select “real” under Output Image Datatype for the DEM.

4.2 Geo-referencing and Resampling

Georeferencing

In the following example, a map using the LtLong coordinate system is reprojected into Lambert Azimutal Equal Area for Asia system. For this, use Idrisi command ‘Reformat → PROJECT’ to reproject the image from the lat/long reference system to the Lambert Azimutal Equal Area for Asia system (LAEA). Type of file is raster, input reference file is lat/long, and reference file for the output image is laea.ref (below). This calculation takes some time.

C:\IDRISIW\GEOREF\laea.ref
ref. system : USGS Lambert Azimuthal Equal Area for Asia
projection : Lambert Oblique Azimuthal Equal Area
datum : NAD27
delta WGS84 : -8 160 176
ellipsoid : Clarke 1866
major s-ax : 6378206.40
minor s-ax : 6356583.80
origin long : 100
origin lat : 45
origin X : 0
origin Y : 0

scale fac : na
units : m
parameters : 0

In case of trouble with this procedure, implementing the following coordinates for the resulting image can help:

Min X -3052609.0
Max X -1880734.0
Min Y -3627619.0
Max Y -2110726.0

Resampling

Use Reformat → RESAMPLE to resize the image to the right number of columns and rows.

5. Calibration of the model using the CropF and C map

The model has to be calibrated and validated in order to get a reliable model output.

1. The first step is to get the annual water balance correct. At this stage you should not worry about peak flows or minimum flows, just compare the annual simulated runoff to the annual measured runoff at points where you have discharge data. If there is some discrepancy, you adjust by playing with the value of CROPF. Just use a multiplier higher than unity to reduce discharge or less than unity to increase it (e.g. multiply by 0.8 for less evapotranspiration or 1.2 for higher evapotranspiration). Once you get the same annual runoff, it means you have the same area under the simulated hydrograph and the measured hydrograph;
2. Next, you calibrate for peak and low flows using the so-called C factor. A typical value for C is between 1 and 3 (See input data section). A low value of C raises the tail of the hydrograph and puts down the peak (and visa versa);
3. Next you can change the TOGW factor. Within the GBM model this is 0.4. Note that for small and steep catchments, this factor is high (0.9) and low for large shallow basins;
4. Finally, you can also multiply the WHOLD map thereby increasing or decreasing the water holding capacity.

6. Creating model output

Discharge hydrographs

If you want to see values of specific points (especially useful for creating hydrographs) a discharge file also has to be created. This is a simple text file named Qout3.dis, which is located in the \input\discharge directory. The file has the following structure (example from the Perfume basin, Vietnam):

53 67 Huu Trach
53 68 Ta Trach
52 67 Huu and Ta just together
36 69 Mouth Huu + Ta together
31 56 Mouth Bo river (too big)
25 49 Mouth O Lau

The first number is the row, the second the column. You can look up these coordinates by making use of Idrisi. It is best to first run STREAM without the Qout3.dis (and thus also placing a # before the scriptlines refering to Qout3.dis (i.e. `timeout(DISQSEC, %DischargePoints, %OutputDirectory)`.

Important! The row and columns presented in Idrisi aren't however the numbers you should enter into your file. You should add one to the number of the row and column (In Idrisi: R 24, C 45 -> Qout3.dis: R 25, C 46).

7. Example Script

```
# Reading init(ial) values. These values have to be altered
iteratively ...
# APWL     the accumulated potential water loss (mm water)
# GW           the groundwater capacity
# SNOW     the initial thickness (mm water) of the snow cover
# SOILSTOR the soil storage of water
Import(APWL, 'input\init\')
Import(GW, 'input\init\')
Import(SNOW, 'input\init\')
Import(SOILSTOR, 'input\init\')
Import(COVERmap, 'input\etc\')

# Masking the init input...
APWL = APWL / COVERmap
GW = GW / COVERmap
SNOW = SNOW / COVERmap
SOILSTOR = SOILSTOR / COVERmap

# Mapping the init...
Export(APWL , %OutputDirectory, 'Input\Palettes\temp.pal')
Export(GW , %OutputDirectory, 'Input\Palettes\prec.pal')
Export(SNOW , %OutputDirectory, 'Input\Palettes\prec.pal')
Export(SOILSTOR , %OutputDirectory, 'Input\Palettes\temp.pal')
#
*********************************************************************
# Reading Etc: Thorntwaite parameters...
# A        is calculated as follows: A = 0.49 + (0.0179 * HEAT) -
(0.000071 * HEAT^2) + (0.00000067 *HEAT^3)
# BPGLDD   is the flow direction of the cell. Mostly derived from
hydro 1K dataset
# C        is a calibration parameter (usually between 3 and 4) to
get the discharge peak and low flow values right
# COVERmap is used to mask the basin (1 (basin) and 0 (outside ba-
sin).
# CROPF    CROP Factor: reflects the effect of crop on PE. This pa-
rameter is mostly derived from USGS landuse data
#           This parameter can also be used to calibrate the overall
annual runoff
# HEAT     is calculated as follows: HEAT = sum(TM/5)^1.514 (where
Tm is the long term monthly average temperature
# MASK     is used to mask the basin (0 (basin) and -9999 (outside
basin).
# WHOLDN   Water HOLDiNg capacity: reflects the waterholding capaic-
ity of the soil (in mm/m)
Import(A, 'input\etc\')
Import (BPGLDD, 'input\etc\')
Import(C, 'input\etc\')
Import(CROPF, 'input\etc\')
Import(HEAT, 'input\etc\')
```

```
Import(MASK, 'input\etc\')
Import(WHOLDN, 'input\etc\')

# Masking the etc input...
A = A / COVERmap
BPGLDD = BPGLDD / COVERmap
C = C / COVERmap
CROPF = CROPF / COVERmap
HEAT = HEAT / COVERmap
WHOLDN = WHOLDN / COVERmap

# Mapping the etc ...
# Export(HEAT , %OutputDirectory, 'Input\Palettes\temp.pal')
# Export(A , %OutputDirectory, 'Input\Palettes\prec.pal')
Export(CROPF , %OutputDirectory, 'Input\Palettes\prec.pal')
Export(WHOLDN , %OutputDirectory, 'Input\Palettes\temp.pal')
# Export(MASK , %OutputDirectory, 'Input\Palettes\prec.pal')
# Export(BPGLDD , %OutputDirectory, 'Input\Palettes\prec.pal')
# Export(COVERmap , %OutputDirectory, 'Input\Palettes\prec.pal')
#
*********************************************************************
# Reading climate scenario data for each month...
# day     is the number of potential sunshine hours per day
# TMP      is the mean monthly temperature (degrees celcius)
# PRE      is the mean monthly precipitation (mm)
ImportTimer(day, %ClimateChange)
ImportTimer(TMP, %ClimateChange)
ImportTimer(PRE, %ClimateChange)
# Masking the etc input...
TMP = TMP / COVERmap
PRE = PRE / COVERmap
day= day / COVERmap
# Mapping the temperature and precipitation ...
ExportTimer(TMP, %OutputDirectory, 'Input\Palettes\temp.pal')
ExportTimer(PRE, %OutputDirectory, 'Input\Palettes\prec.pal')
# ExportTimer(day, %OutputDirectory, 'Input\Palettes\prec.pal')
#
*********************************************************************
# end of importing data
#
*********************************************************************
# Calculating snow fall, snow cover storage and snow melt (based on
TMP)...

SNOW1       = mif(TMP < 0, PRE, 0)
SNOW        = SNOW + SNOW1
MELT        = mif(TMP > 0, 100 * TMP, 0)
SNOW2       = min(SNOW, MELT)
SNOW        = SNOW - SNOW2
MELT2       = SNOW / 24
```

```
SNOW          = SNOW - MELT2
PRE           = PRE + SNOW2 - SNOW1
# ExportTimer(SNOW, %OutputDirectory, 'Input\Palettes\snow.pal')
# Calculate potential evapotranspiration using Thornthwaite.
# The PE is calculated depended on TMP
# The day/12 is necessary because the daylength is given in hours
PE            = 16 * (10 * TMP / HEAT) ^ A
EVEN          = -415.85 + 32.24 * TMP - (0.43 * TMP^2)
PE            = mif(TMP > 26.5, EVEN, PE)
PE            = cover(PE, MASK)
PE            = mif(TMP <= 0, 0, PE)
PE            = PE * (day/12) * CROPF

# Calculate soil storage according to Thornthwaite-Mather ...
PEFF          = PRE – PE
APWL          = mif(PEFF < 0, APWL - PEFF, 0)
EVEN          = SOILSTOR + PRE – PE
SSTOR         = mif(PEFF > 0, EVEN, WHOLDN * exp(-APWL / WHOLDN))
AE            = mif(PEFF >= 0, PE, PRE + SOILSTOR - SSTOR)
TOGW          = mif(PEFF >= 0, max(0, SOILSTOR + PEFF - WHOLDN), 0)
SOILSTOR      = max(0.000001, SOILSTOR + PRE - AE - TOGW)
APWL          = mif(SOILSTOR < WHOLDN, WHOLDN * ln(WHOLDN / SOILSTOR),
0)
APWL          = cover(APWL, MASK)

# Separate direct from delayed runoff (seepage to groundwater)...
RUNOFF        = 0.40 * TOGW
TOGW          = TOGW – RUNOFF

# Calculate volume of groundwater and baseflow...
GW            = GW + TOGW
SLOFLO        = GW / C
GW            = GW – SLOFLO
ExportTimer(TOGW, %OutputDirectory, 'Input\Palettes\prec.pal')
# Calculate discharge (snow melt + runoff + baseflow),
# and create map of total monthly discharge per cel...
# Normally it should be: DSCHRG      = MELT2 + RUNOFF + SLOFLO
DSCHRG        = MELT2 + RUNOFF + SLOFLO
ExportTimer(DSCHRG, %OutputDirectory, 'Input\Palettes\Dis.pal')

# Accumulate discharge from above lying cels (in mm per month),
# and create discharge graphs...
DISMM       = accu(BPGLDD, DSCHRG, 'Input\')
timeout(DISmm, %DischargePoints, %OutputDirectory)


# Convert the discharge (from mm per month to discharge in m3 per
second).
# 1 cell corresponds to 1000 * 1000 m = 10E-06, 1 mm corresponds to
0.001 m -> 1000 m3
# 1 month corresponds to 2592000 seconds.
```

```
DISQSEC    = DISMM * 1000 / 2592000
timeout(DISQSEC, %DischargePoints, %OutputDirectory)

ExportTimer(DISQSEC, %OutputDirectory, 'Input\Palettes\dis.pal')

# Stretching discharge maps (only necessary when there are large
discharges)...
# DISTEMP            = mif(DISQSEC > 40, DISQSEC , 0)
# DISTEMP2           = mif(DISTEMP < 5000, DISTEMP , 5000)
# DISAREA            = DISTEMP2
# ExportTimer(DISAREA, %OutputDirectory, 'Input\Palettes\Dis.pal')

# Calculate aridity index ...
EVEN      = cover(AE/PE,0)
EVEN      = EVEN / COVERmap
ARID      = EVEN
ExportTimer(ARID , %OutputDirectory, 'Input\Palettes\Arid.pal')

# Summarize (give max, min and average) for Actual evapotranspira-
tion,
# Potential evapotranspiration, groundwater budget, snow cover, etc
...
TSummary(AE, %OutputDirectory)
TSummary(PE, %OutputDirectory)
TSummary(GW, %OutputDirectory)
TSummary(SNOW, %OutputDirectory)
TSummary(ARID, %OutputDirectory)
TSummary(APWL, %OutputDirectory)
TSummary(TMP, %OutputDirectory)
TSummary(PRE, %OutputDirectory)
TSummary(TOGW, %OutputDirectory)
TSummary(SLOFLO, %OutputDirectory)
TSummary(RUNOFF, %OutputDirectory)
TSummary(SOILSTOR, %OutputDirectory)
TSummary(PEFF, %OutputDirectory)
TSummary(DSCHRG, %OutputDirectory)
TSummary(DISQSEC, %OutputDirectory)
TSummary(DISMM, %OutputDirectory)
# TSummary(DISAREA, %OutputDirectory)

#
*******************************************************************

ExportTimer(PE, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(PEFF, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(AE, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(TOGW, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(SOILSTOR, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(APWL, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(RUNOFF, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(SLOFLO, %OutputDirectory, 'Input\Palettes\Dis.pal')
ExportTimer(GW, %OutputDirectory, 'Input\Palettes\Dis.pal')
#
*******************************************************************
# ...End of iteration.
```

References

Aerts J.C.J.H., Kriek, M. & Schepel, M. (1999). STREAM, spatial tools for river basins and environment and analysis of management options: 'Set up and requirements'. *Physics and Chemistry of the Earth Part B,* 24(6), 591-595.

Aerts, J.C.J.H., Hassan, A., Savenije, H.H.G. & Khan, M.F. (2000). Using GIS tools and rapid assessment techniques for determining salt intrusion: STREAM, a river basin management instrument. *Physics and Chemistry of the Earth Part B,* 25(3), 265-273.

Aerts, J.C.J.H., & Bouwer, L.M. (2002). *STREAM Krishna - a hydrological model for the Krishna River in India.* RIKZ Workdocument CZM-C 2002.06a, The Hague, 34 pp.

Aerts, J.C.J.H., & Bouwer, L.M. (2002). *STREAM Perfume - calibration and validation for the wider Perfume River Basin in Vietnam.* RIKZ Workdocument CZM-C 2002.06b, The Hague, 35 pp.

Belward, A.S., (Ed.) (1996). *The IGBP-DIS Global 1 km Land Cover Data Set (DISCover) – Proposal and Implementation Plans*. IGBP-DIS Working Paper Number 13, Toulouse, France, 61 p.

Fekete, B.M., Vörösmarty, C.J. & Grabs, W. (2000). *Global, composite runoff fields based on observed river discharge and simulated water balances.* Federal Institute of Hydrology, Koblenz, Germany, 115 pp.

IPCC (2001). Climate Change 2001 – The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton, J.T. et al. (Eds.). Cambridge University Press, Cambridge, UK, 881 pp.

IPCC-TGCIA (1999). *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment Version 1.* Carter, T.R., Hulme, M. & Lal, M. Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, 69 pp.

Nakićenović, N. & Swart, R. (Eds.) (2000). *IPCC Special Report on Emissions Scenarios.* Cambridge University Press, Cambridge, United Kingdom, 599 pp.

Thorntwaite, C.W. & Mather, J.R. (1957). Instructions and tables for computing potential evapotranspiration and the water balance. *Publications in Climatology,* 10(3), 183-243.

Van Deursen, W.P.A. & Kwadijk, J.C.J (1994). *The Impacts of Climate Change on the Water Balance of the Ganges-Brahmaputra and Yangtze Basin*. Resource Analysis report number RA/94-160, 46 pp.

Vörösmarty, C.J., Fekete, B. & Tucker, B.A. (1998). *River Discharge Database, Version 1.1.* Institute for the Study of Earth, Oceans, and Space and University of New Hampshire, Durham NH (USA).