Chapter 18

Geomorphometry in RiverTools

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history and development of RiverTools • preparing a DEM for your study area • kinds of information that can be extracted using RiverTools and DEMs • special visualisation tools in RiverTools • what makes the RiverTools software unique?

18.1 Getting started

RiverTools is a software toolkit with a user-friendly, point-and-click interface that was specifically designed for working with DEMs and extracting hydrologic information from them. As explained in previous chapters, there is a lot of useful information that can be extracted from DEMs since topography exerts a major control on hydrologic fluxes, visibility, solar irradiation, biological communities, accessibility and many human activities. RiverTools has been commercially available since 1998, is well-tested and has been continually improved over the years in response to the release of new elevation data sets and algorithms and ongoing feedback from a global community of users. All algorithms balance work between available RAM and efficient I/O to files to ensure good performance even on very large DEMs (i.e. 400 million pixels or more). RiverTools is a product of Rivix, LLC (`www.rivix.com`) and is available for Windows, Mac OS X and Solaris.

RiverTools 3.0 comes with an installation CD and sample data CD but the installer can also be downloaded from `www.rivertools.com`. It uses the industry-standard InstallShield installer and is therefore easy to install or uninstall. The HTML-based help system and user's guide includes a set of illustrated tutorials, a glossary, step-by-step explanations of how to perform many common tasks, a description of each dialog and a set of executive summaries for major DEM data sets and formats. All of the RiverTools file formats are nonproprietary and are explained in detail in an appendix to the user's guide. In addition, each dialog has a Help button at the bottom that jumps directly to the relevant section of the user's guide.

The purpose of this chapter is to provide an overview of what RiverTools can do and how it can be used to rapidly perform a variety of tasks with elevation data. §18.1.1 explains the layout of the RiverTools menus and dialogs. §18.2 briefly discusses GIS issues such as ellipsoids and map projections. §18.3 introduces some tools in the Prepare menu that simplify the task of preparing a DEM that spans a given area of interest. §18.4 discusses how dialogs in the Extract menu can be used to extract various grid layers and masks from a DEM. §18.5 highlights some of the visualisation tools in the Display menu and §18.5.1 introduces some of the Interactive Window Tools that can be used to query and interact with an image.

18.1.1 The RiverTools menu and dialogs

RiverTools 3.0 can be started by double-clicking on a shortcut icon or by selecting it from a list of programs in the Windows Start menu. After a startup image is displayed, the Main Window appears with a set of pull-down menus across the top labeled: *File*, *Prepare*, *Extract*, *Display*, *An-*

alyze, *Window*, *User* and *Help*. Each pull-down menu contains numerous entries, and sometimes cascading menus with additional entries. Selecting one of these entries usually opens a point-and-click dialog that can be used to change various settings for the selected task. Buttons labeled *Start*, *Help* and *Close* are located at the bottom of most dialogs. Clicking on the Start button begins the task with the current settings. Clicking on the Help button opens a browser window to a context-specific help page and clicking on a Close or Cancel button dismisses the dialog.

The **File menu** contains tools for opening data sets, importing and exporting data in many different formats, and for changing and/or saving various program settings and preferences. The **Prepare menu** contains a collection of tools that can be used at the beginning of a project to prepare a DEM for further analysis, such as mosaicking and sub-setting tiles, replacing bad values, uncompressing files and changing DEM attributes such as elevation units, byte order, orientation and data type. The **Extract menu** contains a large set of tools for extracting new grid layers (e.g. slope, curvature and contributing area), vectors (e.g. channels and basin boundaries) and masks (e.g. lakes and basins) from a DEM or a previously extracted grid layer. The **Display menu** has a collection of different visualisation tools such as density plots, contour plots, shaded relief, surface plots, river network maps, multi-layer plots and many more. Images can be displayed with any of 17 different map projections or without a map projection.

There is also an extensive set of Interactive Window Tools that makes it easy to query and zoom into these images to extract additional information. The **Analyze menu** has a number of tools for analysing and plotting terrain and watershed attributes that have been measured with the extraction tools. Graphics windows can be managed with a set of tools in the **Window menu** and RiverTools can be extended by users with plug-ins that appear in the **User menu**.

18.2 Advanced GIS functionality

18.2.1 Fixed-angle and fixed-length grid cells

Virtually all elevation data providers distribute raster DEMs in one of two basic forms. In the *geographic* or *fixed-angle* form, the underlying grid mesh is defined by lines of latitude and longitude on the surface of a chosen ellipsoid model and each grid cell spans a fixed angular distance such as 3 arcsec. Lines of constant latitude (parallels) and lines of constant longitude (meridians) always intersect at right angles. However, since the meridians intersect at the poles, the distance between two meridians depends on which parallel that you measure along. This distance varies with the cosine of the latitude and is largest at the equator and zero at the poles. So while each grid cell spans a fixed angle, its width is a function of its latitude. The fixed-angle type of DEM is the most common and is used for all global or near-global elevation data sets such as SRTM, USGS 1-Degree, NED, DTED, GLOBE, ETOPO2, GTOPO30, MOLA and many others.

The second basic type of raster DEM is the "*fixed-length*" form, where both the east-west and north-south dimensions of each grid cell span a fixed distance such as 30 metres. This type of DEM is commonly used for high-resolution elevation data that spans a small geographic extent so that the Earth's surface can be treated as essentially planar. They are almost always created using a Transverse Mercator projection such as Universal Transverse Mercator (UTM). Examples include USGS 7.5-Minute quad DEMs, most LiDAR DEMs and many state and municipal DEMs. When mosaicked to cover large regions, fixed-length DEMs suffer from distortion and lead to inaccurate calculations of lengths, slopes, curvatures and contributing areas.

18.2.2 Ellipsoids and projections

Unlike most GIS programs, RiverTools always takes the latitude-dependence of grid cell dimensions into account when computing any type of length, slope or area in a *geographic* or fixed-angle DEM. It does this by integrating directly on the ellipsoid model that was used to create the DEM. In addition, when measuring *straight-line* distance between any two points on an ellipsoid, the highly accurate Sodano algorithm is used (Sodano, 1965). Other GIS programs project the fixed-angle elevation data with a fixed-length map projection such as UTM and then compute all length, slope and area measurements in the projected and therefore distorted DEM.

In RiverTools, various properties of the DEM such as its pixel geometry (fixed-angle or fixed-length), number of rows and columns and bounding box can be viewed (and edited if necessary) with the View DEM Info dialog in the File menu. When working with a fixed-angle DEM, the user should set the ellipsoid model to the one that was used in the creation of the original DEM data. This is done by opening the Set Preferences dialog in the File menu and selecting the Planet Info panel. A list of 51 built-in ellipsoid models for Earth are provided in a droplist, as well as information for several other planets and moons. The ellipsoid models that were used to create several of the major DEM data sets is provided in the RiverTools documentation. Most modern DEM data sets and all GPS units now use the WGS84 ellipsoid model and this is the default. Since maps and images are necessarily two-dimensional, RiverTools also offers 17 different map projections for display purposes via the Map Projection Info dialog in the Display menu.

18.3 Preparing DEMs for a study area

18.3.1 Importing DEMs

Since elevation and bathymetric data is distributed in many different data formats, the first step when working with DEMs is to import the data, that is, to convert it to the format that is used by the analysis software. The DEM formats that can currently be imported include: ARC BIL, ARC FLT, ENVI Raster, Flat Binary, SDTS Raster Profile (USGS), USGS Standard ASCII, CDED, DTED Level 0, 1 or 2, GeoTIFF, NOAA/NOS EEZ Bathymetry, GMT Raster (netCDF), GRD98 Raster, ASTER, MOLA (for Mars), SRTM, ARC Gridded ASCII, Gridded ASCII, and Irregular XYZ ASCII. While some DEMs simply store the elevations as numbers in text (or ASCII) files, this is an extremely inefficient format, both in terms of the size of the data files and the time required for any type of processing. Because of this, elevation data providers and commercial software developers usually use a binary data format as their native format and then provide a query tool such as the Value Zoom tool in RiverTools for viewing DEM and grid values.

A simple, efficient and commonly used format consists of storing elevation values as binary numbers with 2, 4 or 8 bytes devoted to each number, depending on whether the DEM data type is integer (2 bytes), long integer (4 bytes), floating point (4 bytes) or double-precision (8 bytes). The numbers are written to the binary file row by row, starting with the top (usually northernmost) row — this is referred to as *row major format*. The size of the binary file is then simply the product of the number of columns, the number of rows and the number of bytes used per elevation value. All of the descriptive or georeferencing information for the DEM, such as the number of rows and columns, pixel dimensions, data type, byte order, bounding box coordinates and so on is then stored in a separate text file with the same filename prefix as the binary data file and a standard three-letter extension. This basic format is used by ARC BIL, ARC FLT, ENVI Raster, MOLA, SRTM, RTG and many others. Many of the other common formats, such as SDTS Raster, GeoTIFF and netCDF also store the elevation data in binary, row major format but add descriptive header information into the same file, either before or after the data.

To import a DEM into RiverTools, you choose Import DEM from the File menu and then select the format of the DEM you want to import. If the format is one that is a special-case of the RiverTools Grid (RTG) format (listed above), then the binary data file can be used directly and only a RiverTools Information (RTI) file needs to be created. You can import many DEMs that have the same format as a batch job by entering a "*matching wildcard*" (an asterisk) in both the input and output filename boxes. For example, to import all of the SRTM tiles in a given directory or folder that start with "N30", you can type "N30*.hgt" into both filename boxes.

Elevation data is sometimes distributed as irregularly-spaced XYZ triples in a multi-column text file. RiverTools has an import tool for gridding this type of elevation data. In the current version, Delaunay triangulation is used but in the next release six additional gridding algorithms will be added.

18.3.2 Mosaicking DEM Tiles

The second step in preparing a DEM that spans a given area of interest is to mosaic many individual tiles to create a seamless DEM for the area. These tiles are typically of uniform size and are distributed by DEM providers in separate files. For example, SRTM tiles span a region on the Earth's surface that is one degree of latitude by one degree of longitude and have dimensions of either 1201×1201 (3 arc second grid cells) or 3601×3601 (1 arc second grid cells).

To mosaic or subset DEM tiles in RiverTools, you first choose Patch RTG DEMs from the Prepare menu. This opens an Add/Remove dialog that makes it easy to add each of the tiles that you wish to mosaic to a list (Fig. 18.1a). Tiles can be viewed individually by clicking on the filename for the tile and then on the Preview button. Similarly, their georeferencing information can be viewed by clicking on the *View Infofile* button. Tiles with incompatible georeferencing information may sometimes need to be preprocessed in some way (e.g. units converted from feet to metres or subsampled to have the same grid cell size) and this can easily be done with the Convert Grid dialog in the Prepare menu.

The file selection dialog that is used to add tiles to the list provides a filtering option for showing only the files with names that match a specified pattern. This dialog also allows multiple files to be selected at once by holding down the shift key while selecting files. If these two features are used, even large numbers of tiles can be rapidly added to the list. The *Add/Remove* dialog itself has an Options menu with a Save List entry that allows you to save the current list of tiles to a text file. You can then later select the Use Saved List option to instantly add the saved list of files to the dialog.

Once you have finished adding DEM tiles to the list, you can type a prefix into the dialog for the DEM to be created and then click on the Start button to display the DEM Patching Preview Window (Fig. 18.1b). This shaded relief image in this window shows how all of the tiles fit together. You can then click and drag within the image to select the subregion that is of interest with a "*rubber band box*", or select the entire region spanned by the tiles by clicking the right mouse button. It is usually best to select the smallest rectangular region that encloses the river basin of interest. If you can't discern the basin boundary, you can easily iterate the process a couple of times since everything is automated. The *DEM Patching Preview* window has its own Options menu near the top and begins with the entry *Save New DEM.* A button with the same label is also available just below the image. These are two different ways of doing the same thing, namely to read data from each of the DEM tiles to create a new DEM that spans the selected region. If there are any "*missing tiles*" that intersect the region of interest (perhaps in the ocean) they are automatically filled with nodata values. Other entries in the Options menu allow you to do things like (1) label each tile with its filename, (2) "*burn in*" the rubber band box and labels and (3) save the preview image in any of several common image formats. Once your new DEM has been created, it is automatically selected just as if you had opened it with the Open Data Set dialog in the File menu. You can view its attributes using the *View DEM Info* tool in the File menu.

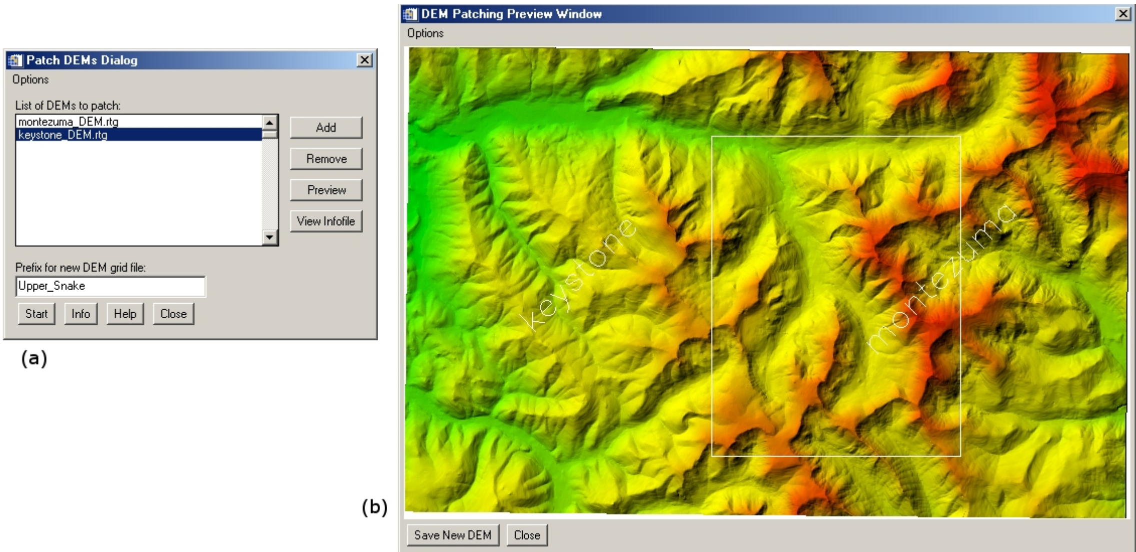

Fig. 18.1: (a) The Patch RTG DEM dialog; (b) The DEM Patching Preview window with subregion selected with a rubber-band box and both tiles labeled with filename prefixes. (© Rivix, LLC, used with permission)

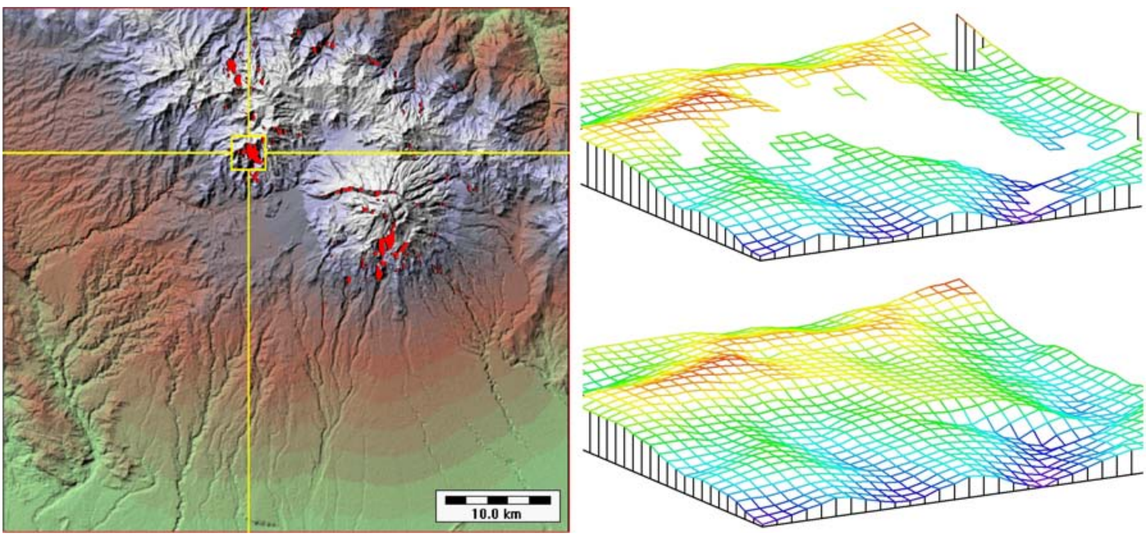

Fig. 18.2: A yellow box and crosshairs on a shaded relief image shows the location of a hole (red) in an SRTM DEM for Volcan Baru, Panama. The two images on the right show wire mesh surface plots of the area near the hole, before and after using the Repair Bad Values tool. (© Rivix, LLC, used with permission)

18.3.3 Replacing Bad Values

Sometimes a third step is required to prepare a DEM that spans a region of interest. In SRTM tiles, for example, there are often nodata "*holes*" in high-relief areas that were not in the line of sight of the instrument aboard the Space Shuttle that was used to measure the terrain heights. These holes usually span small areas between 1 and 20 grid cells but can be larger. For most types of analysis, these holes must be repaired prior to further processing. RiverTools has a *Replace Bad Values* tool in the Prepare menu that fills these holes with reasonable values by iteratively averaging from the edges of the holes until the hole is filled. The output filename should usually be changed to have a new prefix and the compound extension `_DEM.rtg`. (Fig. 18.2) shows the result of applying this tool to an SRTM DEM for Volcan Baru, in Panama.

18.4 Extracting land-surface parameters and objects from DEMs

18.4.1 Extracting a D8 Flow Grid

Once you have a DEM for an area of interest, there are a surprising number of additional grid layers, polygons, profiles and other objects that can be extracted with software tools and which are useful for various applications. Some of these were discussed in §7. Fig. 18.3 shows several land-surface parameters and objects that were extracted for the Baranja Hill case study DEM and which will be discussed throughout this section. A DEM with 5–meter grid cells was created from a source DEM with 25–meter grid cells via binlinear interpolation followed by smoothing with a 5×5 moving window, using the RiverTools Grid Calculator. This smoother DEM was used for creating the images shown except for Fig. 18.3(d).

A D8 flow grid is perhaps the most fundamental grid layer that can be derived from a DEM, as it is a necessary first step before extracting many other objects. RiverTools makes it easy to create a D8 flow grid and offers multiple options for resolving the ambiguity of flow direction within pits and flats. Choosing Flow Grid (D8) from the Extract menu opens a dialog which shows the available options. The default pit resolution method is "*Fill all depressions*". In most cases, filling all depressions will produce a satisfactory result since it handles the typically very large number of nested, artificial depressions that occur in DEMs and even provides reasonable flow paths through chains of lakes. However, support for closed basins is also provided and is necessary for cases where flow paths terminate in the interior of a DEM, such as at sinkholes, landlocked lakes or craters. The default flat resolution method is "*Iterative linking*". As long as the entire boundary of a river basin is contained within the bounding box of the DEM, each of the flat resolution methods will almost always produce flow directions within flat areas of the basin that send water in the right direction, despite the absence of a local elevation gradient (see the discussion of edge effects in §7).

Within broad, flat valleys, however, the "*iterative linking*" method (Jenson, 1985, 1991) produces multiple streamlines that flow parallel to one another until there is a bend in the axis of the valley that causes them to merge. The main problem with these parallel flow paths is that the point at which one stream merges into another (the confluence) is often displaced downstream a considerable distance from where it should be. The "*Imposed gradients*" option uses the method published by Garbrecht and Martz (1997) to create a cross-valley elevation gradient in flats and tends to produce a single flow path near the center of the valley. However, this method sometimes results in two parallel flow paths near the center of valleys instead of one. The "*Imposed gradients plus*" option was developed by Rivix to merge any parallel flow path pairs (in flats) into a single flow path.

Note: Increasing the vertical or horizontal resolution of DEMs does not eliminate artificial pits and flats and can even increase their numbers.

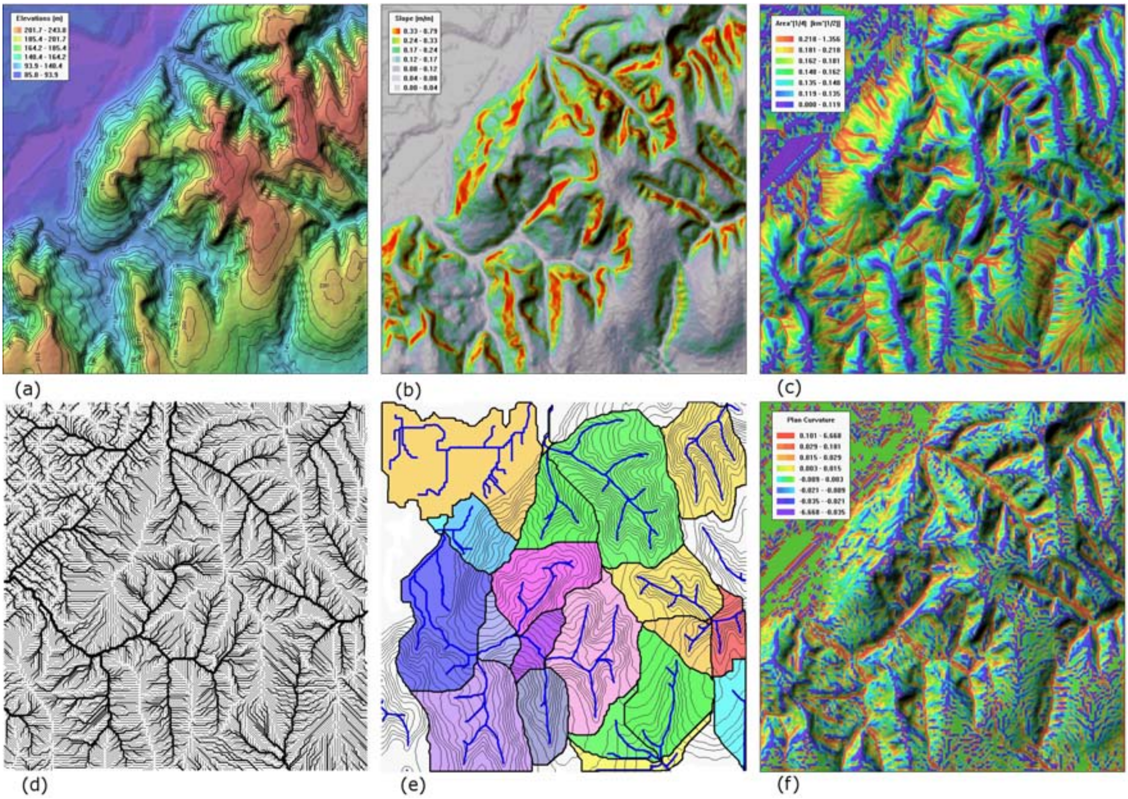

Fig. 18.3: (a) Shaded relief image with labeled contour line overlay; (b) Shaded image of a D8 slope grid; (c) Shaded image of a total contributing area grid, extracted using the mass flux method; (d) Drainage pattern obtained by plotting all D8 flow vectors; (e) Watershed subunits with overlaid contours and channels (blue), using a D8 area threshold of 0.025 km^2; (f) Shaded image of plan curvature, extracted using the method of Zevenbergen–Thorne. (© Rivix, LLC, used with permission)

18.4.2 Extracting and Saving a Basin Outlet

Once you have created a D8 flow grid, there is an easy-to-use graphical tool in RiverTools for precisely selecting which grid cell you want to use as a basin outlet. Choosing Basin Outlet from the Extract menu opens a dialog. Clicking on the dialog's Start button produces an image (shaded relief or density plot) that shows the entire DEM. If you then click within the image window, a streamline from the place where you clicked to the edge of the DEM will be overplotted on the image. You can move the mouse and click again to select and plot another streamline. Some of the streamlines will flow into the main channel of your basin of interest and some will flow into other, disjoint basins. Once you have selected a streamline that flows through the point you wish to use as a basin outlet, you can then use the slider in the dialog to move a red/white indicator along the streamline to your desired basin outlet point.

The precise grid cell coordinates are printed in the *Output Log* window, and you can click on the arrow buttons beside the slider to select any grid cell along the streamline, even if the image dimensions are many times smaller than the DEM dimensions. This graphical tool is designed so that you are sure to select a grid cell for the basin outlet that lies along any streamline that you select, instead of a few pixels to one side or the other. Once you have selected a grid cell as a basin outlet with this two-step graphical process, you simply click on the Save Outlet button in the dialog to save the coordinates in a text file with the extension "`_basin.txt`".

These coordinates identify the watershed that is of interest to you and are used by subsequent processing routines. Additional basic info for the basin will be appended to this file as you complete additional processing steps. By allowing any number of *basin prefixes* in addition to the *data prefix* associated with the DEM filename, RiverTools makes it easy to identify several watersheds in a given DEM and extract information for each of them separately while allowing them to share the same D8 flow grid and other data layers. You can change the basin prefix at any time using the *Change Basin Prefix* dialog in the File menu. This tells RiverTools which watershed you want to work with.

18.4.3 Extracting a River Network

A river network can be viewed as a tree graph with its root at a particular grid cell, the outlet grid cell. The *Extract* ↦ *RT Treefile* dialog extracts the "*drainage tree*" for the watershed that drains to the outlet grid cell that you selected previously and saved. This is a raster to vector step that builds and saves the topology of the river network and also measures and saves a large number of attributes in a RiverTools vector (RTV) file with compound extension `_tree.rtv`. The *Extract* ↦ *River Network* dialog can then be used to distinguish between flow vectors on hillslopes and those that correspond to channels in a river network. The flow vectors on the hillslopes are *pruned away* and the remaining stream channels are saved in another RTV file with extension `_links.rtv`, along with numerous attributes. A variety of different pruning methods have been proposed in the literature and each has its own list of pros and cons. Fig. 18.4 shows a river network extracted from SRTM data for the Jing River in China.

RiverTools supports pruning by D8 contributing area, by Horton-Strahler order, or by following each streamline from its starting point on a divide to the first inflection point (transition from convex to concave). In addition, you can use any grid, such as a grid created with the Grid Calculator (via *Extract* ↦ *Derived Grid*) together with any threshold value to define your own pruning method. The real test of a pruning method is whether the locations of channel heads correspond to their actual locations in the landscape, and this can only be verified by field observations. Montgomery and Dietrich (1989, 1992) provide some guidance on this issue. See Fig. 7.4 on page 141 for additional information on pruning methods.

Fig. 18.4: Jing River in the Loess Plateau of China, extracted from SRTM data with 3-arcsec grid cells.

Once you have completed the *Extract* ↦ *RT Treefile* and *Extract* ↦ *River Network* processing steps, you will find that your working directory now contains many additional files with the same basin prefix and different filename extensions. Each of these files contains information that is useful for subsequent analysis. Three of these files end with the compound extensions `_tree.rtv`, `_links.rtv` and `_streams.rtv`. These RTV files contain network topology as well as many measured attributes. For example, the attributes stored in the *stream file* for each Horton-Strahler stream are: upstream end pixel ID, downstream end pixel ID, Strahler order, drainage area, straight-line length, along-channel length, elevation drop, straight-line slope, along-channel slope, total length (of all channels upstream), Shreve magnitude, length of longest channel, relief, network diameter, absolute sinuosity, drainage density, source density, number of links per stream, and number of tributaries of various orders. RTV files and their attributes can also be exported as shapefiles with the *Export Vector* ↦ *Channels* dialog in the File menu.

18.4.4 Extracting Grids

D8-based Grids Once you have a D8 flow grid for a DEM, there are a large number of additional grid layers that can be extracted within the D8 framework. RiverTools currently has 14 different options in the *Extract* ↦ *D8-based Grid* menu. D8 area grids and slope grids are perhaps the best-known (see §7), but many other useful grid layers can be defined and computed, including grids of flow distance, relief, watershed subunits and many others. Each of these derived grids inherits the same georeferencing information as the DEM.

D-Infinity Grids As explained in §7, the D-Infinity algorithms introduced by Tarboton (1997) utilise a continuous flow or aspect angle and can capture the geometry of divergent flow by allowing "*flow*" to more than one of the eight neighbouring grid cells. These grids can be computed in RiverTools by selecting options from the *Extract* ↦ *D-Infinity Grid* menu.

Mass Flux Grids As also explained in §7, the RiverTools Mass Flux algorithms provide an even better method for capturing the complex geometry of divergent and convergent flow and its effect on total contributing area (TCA) and specific contributing area (SCA). These grids can be computed in RiverTools by selecting options from the *Extract* ↦ *Mass Flux Grid* menu. Fig. 18.5 and Fig. 18.3(c) show examples of contributing area grids computed via this method. Fig. 18.6 shows continuous-angle flow vectors in the vicinity of a channel junction or fork that were extracted using the Mass Flux method and then displayed with one of the interactive window tools.

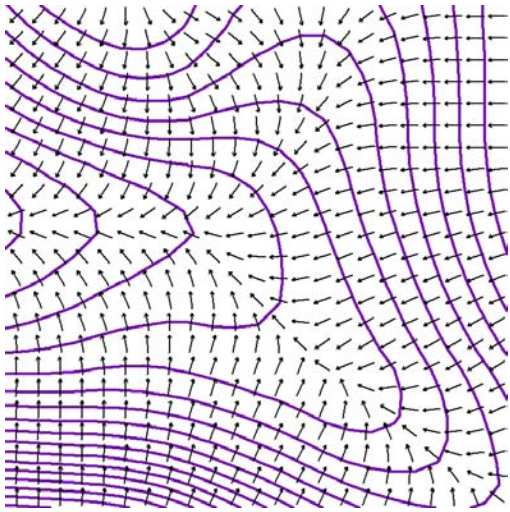

Fig. 18.6: Continuous-angle flow vectors in the vicinity of a channel junction or fork, extracted using the Mass Flux method. (© Rivix, LLC, used with permission)

Finite Difference Grids RiverTools can compute many standard morphometric parameters such as slope, aspect, first and second derivatives, and five different types of curvature. It currently does this using the well-known method of Zevenbergen and Thorne (1987) that fits a *partial quartic* surface to the (3×3) neighbourhood of each pixel in the input DEM and saves the resulting grid as a RiverTools Grid (RTG) file. Additional methods are planned for inclusion in the next release. These grids can be computed by selecting options from the *Extract* ↦ *Finite Difference Grid* menu.

Other Derived Grids The *Extract* ↦ *Derived Grids* menu lists several other tools for creating grids. The most powerful of these is the Grid Calculator that can create a new grid as a function of up to three existing grids without requiring the user to write a script. For exam-

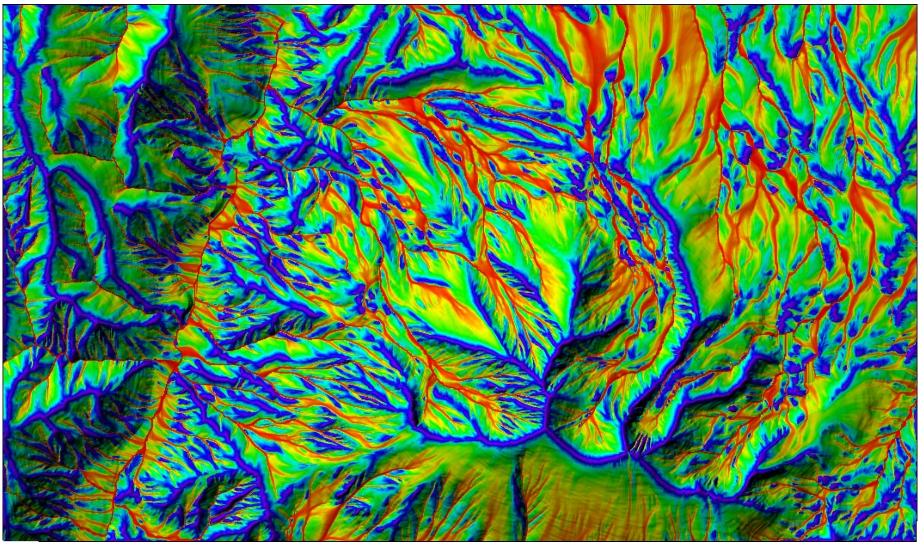

Fig. 18.5: A relief-shaded image of a TCA grid for Mt. Sopris, Colorado, that was created using the Mass Flux method. Areas with a large TCA are shown in red while areas with a small TCA value (e.g. ridgelines) are shown in blue and purple. Complex flow paths are clearly visible and results are superior to both the D8 and D-infinity methods. (© Rivix, LLC, used with permission)

ple, it can be used to create any type of *wetness index* grid from grids of slope and specific area. The dialog resembles a standard scientific calculator. In addition to the operators shown, any IDL command that operates on 2D arrays (i.e. grids) can be typed into the function text box. The Restricted to RTM tool lets you create grids in which masked values are reassigned to have nodata values. For example, this tool can be used to create a new DEM in which every grid cell that lies outside of a given watershed's boundary is assigned the nodata value.

18.4.5 Extracting Masks or Regions of Interest

Within grid layers one often wishes to restrict attention or analysis to particular *regions of interest* or *polygons*, such as watersheds, lakes, craters, or places with elevation greater than some value. In order to display or perform any kind of analysis for such a region, we need to know which grid cells are in the region and which are not. This is equivalent to knowing the spatial coordinates of its boundary. A large number of different attributes can be associated with any such polygon, such as its area, perimeter, diameter (maximum distance between any two points on the boundary), average elevation, maximum flow distance or centroid coordinates. RiverTools Mask (RTM) files provide a simple and compact way to store one or more *masked regions* in a file. A complete description of RTM files is given in an appendix to the User's Guide.

There are a number of different tools in the *Extract* ↦ *Mask* submenu that can be used to create RTM files. For example, watershed polygons of various kinds can be extracted with the Sub-basin Mask tool, lake polygons can be extracted with the Connected-to-Seed Mask tool, and *threshold* polygons can be extracted with the Grid Threshold Mask tool. Creative use of these tools can solve a large number of GIS-query problems. RTM files that record the locations of single or multi-pixel pits are created automatically by the *Extract* ↦ *Flow Grid (D8)* tool. A tesselation of watershed *subunits* can be created with the *Extract* ↦ *D8-based Grid* ↦ *Watershed*

Subunits tool. RTM files can also be merged by the *Merge Files* tool in the *Prepare* menu. Given an RTM file for a region of interest, the *Export Vector* ↦ *Boundaries* tool in the File menu can create an ESRI shapefile for the polygon and can also compute and save 36 optional attributes (new in the next release).

18.4.6 Extracting Functions

Hypsometric curves or **area-altitude functions** have a long history (Strahler, 1952; Pike and Wilson, 1971; Howard, 1990) and RiverTools can extract this and several other functions from a DEM (Fig. 18.7). The **width function** (Kirkby, 1976; Gupta et al., 1980; Troutman and Karlinger, 1984) and closely related **area-distance function** measure the fraction of a watershed (as number of links or percent area) that is at any given flow distance from the outlet (*Extract* ↦ *Function menu*) and are tied to the instantaneous unit hydrograph concept. The **cumulative area function** (Rigon et al., 1993; Peckham, 1995b) measures the fraction of a watershed that has a contributing area greater than any given value (*Extract* ↦ *Channel Links* ↦ *Link CDF*). **Empirical cumulative distribution functions** (ECDFs) (Peckham, 1995b; Peckham and Gupta, 1999) for ensembles of basins of different Strahler orders have been shown to exhibit statistical self-similarity: *Analyze* ↦ *Strahler streams* ↦ *Stream CDFs.* It has been suggested by Willgoose et al. (2003) that some of these functions can be used together to measure the correspondence between real and simulated landscapes.

18.5 Visualisation tools

RiverTools has a rich set of visualisation tools, many of which are centrally located in the **Display menu**. Each tool provides numerous options which are explained in context-specific help pages, available by clicking on the Help button at the bottom of the dialog. After changing the settings in the dialog, you click on the Start button to create the image. There are too many display tools and options to describe each one in detail here, so the purpose of this section is to provide a high-level overview. Many of the tools have their own colour controls, but colour schemes can also be set globally with the **Set Colors** dialog and saved with the **Set Preferences** dialog. Both of these are launched from the File menu. Most of the images created by tools in the Display menu can be shown with a map projection, and the projection can be configured with the **Map Projection Info** dialog at the bottom of the menu. Menus labelled *Options*, *Tools* and *Info* at the top of image windows provide additional functionality, such as the ability to print an image or save it in any of several popular image formats. The Tools menu contains a large number of Interactive Window Tools that will be highlighted in the next section.

The **Density Plot** tool creates colour-by-number plots, and offers many different types of contrast-enhancing '*stretches*' including linear, logarithmic, power-law and histogram equalisation. For example, contributing area grids are best viewed with a power-law stretch, due to the fact that there are a small number of grid cells with very large values and a large number with very small values. The **Contour Plot** tool makes it easy to create either standard or filled contour plots (or both as a multi-layer plot) and provides a large number of options such as the ability to control the line style, width and colour of each contour line. Colour shaded relief images with different colour tables and lighting conditions can easily be created with the **Shaded Relief** tool (Fig. 18.8). There is also a tool called **Shaded Aspect** that simply uses D8 flow direction values with special colour tables to visualise DEM texture. A **Masked Region** tool allows you to display the boundaries or interiors of one or more "*mask cells*" or polygons (e.g. basins, pits, lakes, etc.) which are stored in RTM (RiverTools Mask) files with the extension `.rtm`. A related tool is the **ESRI Shapefile** tool which has numerous options for plotting vector data that is stored in a shapefile, including points, polylines and polygons. (Shapefiles may be created from RTV and RTM files with the *Export Vector*

↦ *Channels* and *Export Vector* ↦ *Boundaries* tools in the File menu.) A button labeled *View Attr. Table* at the bottom of this dialog displays a shapefile's attribute table, and the table can be sorted by clicking on column headings. Digital Line Graph (DLG) data in the now-standard SDTS format can be displayed by itself or as a vector overlay with the **DLG–SDTS** tool.

The **Function** tool in the Display menu reads data from a multi-column text file and creates a plot of any two columns. There are several places in RiverTools where data can be saved to a multi-column text file (e.g. longitudinal profiles) and later displayed with this tool. Perspective-view plots for an entire DEM can be displayed with the **Surface Plot** tool as wire-mesh, lego-style or shaded. For larger DEMs, however, better results are obtained with the Surface Zoom window tool which is explained in the next section. Extracted river networks, which are saved in RTV (RiverTools Vector) files can be displayed with the **River Network** tool, or first exported via *File* ↦ *Export Vector* ↦ *Channels* and displayed with the ESRI Shapefile tool. Using the **Multi-Layer Plot** tool, images created by many of the tools in the Display menu can be overlaid, that is, any number of vector plots can be overlaid on any raster image.

One of the most powerful tools in the Display menu is the **Grid Sequence** tool. This tool is for use with RTS (RiverTools Sequence) files, which are a simple extension[1] of the RTG (RiverTools Grid) format. RTS files contain a grid sequence, or grid stack, usually with the same georeferencing as the DEM. Grids in the stack are usually indexed by time and are typically created with a spatially-distributed model that computes how values in every grid cell change over time. For example, a distributed hydrologic model called TopoFlow[2] can be used as a plug-in to RiverTools (see §25). TopoFlow computes the time evolution of dynamic quantities (e.g. water depth, velocity, discharge, etc.) and can save the resulting sequence of grids as an RTS file. Landscape evolution models also generate grid stacks that show how elevations change over time. This tool can show a grid stack as an animation or save it in the AVI movie format. It allows you to jump to a particular frame, change colours and much more. The Options menu at the top of the dialog has many additional options and there is also a Tools menu that has tools for interactively exploring grid stack data, such as the **Time Profile** and **Animated Profile** tools.

[1] All of the RiverTools formats are nonproprietary and are explained in detail in an appendix to the user's guide.
[2] http://instaar.colorado.edu/topoflow/

18.5.1 Interactive Window Tools

As mentioned previously, image windows that are created with the tools in the Display menu typically have three menus near the top of the window labelled Options, Tools and Info. In RiverTools, the entries in an Options menu represent simple things that you can do to the window, such as resize it, print it, close it or save the image to a file. The entries in a Tools menu represent ways that you can use the mouse and cursor to interact with or query the image. Here again we will simply give a high-level overview of several of these tools, but more information is provided in the user's guide.

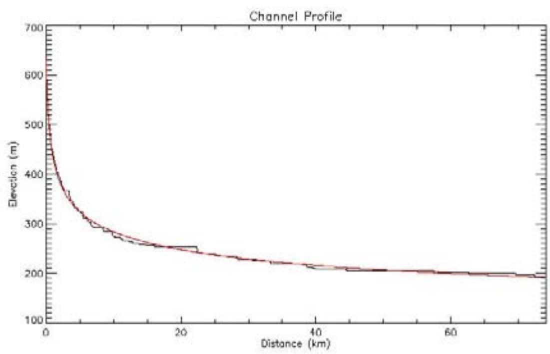

Fig. 18.9: Longitudinal profile plot created for a main channel of the Beaver Creek DEM with the Channel Profile tool.

The **Line Profile** tool lets you click and drag in an image to draw a transect and then opens another small window to display the elevation values along that transect. Note that this new window has its own Options menu that lets you

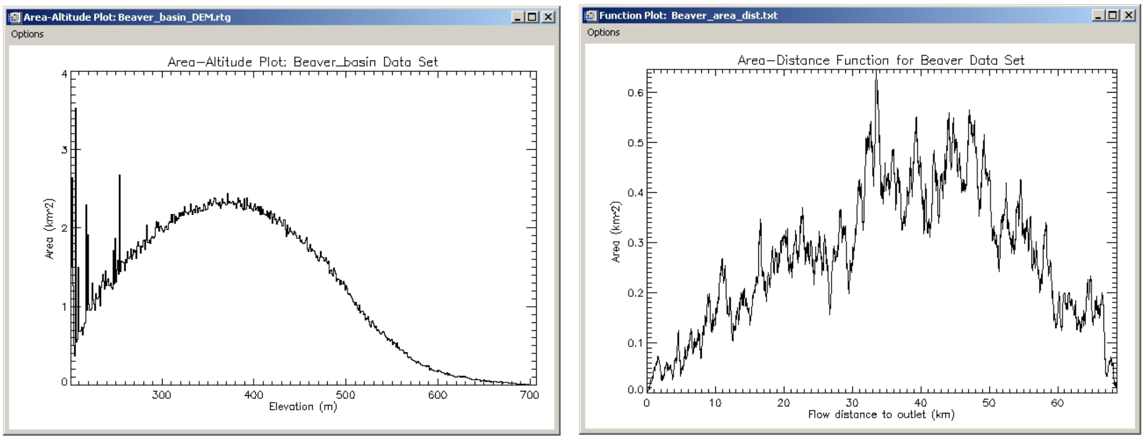

Fig. 18.7: Functions extracted from a DEM for Beaver Creek, Kentucky: (a) an area-altitude plot and (b) an area-distance plot.

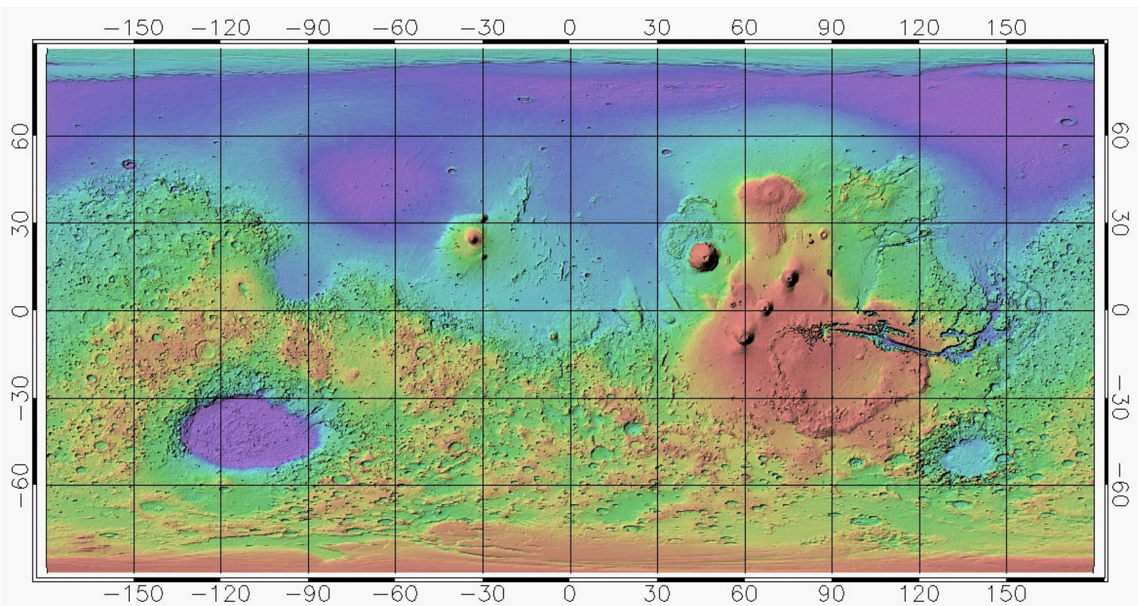

Fig. 18.8: High-resolution MOLA (Mars Orbiter Laser Altimeter) DEM displayed in RiverTools: colour shaded relief image for planet Mars shown by the cylindrical equidistant map projection.

do things like save the actual profile data to a multi-column text file. The **Channel Profile** tool is similar (Fig. 18.9), except that you click somewhere in the image and then the flow path or streamline from the place where you clicked to the edge of the DEM is overlaid on the image. The elevations (or optionally, the values in any other grid) along that streamline are plotted vs. distance along the streamline in another small window. Again, the Options menu of this new window has numerous entries.

The **Reach Info** tool is similar to the Channel Profile tool but opens an additional dialog with sliders that let you graphically select the upstream and downstream endpoints of any reach contained within the streamline and displays various attributes of that reach. If you select **Vector Zoom** from the Tools menu and then click in the image, crosshairs are overlaid on the image and a small window is displayed that shows grid cell boundaries, D8 flow paths and contour lines in the vicinity of where you clicked.

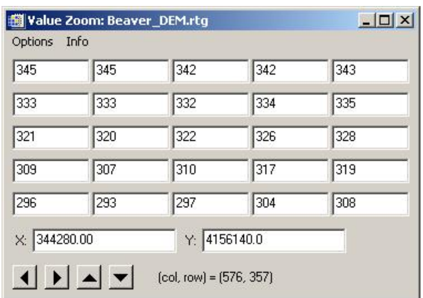

Fig. 18.10: The Value Zoom dialog.

The **Value Zoom** tool is similar but displays actual grid values as numbers and also shows the coordinates of the selected grid cell (Fig. 18.10). This tool has many other capabilities listed in its Options menu, such as the ability to edit grids or jump to specified coordinates. Perspective, wire mesh plots are more effective when applied to smaller regions rather than to entire DEMs, so the **Surface Zoom** tool provides a powerful way to interactively explore a landscape (Fig. 18.11). This tool has many settings at the bottom of the display window and many entries in its Options menu. The **Density Zoom** and **Relief Zoom** tools show density plots (see last section) and shaded relief plots at full resolution for a selected region even though the main image may show the entire area of the DEM at a greatly reduced resolution. All of the Zoom-tools are automatically linked, so that they all update when you move the mouse to another location in the image. The **Add Scale Bar**, **Add Colour Bar**, **Add Text** and **Add Marker** tools can be used to interactively annotate an image prior to saving it to an image file with *Options* ↦ *Save* Window.

Finally, the **Flood Image** tool allows you to change the colour of all pixels below a given elevation to blue, either instantly or as an animation. It is a useful visualisation tool but does not model the dynamics of an actual flood.

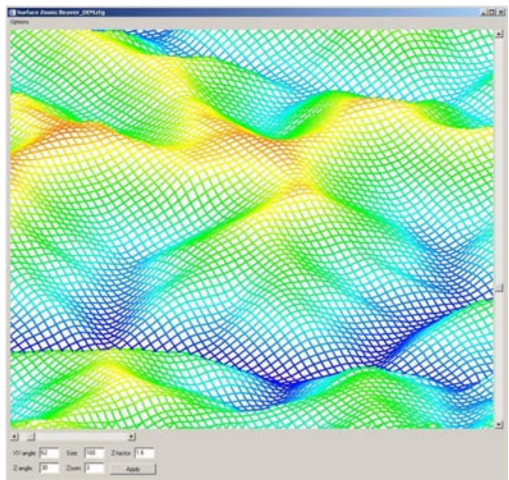

Fig. 18.11: The Surface Zoom display window.

18.6 Summary Points

RiverTools is a powerful but easy-to-use toolkit for visualising and extracting information from digital elevation data. It has an intuitive, point-and-click graphical interface, an extensive HTML-based help system and much of the power of a full-featured GIS even though its main focus is on digital elevation data. It also contains state-of-the-art algorithms for computing geomorphometric quantities, such as the new Mass Flux method for computing contributing area. This unique combination of features makes it ideal for teaching courses in hydrology, landscape ecology and geomorphology. RiverTools can import a wide variety of DEM formats as well as vector data in the ESRI shapefile and DLG-SDTS formats. It works well together with other GIS software since it can also export raster data in several common formats (via *File* ↦ *Export Grid*) and vector data in the industry-standard shapefile format (via *File* ↦ *Export Vector*). Publication-quality graphics and posters are easily created and annotated. Many built-in features including a graphical Grid Calculator and support for wildcards in many places where an input filename is required (to allow batch processing) mean that writing scripts is usually not necessary. However, in cases where scripting is required, users have the option to purchase another product called IDL (Interactive Data Language, a product of ITT Visual Information Solutions, `www.ittvis.com`) that can be used to write extensions to RiverTools. This option provides access to all of the features of the IDL programming language in addition to a large set of documented, low-level RiverTools commands for customisation. Users can also extend RiverTools with free User menu plug-ins, such as a landscape evolution model called Erode and a spatially-distributed hydrologic model called TopoFlow.

RiverTools has been developed and refined over many years around three central themes, namely (1) ease of use, (2) ability to handle very large DEMs (whatever the task) and (3) accuracy of measurements. With regard to ease of use, Rivix has worked with users for many years to develop a user-friendly graphical interface and HTML help system. As for the ability to rapidly extract information from very large DEMs, this has driven the development of advanced algorithms that efficiently distribute the computational workload between available RAM and I/O to files. These types of algorithms are used throughout RiverTools. Finally, RiverTools and MicroDEM may be the only GIS applications that always take the latitude-dependence of pixel geometry into account when working with geographic DEMs. All lengths, slopes and areas are computed by integrating on the surface of the appropriate ellipsoid model to avoid the geometric distortion that is associated with map projections. This feature is especially important when working with DEMs at the regional, continental or global scale.

Important sources:

★ Rivix LLC, 2004. RiverTools *3.0 User's Guide*. Rivix Limited Liability Company, Broomfield, CO, 218 pp.

★ `http://rivertools.com` — RiverTools website.

★ `http://instaar.colorado.edu/topoflow/` — TopoFlow Website.

★ `http://www.ittvis.com` — ITT Visual Information Solutions.