HYDROTOOLS 1.0
for ArcView 3.x

Author:
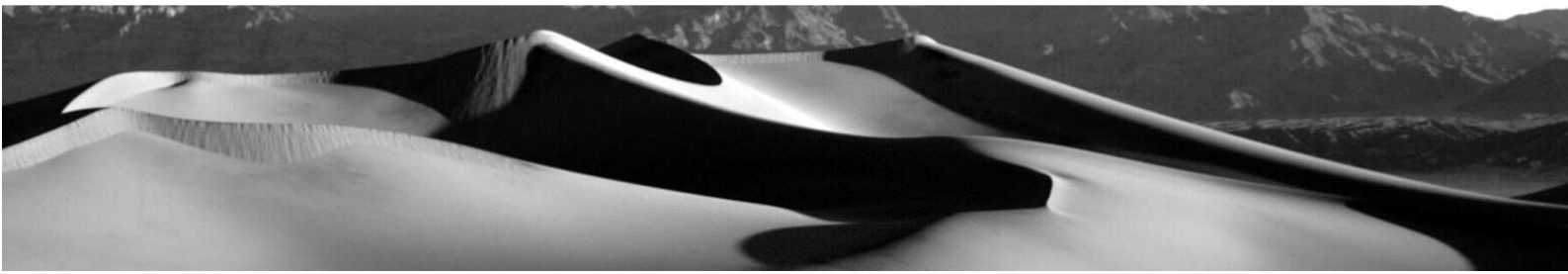
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1. Basics

The software **HydroTools (HTools)** is an add-in program for ArcView GIS 3.x and provides various hydrological functions which were unavailable in most GIS-Systems up to now. HTools is capable to analyse many important hydrological properties of big catchments and the spreading of pollutants as well. In contrast to other hydrological programs like TAPES-G (see WILSON & GALLANT 2000) or HSPF (see SINGH 1995), HTools has two important advantages:

1. Amongst the variety of hydrological functions, only the most important are provided. Beside that, some new functions are included which can be used in an intuitive manner (e.g. an algorithm which combines multiple flow and single flow procedures or the change to work with additional infiltration grids which simulate the behaviour of the ground)

2. HTools is completely integrated in the most popular GIS-Software, the program ArcView 3.x. So the time to get familiar with it is minimized and beyond it no data conversion is necessary (HTools reads and writes ESRI grids directly and does not need ASCII-like import files as the most other hydrological programs).

HTools is supplied with two different data files, an extension file called **hydrotools.avx** and a runtime library called **hydrotools.dll**. While the extension file is responsible for the communication between the user and ArcView, the runtime library hydrotools.dll comprises all functions needed for comprehensive hydrological simulations. In order to install HTools, the two files have to be copied in different directories:

1. The extension file hydrotools.avx has to be copied in the extension directory of ArcView. This directory is a subdirectory of ArcView's main directory and has usually the name **EXT32** (e.g. ...\Av_gis30\ArcView\Ext32\...).

2. The runtime library hydrotools.dll has to be copied in the program directory of ArcView. This directory is also a subdirectory of ArcView and has the name **BIN32** (e.g. ...\Av_gis30\ArcView\Bin32\...).

Note that HTools just works on computers with Windows installed as operating system (Windows 95/98/ME/2000/XP), it is not allowed to install HTools on other computer systems like LINUX, MACOS, etc. After installation, HTools can be activated in the same manner like every extension in ArcView. That means by opening the menu item File/Extensions… first and then activating HydroTools 1.0 as an extension (Figure 1). After having activated HTools, two new buttons will appear with every new view (Figure 2). Each button will launch a separate analysis window with different functions for the examination of digital elevations models and the hydrological analysis of catchments. All functions are described on the next pages, with detailed explanations and short examples.
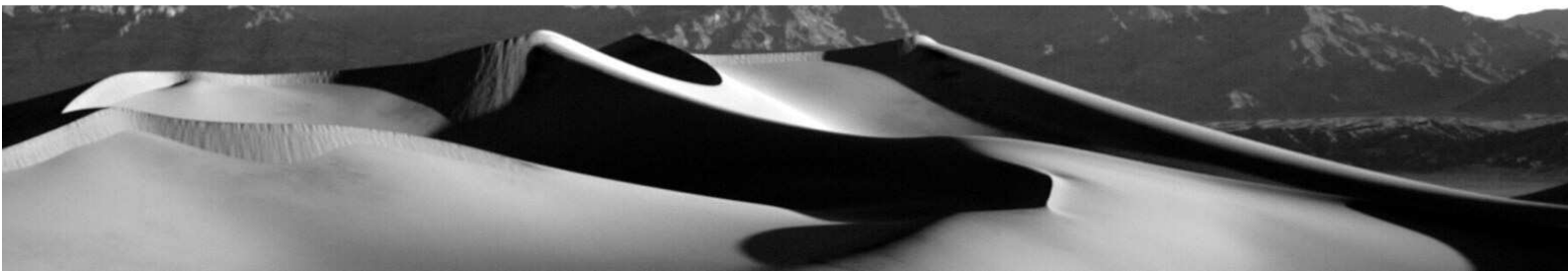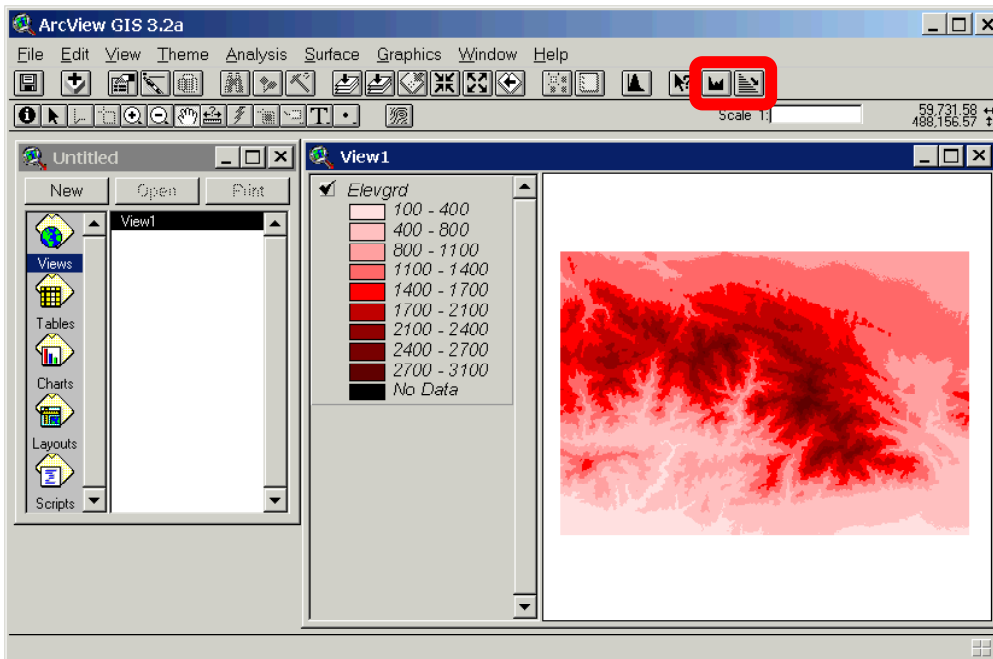
Figure 1:

Activation of HydroTools 1.0
in the Extensions window of ArcView 3.x
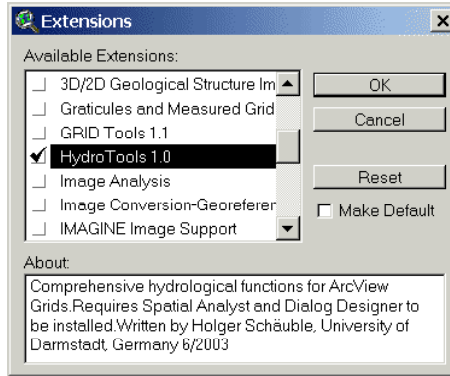
Figure 2:

Buttons of HydroTools 1.0 (in red colour) which enable the selection of different analysis windows

By pressing one of the two new buttons, specific functions will provided, of which some are comprising the correction of digital elevation models wheras others are responsible for the hydrological analysis of huge catchments. The first button (☒ .) opens the **„Preparation"-window** (Figure 3), which provides funtions to find out and correct errors in digital elevation models. Without such corrections every following calculation
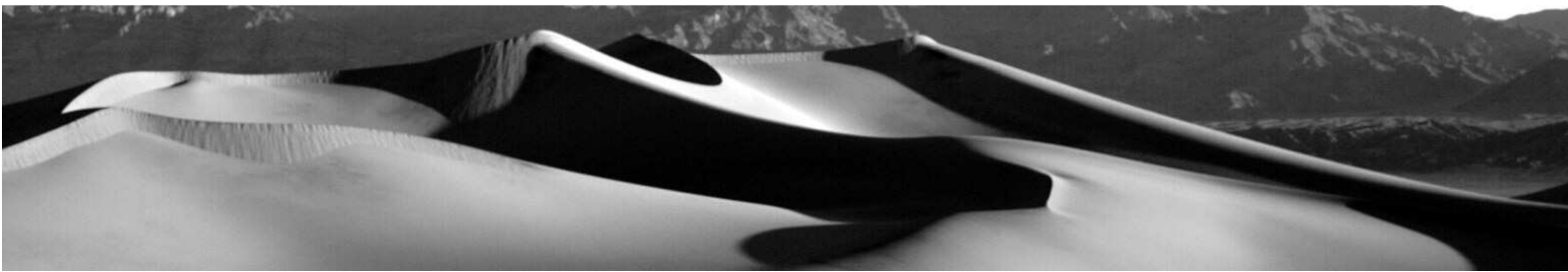
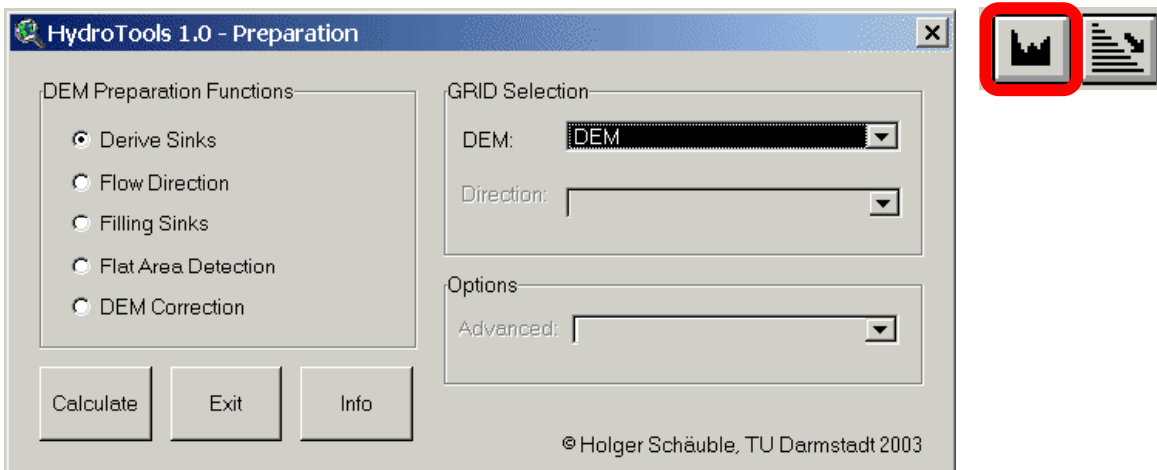could be full of mistakes, so this window should be at the beginning of each analysis. The second button ( ) opens the **„Hydrology"-window** (Figure 4) which provides different functions to analyse the hydrological properties of catchments.

Figure 3:
„Preparation" window with functions to correct digital elevation models

Figure 4:
„Hydrology" window with hydrological functions to analyse digital elevation models and catchments
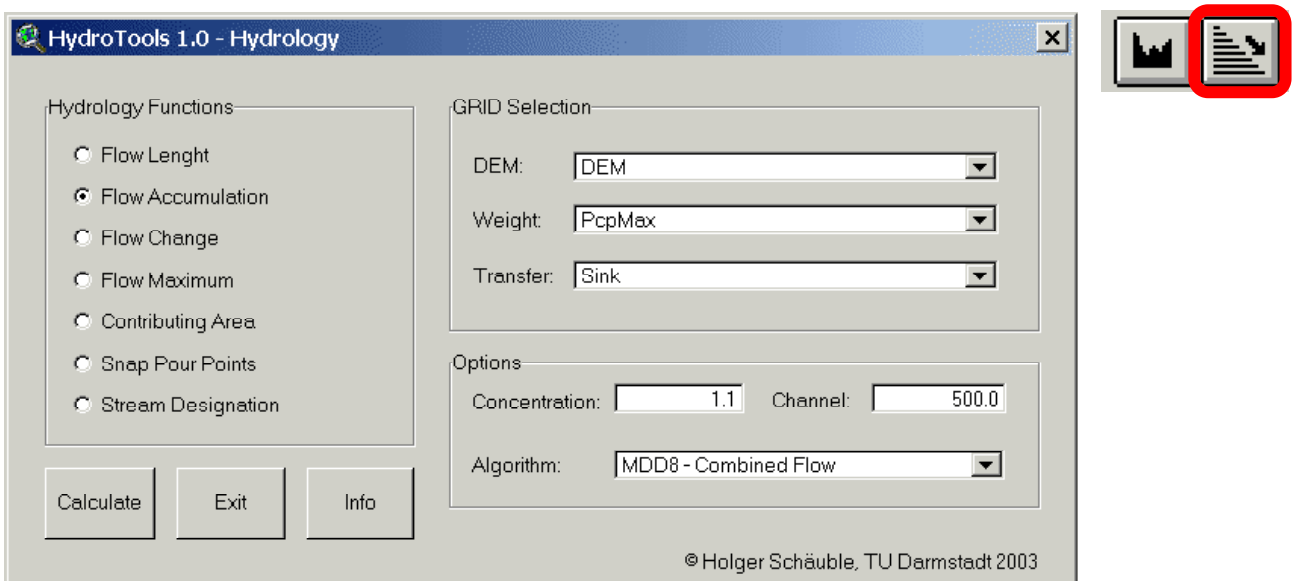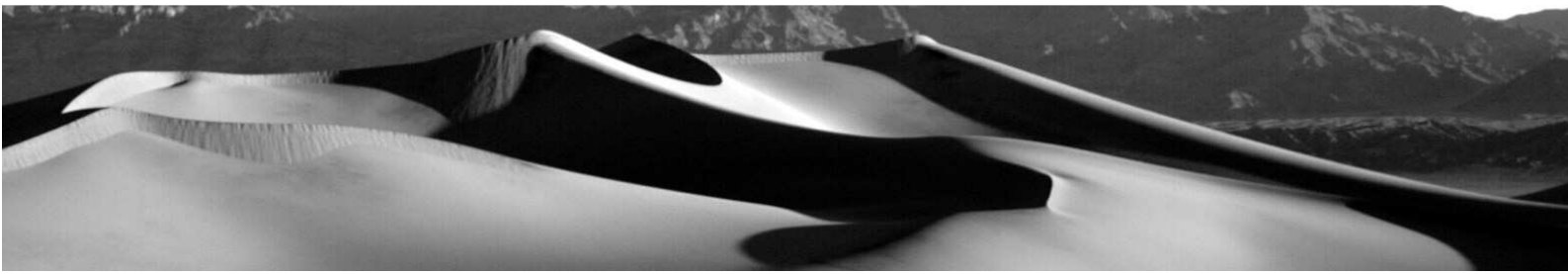
The „Preparation" window: Functions for the correction of digital elevation models

At the beginning of each hydrological analysis, the correctioness and accuracy of the digital elevation model has to be guaranteed. This is necessary because digital elevation models have little errors and artefacts in most cases. Some of them are dischargeless sinks which were created during the interpolation of a digital elevation model, others are artificial pits or flat areas which do often cover little parts of the topography. In this context, the most crucial elements are dischargeles sinks, which cut off the flow of water and therefore leading to erroneous results of hydrological calculations (see Figure 5, left and Figure 6). In order to detect and to correct them, 4 functions are available in the *„Preparation"-window*, they are accompanied by a routine which calculates the flow directions from a digital elevation model (Figure 3):

1. *Derive Sinks:*
   A function which discovers dischargeless sinks in a digital elevation model and gives each of them a separate number. A new grid is calculated from a digital elevation model which has to be selected from the DEM-selection combo box. All hydrological correct areas will be marked with NoData values, all dischargeless sinks will be marked with individual integer numbers.

2. *Filling Sinks:*
   A function which fills up dischargeless sinks until an equal height to the adjacent areas is reached (Figure 5, middle). A digital elevation model has to be selected from the DEM-selection combo box. Because of the iterative algorithm, the calculation can take a fairly long time especially in case of big data files.

3. *Flat Area Detection:*
   A function which is detects flat areas in a digital elevation model and gives each of them an individual number. Usage and the calculated values are the same as with the Derive Sinks function (correct areas = NoData values; flat areas = integer numbers).

4. *Flow Direction:*
   A function which calculates the flow direction from a digital elevation model. A new grid is calculated from a digital elevation model which must have to be modified by the Filling Sinks function before (the altitude data must be correct with no dischargeless sinks inside). The new direction grid will have integer numbers from 1 to 128 (see. ESRI ARCVIEW 3.X ONLINE HELP, BURROUGH & MCDONNELL 1998). It is possible to specify the treatment of the calulation at the borders of the grid by selecting two different options in the
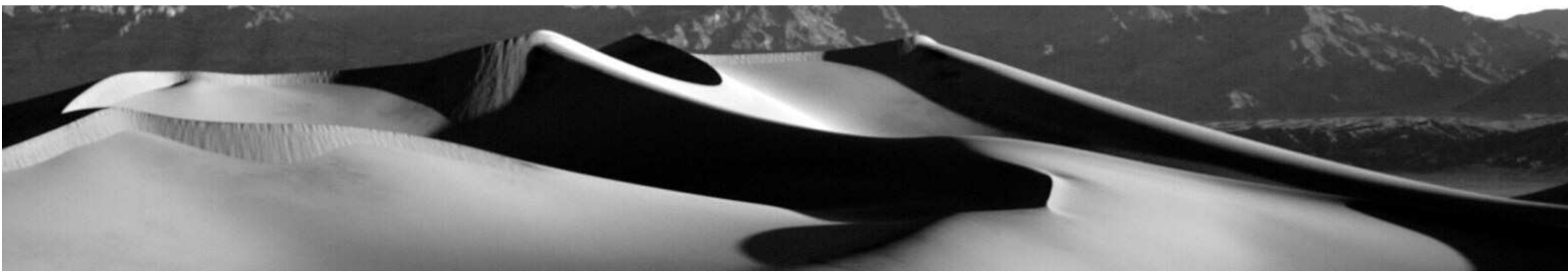
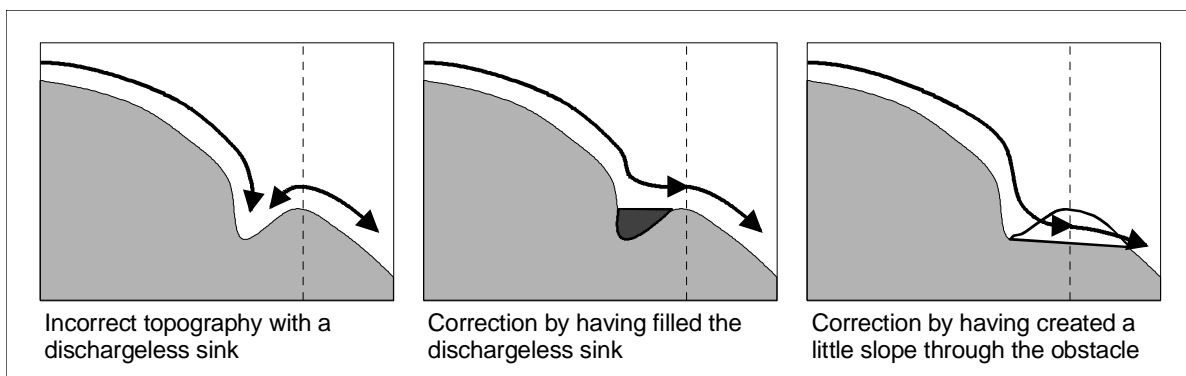Advanced combo box: the Force Edge option calculates flow direction values which leave the grid to the outside, the No Force Edges option calculates flow direction values which go to the inner side of the grid.
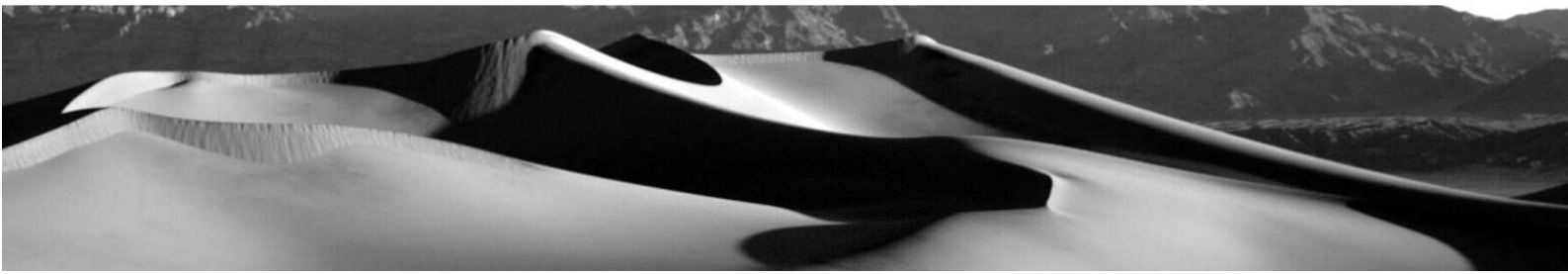
5. *DEM Correction:*

A function which corrects dischargeless sinks and flat areas in a digital elevation model by lowering all important neighbourhood areas (Figure 5, right). This is accomplished by comparing the altitudes in a digital elevation model with the flow directions in a flow direction grid. In case of any inconsistencies (flow directions which indicate a downward slope but altitudes which indicate an upward slope), the digital elevation model is lowered by a slight value (a number of 0.0001) until the contradiction is vanished (i.e. the obstacle is broken through). In case of full agreement between the altitudes and the flow direction values (downward slopes and downward decreasing altitudes) the digital elevation model will kept unchanged.

Figure 5
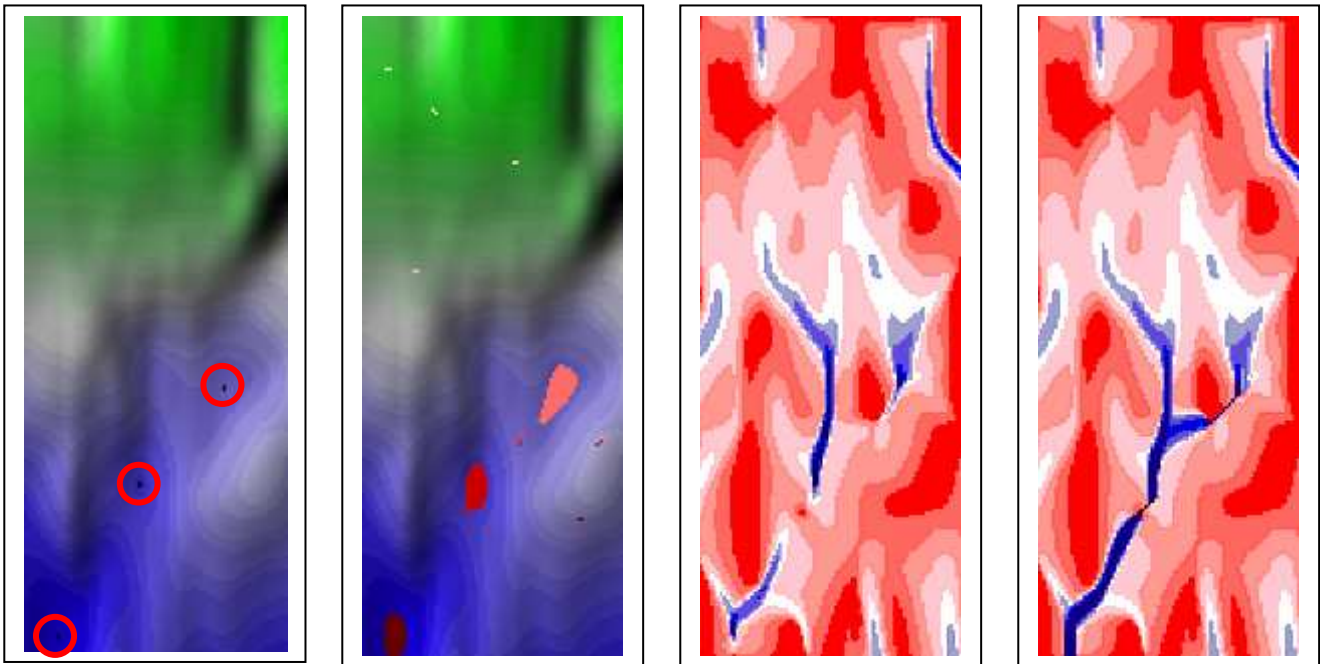Dischargeless sinks in a digital elevation modell and their treatment

| Incorrect topography with a dischargeless sink | Correction by having filled the dischargeless sink | Correction by having created a little slope through the obstacle |

Left: Dischargeless sinks and their effetcs on the flow of water, illustrated by the example of a two dimensional slope; sinks like those do interrupt the flow of water and falsify hydrological calculations, especially when they were born as artefacts during the interpolation of digital elevation models; *Middle*: 1.Possibility to prepare a digital elevation model for subsequent hydrological analyses: Filling up a dischargeless sinks by using the function Filling Sinks (necessary for subsequent calculations with the D8 – Single Flow algorithm); *Right*: 2.Possibility to prepare a digital elevation model for subsequent hydrological analyses: Breakthrough of an obstacle by using the function DEM Correction (necessary for subsequent calculations with the MD – Multiple Flow and the MDD8 – Combined Flow algorithm)

Figure 6
Necessity and functions for the correction of a digital elevation model
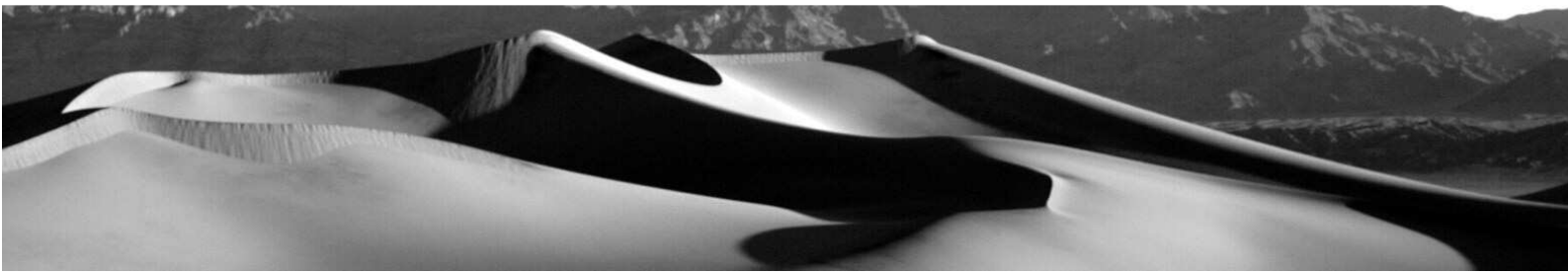

Left: Digital elevation model with dischargeless sinks (black pixels with red borders); *Left middle*: Corrected digital elevation model by whitch previous dischargeless sinks now have been filled up (areas in red colours); *Right middle*: Discharge, calculated by having used the digital elevation model with sinks inside (model at the left side, discharge increases from red to blues colours); *Right*: Discharge, calculated by having used the modified version of the digital elevation model without any sinks (model at the left middle side, discharge increases from red to blue colours)

The „Hydrology" window: Functions for the analysis of digital elevation models

The „Hydrology"-window provides various functions to analyse digital elevation models and big catchments. Some of them are already incorporated in a few GIS-Systems (analysis of flow length or simple flow accumulation), the most interesting of them however were not available up to now. Especially to mention the functions „Flow Accumulation", „Flow Change" and „Flow Maximum". They provide the capability to consider different rates of seepage on one side and the capability to apply different flow algorithms on the other side (like common single flow algorithms (D8), advanced multiple flow algorithms (MD) or a combination of both (MDD8); see WILSON & GALLANT 2000, O'CALLAGHAN & MARK 1984, QUINN ET AL. 1991). You can choose between the following functions (Figure 4):
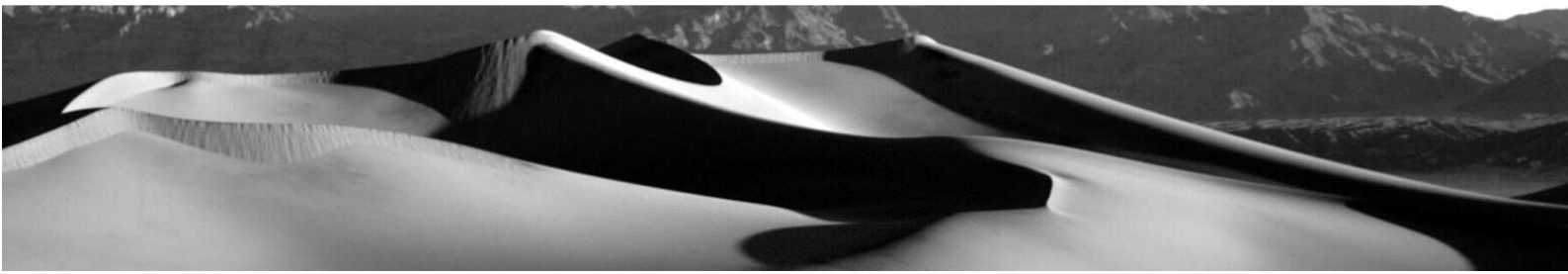
1. *Flow Lenght:*

A function which calculates flow lenghts from a flow direction grid (selection in the combo box Direction) which was derived from a digital elevation model. Every pixel is numbered with the flow lenght of the flow path that covers the longest distance to the watershed. You can also perfom flow length calculations by considering an additional weight grid (selection in the Weight combo box) and by choosing between an upward or downward direction. If you select the Option Downward from divides, the flow length is calculated in the direction of the slope, if you select Upward from divides, the flow length is calculated against the direction of the slope. As that function is part of the extended functionality of ArcView 3.x, you can get detailed help by typing in the keyword FLOWLENGTH at the ArcView online help system.

2. *Flow Accumulation:*

A function which calculates the flow accumulation from a digital elevation model. The flow accumulation is a function which computes the amount of water or pollutant particles moving from the divides to the valleys of a catchment (Figure 10, right). You can choose between different options and methods of calculation:

- **D8 – Single Flow**: Flow accumulation which is calculated by a single flow algorithm (D8 single flow algorithm after O'CALLAGHAN & MARK 1984). That method is illustrated in Figure 7. HTools does need at least one flow direction grid which must have been already calculated by the function Flow Direction (selection in the combo box Direction). Beside that, it is possible to make more sophisticated analyses by using an additional weight and/or seepage grid (see below).

- **MD – Multiple Flow**: Flow accumulation which is calculated by a multiple flow algorithm (MD multiple flow algorithm after QUINN ET AL. 1991). That method is illustrated in Figure 7. HTools does need at least two specifications: a digital elevation model (selection in the combo box DEM) and a general weight number which specifies the kind of the flow (a given number in the input field Concentration; numbers < 1 will produce a more disperse flow, numbers > 1 will lead to a more concentrated flow, see Figure 8).

- **MDD8 – Combined Flow**: Flow accumulation which is calculated by a combined use of the multiple flow and the single flow algorithm as described above. In this context, the MD multiple flow algorithm is used until a specified threshold value is reached. After then the method is changed to the D8 single flow algorithm for all succeeding calculations downstream (Figure 7). Hence an accurate calculation of catchment areas (with flow dispersion and accumulation) is guaranteed and the morphology of rivers is maintained as well (with no flow dispersion and a concentration of the discharge in the river bed). Note that in special cases, the method of calculation can also change from single flow to multiple flow (if an infiltration grid is used which reduces the discharge in the river bed). HTools does need at least three specifications for the calculation:

2. ***Flow Accumulation:*** (Continuation)

A digital elevation model, a general weight number which determines the kind of the flow (see above) and a number which specifies the threshold value by which the calculation will change between the MD multiple flow and the D8 single flow algorithm (flow value above theshold => Change to D8 single flow, flow value below theshold => Change to MD multiple flow; this number has to be specified in the input box Channel).

Regardless which algorithm is used, the analysis of flow accumulation can be modified by considering an optional weight and/or transfergrid. By using a weight grid (selection in the combo box Weight) the normal weight of a pixel (value = 1) can be changed to take into account spatial variing precipitation. By using a transfer grid (selection in the combo box Transfer) the usual seepage value of a pixel (value = 1) can be changed in the same manner. A value of 1 stands for no seepage, values below 1 give a transmission in %*100 (or seepage values in 1/%*100) and values above 1 give an (additional) transmission in %*100 (e.g. for considering chemical reactions which increase the amount of a pollutant by a specified multiplier).

3. ***Flow Change:***

A function which calculates the alteration in slope direction. By using a specified weight grid it can be determined if the pixel values are increasing or decresing in downslope direction (Figure 10, left). Only that adjacent pixels are taken into consideration which are draining directly in the current pixel. You can choose between different options and methods of calculation:

- **D8 – Single Flow**: Calculation of the flow change by use of a single flow algorithm (Figure 7). It will be analysed how much the pixel values are changing in the direction of the steepest slope. HTools does need at least a flow direction grid which must have been already calculated by the function Flow Direction (selection in the combo box Direction) and a weight grid which should be examined (selection in the combo box Value).

- **MD – Multiple Flow**: Calculation of the flow change by use of a multiple flow algorithm (Figure 7). It will be   analysed how much the pixel values are changing in downslope direction. In contrast to the single flow method above, every upper pixel is taken into consideration which drains directly to the current pixel. HTools does need at least 3 specifications for the computation: a digital elevation model (selection in the combo box DEM), a weight grid which should be examined and a general weight number which specifies the kind of the flow (a number in the input field Concentration, see above).

- **MDD8 – Combined Flow**: Calculation of the flow change by a combined use of a single and a multiple flow algorithm. After having reached a specified threshold value, the algorithm changes from multiple flow to single flow and vice versa. HTools does need at least 4 specifications for the
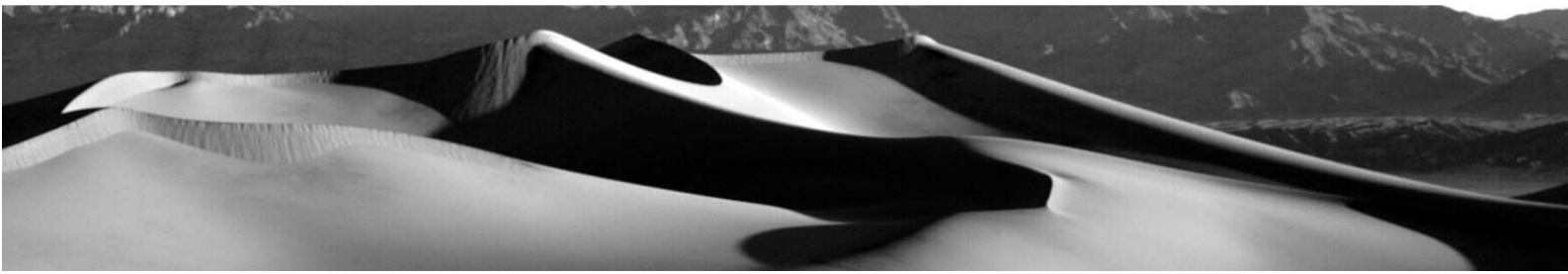
computation: a digital elevation model (selection in the combo box DEM), a weight grid which shloud be examined, a channel grid which gives informations about the streams and rivers (selection in the combo box Channel) and a general weight number which specifies the kind of the flow (see above). The so-called channel grid is necessary to show HTools where to apply single flow and multiple flow algorithms. A multiple flow algorithm is used at any area which is specified as NoData or 0 in the channel grid, a single flow algorithm is used at any pixel which is specified with a value of 1 in the channel grid.

4. *Flow Maximum:*

A function which calculates the maximum values of flow occuring in the upstream areas of a catchment (Figure 10, middle). In contrast to the function Flow Accumulation only the highest value is determined and maintained right to the outlet of a catchment. You can choose between different options and methods of calculation:

- **D8 – Single Flow**: Calculation of the maximum values by use of a single flow algorithm (Figure 7). HTools does need a flow direction grid (selection in the combo box Direction) and a weight grid which has to be examined (selection in the combo box Value).

- **MD – Multiple Flow**: Calculation of the maximum values by use of a multiple flow algorithm (Figure 7). HTools does need a digital elevation model (selection in the combo box DEM) and a weight grid which has to be examined. In opposite to the MD flow accumulation function, a general weight number can not be specified here – such kind of value is irrelevant for the computation of maximim values.

- **MDD8 – Combined Flow**: Calculation of the maximum values by combined use of a multiple flow and a single flow algorithm (Figure 7). A MD multiple flow algorithm is used until a specified threshold value is reached. After then the method is changed to the D8 single flow algorithm for all succeeding calculations downstream (see above). HTools does need 3 kinds of data: a digital elevation model (selection in the combo box DEM), a weight grid which has to be examined (selection in the combo box Value) and an additional treshold value which specifies the moment of change beetwen the MD and the D8 method (specification in the input box Channel, see above).

5. *Contributing Area:*

A function which calculates the contributing area of each single cell or area (see Figure 12, left). HTools does need a flow direction grid (selection in the combo box Direction) and an source grid which specifies the starting points of the analysis (e.g. cells which specify gauging stations or areas which specify river valleys). All cells in the source grid (selection in the combo box Source) must have integer numbers
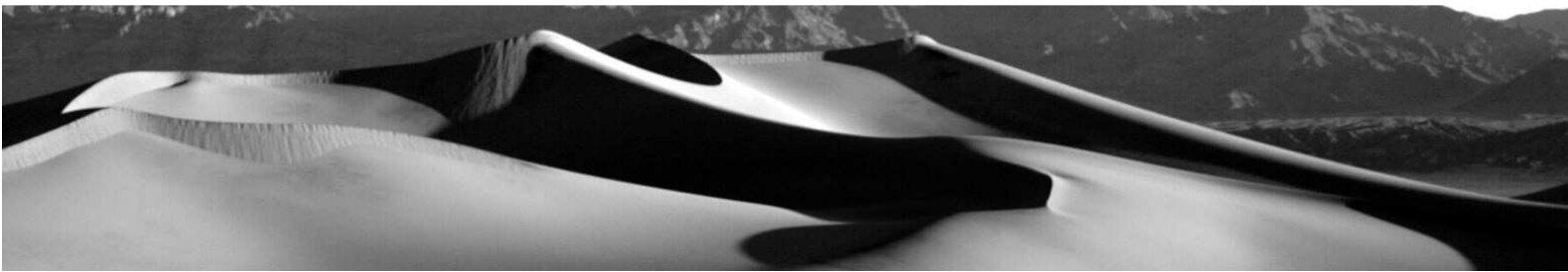
(points of examination) or NoData values (area of no examination). As that function is part of the extended functionality of ArcView 3.x, you can get detailed help by typing in the keyword WATERSHED at the ArcView online help system.

6. ***Snap Pour Points:***

A function which moves badly localized gauging points automatically to their correct position (see Figure 12, right).   This is accomplished by moving each points within a specified search radius to that position where a weight grid has the highest cell value. HTools does need 3 kinds of data: a grid with badly localized gauging points (selection in the combo box Points), a weight grid (selection in the combo box Value) and a value of the maximum search radius, in which the movement may take place (specification in the input field Distance). All cells in the points grid must have either integer numbers (points to move) or NoData values (areas of no action). As that function is part of the extended functionality of ArcView 3.x, you can get detailed help by typing in the keyword SNAPPOURPOINT at the ArcView online help system.

7. ***Stream Designation:***

A function which characterizises and numbers single reaches of a river system (see Figure 12, middle). This is accomplished by the exaination of a special stream grid with the help of a flow direction raster. The stream grid consists of integer numbers which characterize the river system and of NoData values which specfiy the remaining areas. Htools does need 3 kinds of data: a stream grid (selection in the combo box Streams), a flow direction grid (selection in the combo box Direction) and a specification about the method of characterisation (option in the combo box Method; Stream Link = each river reach gets an individual number, Stream Order – Strahler = renumbering of the river reachers after the Strahler method, Stream Order – Shreve = renumbering of the river reaches after the Shreve method). As that function is part of the extended functionality of ArcView 3.x, you can get detailed help by typing in the keyword STREAMLINK and STREAMORDERat the ArcView online help system.
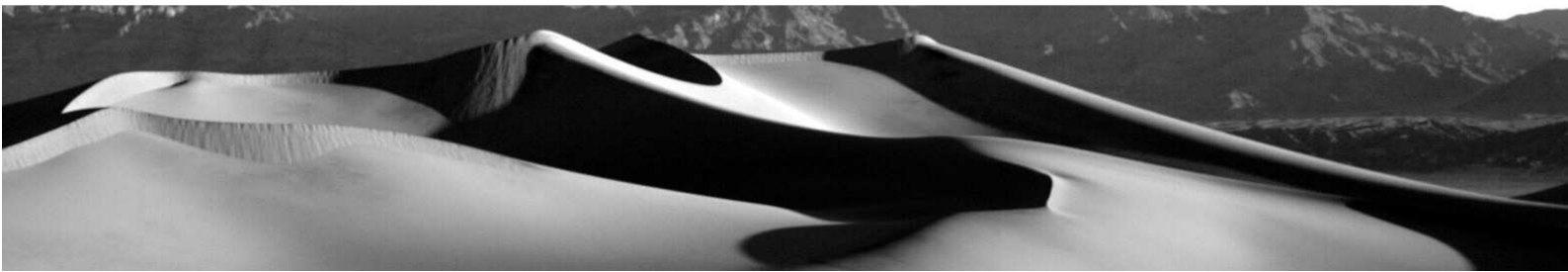
Figure 7:
Basic algorithms for calculating flow movement (Single flow versus multiple flow)
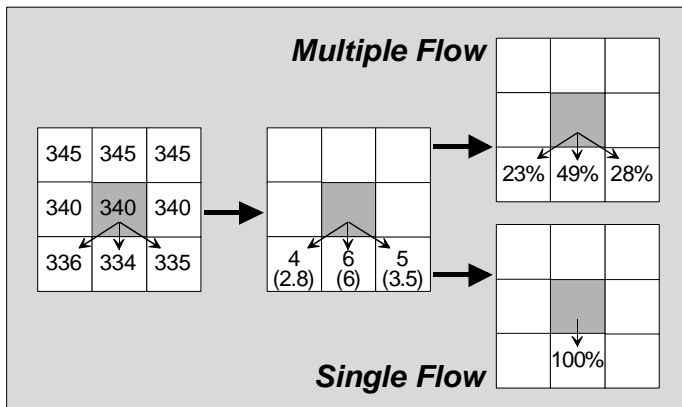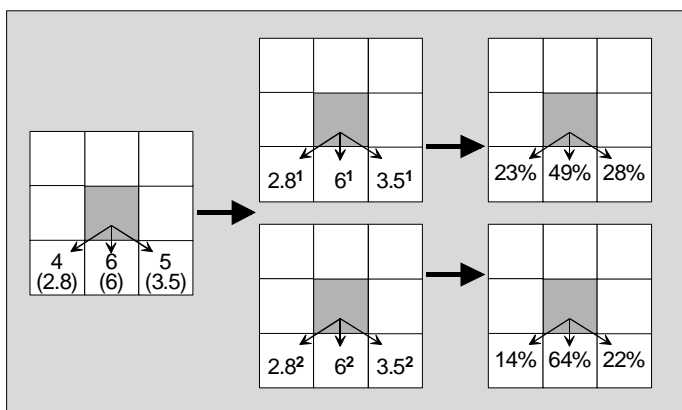

Left:
Part of a digital elevation model with altitudes in m; black arrows show possible flow paths of flow from the central grey pixel

Middle:
Differences in altitude of the flow paths in m; adjusted differences in brackets (because of the longer distance the differences to the corner cells are recalculated by the formula: (height difference / $\sqrt{2}$)

Right, upper part:
Received portion of flow, calculated with a multiple flow algorithm and the formula: difference / $\sum$ difference

Right, lower part:
Received portion of flow, calculated with a single flow algorithm and the principle: 100% flow to the cell of the steepest descent
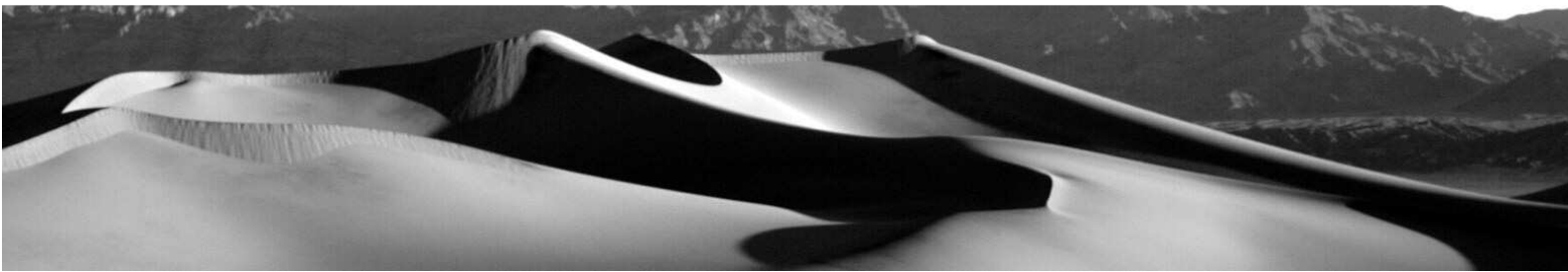
Figure 8:
Multiple flow calculations with different weighting

Left:
Differences in altitude of the flow paths in m; same as above in Figure 7, middle

Upper, middle-right:
Received portion of flow by the multiple flow method; calculated with a weighting value of $c = 1$ and the subsequent formula: portion of flow = difference^c / Sum (difference^c)

Lower, middle-right:
Received portion of flow by the multiple flow method, calculated with a weighting value of $c = 2$ and the subsequent formula, portion of flow = difference^c / Sum (difference^c)

Figure 9:
Calculations of the flow accumulation with different algorithms
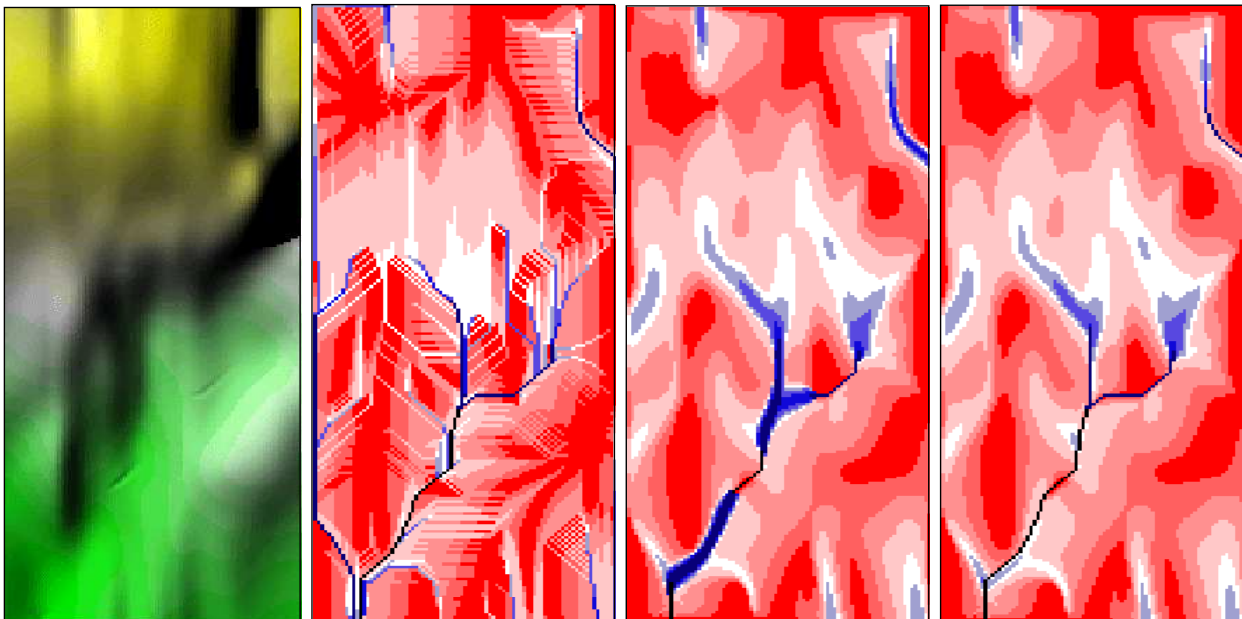
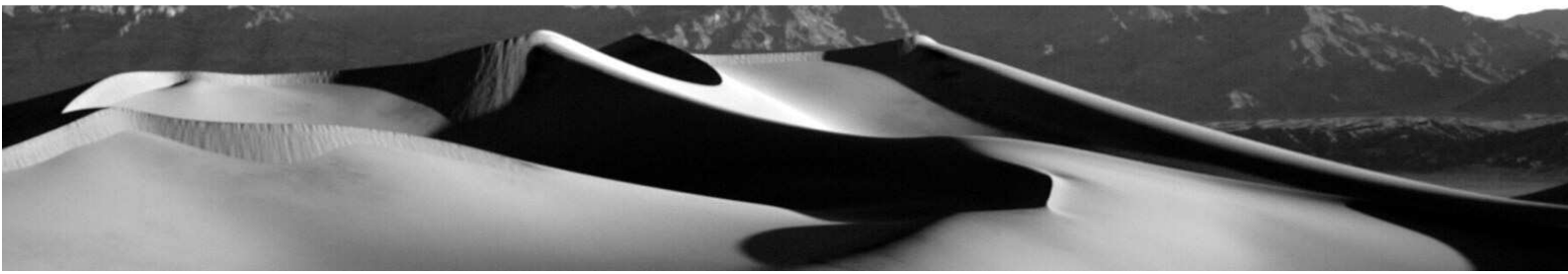*Left*: Digital elevation model; *Middle left*: Flow Accumulation by the D8 – Single Flow method (Discharge increases from red to blue colours); *Middle right*: Flow Accumulation by the MD – Multiple Flow method; *Right*: Flow Accumulation by the MDD8 – Combined Flow method (a combination of the two methods above)

Figure 10:
Basic functions for the calculation of flow properties
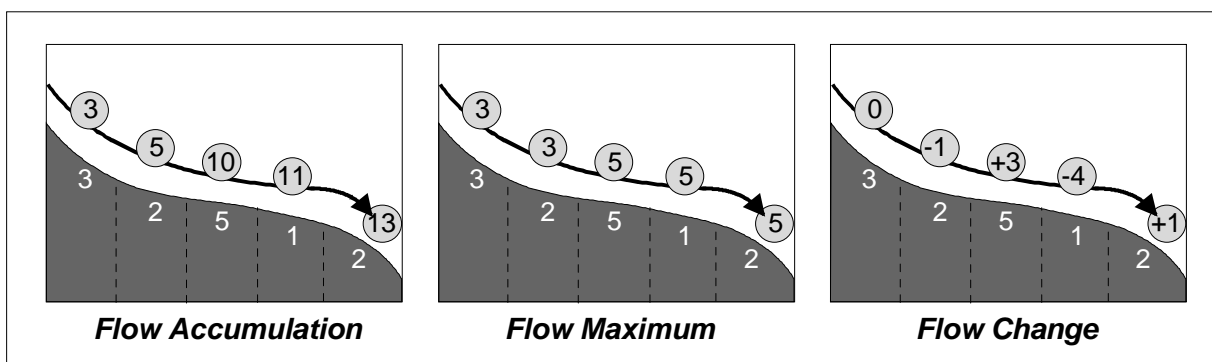
Principles of basic flow functions shown by the example of a two-dimensional slope; white nuumbers below the surface specify the amount of precipitation in litres, black circled numbers above the surface show the results of the current function; *Left*: Summarized amount of water, calculated with the function Flow Accumulation; *Middle*: Highest depth of rainfall in the upper parts of the catchment, calculated with thefunction Flow Maximum; *Right*: Alteration of the depth of rainfall in slope direction, calculated with the function Flow Change

Figure 11:
Calculations with a weight grid or a transfer grid
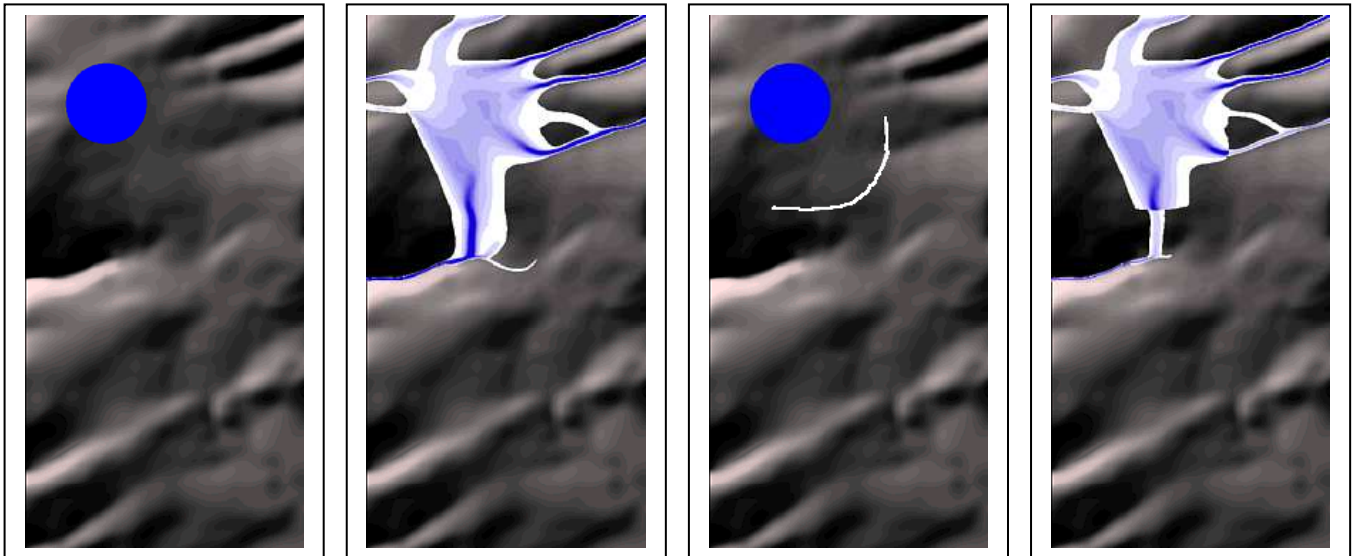
Illustrations of computations with the function Flow Accumulation, in case of using a weight grid or a transfer grid (= seepage grid). *Left*: Weight grid in front of a hillshaded digital elevation model, the blue area shows a source of water or pollutants; *Middle, left side*: Flow Accumulation, calculated from the weight grid and the digital elevation model; the amount of water/pollutants increases from white to blue colours; *Middle, right side*: Combined use of a weight grid (= blue colours) and a transfer grid (= white colours) in conjunction with a digital elevation model; the white symbolizes a dam which is able to reduce the amount of water/pollutants by 90% (this corresponds to a value of 0.1 in the transfer grid which acts as a multiplier of the flow); *Right*: Flow Accumulation, calculated from the data of the adjacent figure at the left side, the amount of water/pollutants increases from white to blue colours

PS: *NoData Values:*

Hydrological analyses with the functions mentioned above can be strongly improved by incorporating NoData values. Cells with NoData stop the flow of water/pollutant during the computation and behave thus as hydrological barriers or areas without any discharge. Some examples can be found in figure 13.
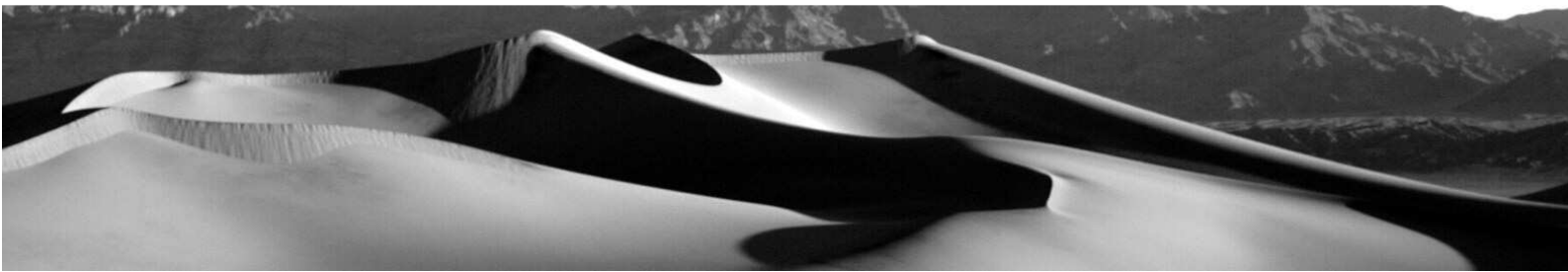
Figure 12:
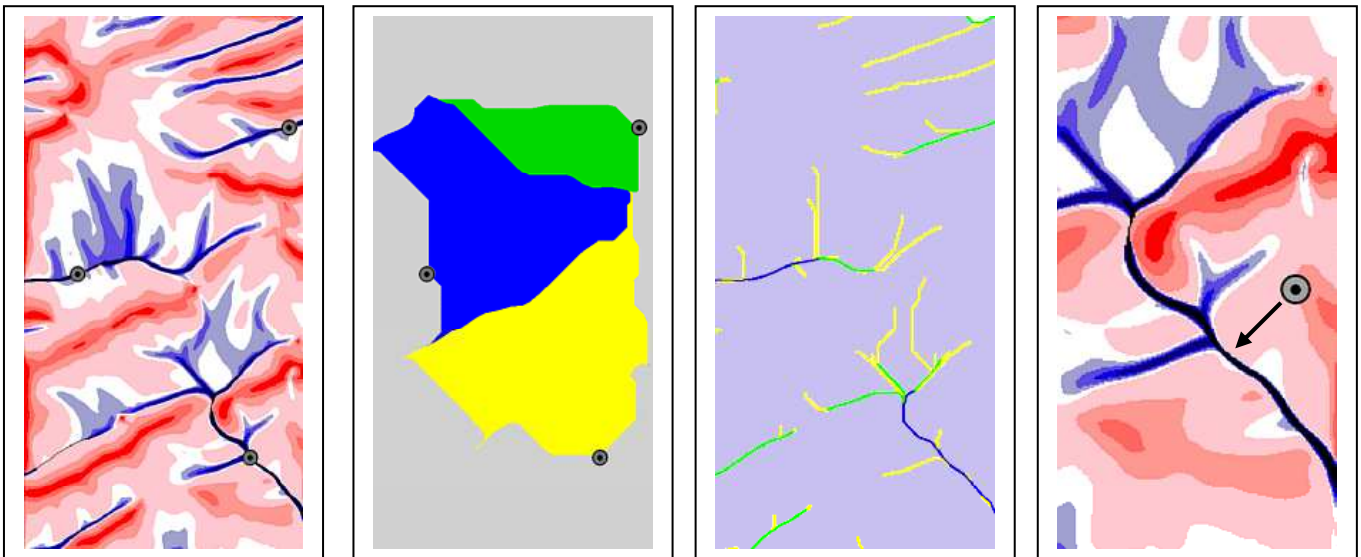Analysis of catchment areas and stream reaches, geocoding of a gaging station

Illustration of basic functions to characterise catchments and river systems and to improve the position of badly localized gauging stations. *Left*: Gaugung stations (= points in grey) in front of a flow accumulation grid; *Middle, left side*: Catchment areas of the gauging stations shown in the left figure, calculated with the function Contributing Area; *Middle, right side*: Classification of the river reaches after the Strahler method (yellow = 1.order, green = 2.order, blue = 3.order), calculated with the function Stream Designation; *Right*: Illustration of the Snap Pour Points function by the example of a badly geocoded point which is moved to the cell with the highest discharge in the immediate neighbourhood

Figure 13:
Sophisticated analyses with NoData values: Hydrological barriers and pointwise spreading of flow
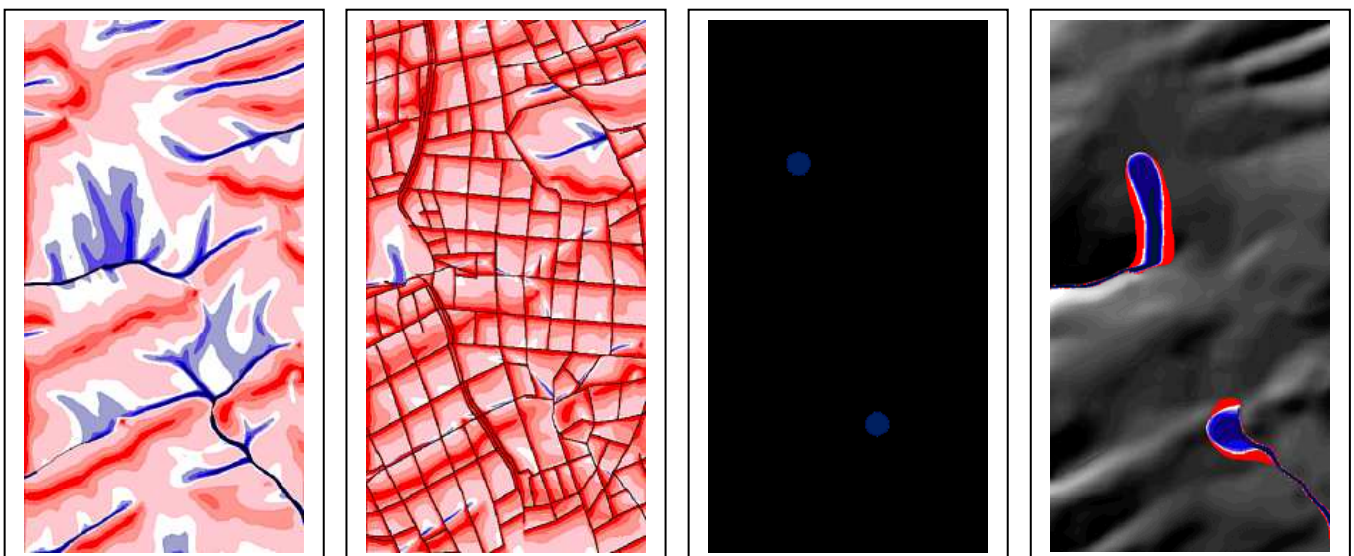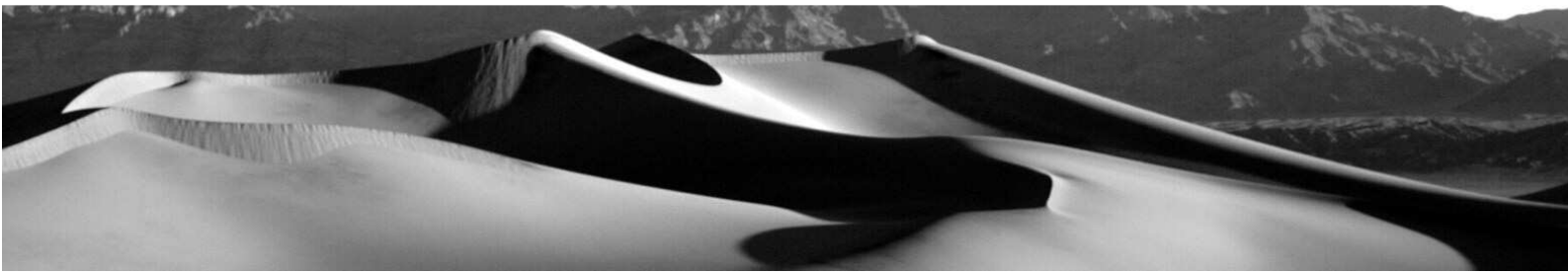
Illustration of hydrological analyses by incorporating NoData values (some cells or entire areas with NoData values); *Left*: Flow Accumulation by the MD – Multiple Flow method, regular computation; ***Middle, left side***: Flow Accumulation by the MD – Multiple Flow method, computation by having used hydrological barriers which were specified as NoData values in a weight grid (= black lines, i.e. drainage trenches which stop surface flow); ***Middle, right side***: Weigt grid with two point sources of water/pollutants (= circles in blue) and areas with no supply of water/pollutants (= black areas with NoData values); ***Right***: Flow Accumulation, calculated with the MD – Multiple Flow method, calculated from the data of the adjacent figure at the left side

Recommended Readings:

Burrough, P.A. & McDonnell, R.A. (1998):
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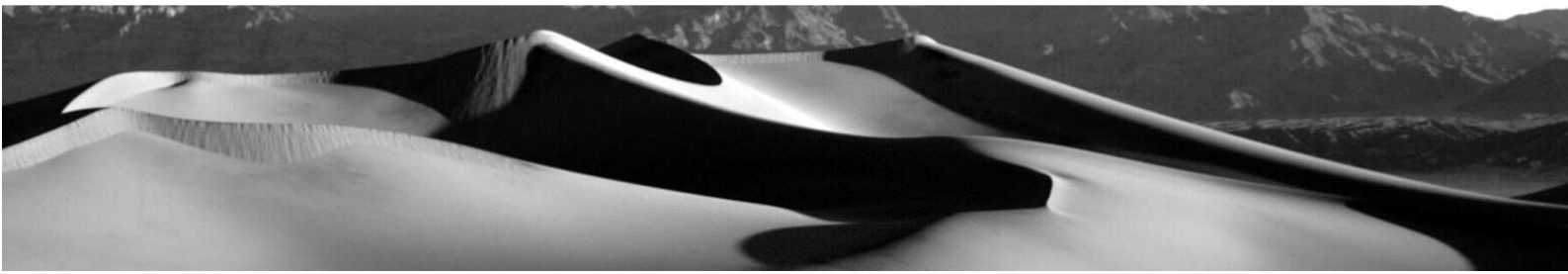
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Some closing words

HydroTools 1.0 is the hydrological part of the much more extensive program SedimentYieldTools 1.02 which I have written for my PhD thesis and which is capable to create comprehensive sediment yield models in a GIS-environment. Nevertheless HydroTools provides all important functions for analysing the flow of water and pollutants in a catchment. Those functions should close the gap between customary GIS-Software like

ArcView, Idrisi, GRASS and more specialized hydrological programs of great complexity. HydroTools is appealing to all ambitioned GIS-Users who are willing to acomplish more sophisticated hydrological analyses with customary GIS-Software – and without the need to struggle against the various obstacles of hydrological expert programs. This and only this is the intention of Hydro-Tools: a program that can be used in an intuitive way for common questions in the fields of applied hydrology and environmental conservation. More sophisticated functions are still reserved to the big number of excellent expert programs (see SINGH 1995). Usage of HydroTool is free for private purposes and in science (Universities, Schools and Organisations of General Public Interest). Commercial usage is just allowed with my explicit approval. In order to improve HydroTools and this small instructions I am relying strongly on your collaboration. Thus hints or comments of all kinds (positive and/or negative) will be appreciated. Please send a short (or long :)) email to the following destination: schaeuble@terracs.com

Have a lot of fun with HydroTools,
Yours Holger Schäuble

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