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Automatic Adjustment of Image Sharpness in Relief Shading

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Abstract

Relief shading is a technique to depict topography on maps in a way that it is intuitively understood by the user. While relief shading was traditionally performed manually, nowadays digital elevation models are used as basis for analytical (i.e., automatic) relief shading methods. This Master thesis aims at the creation of a new method to perform automatic contrast adjustment in analytical relief shading. This is one of the core tasks of Swiss-style relief shading and relies on applying the aerial perspective effect. The aerial perspective effect should imitate manual relief shading – the gold standard – as close as possible. The new method was implemented in a Geographic Information System (GIS) environment (ArcGIS), since currently there is no standardized method to employ atmospheric corrections in GIS. As a first step in developing a novel method, two existing approaches for analytical relief shading were implemented as ArcGIS geoprocessing models. Then, the novel method was developed by making the following improvements: (1) emphasizing sharpness of ridges and (2) placing the haze effect in the lower elevations. The novel approach is designed to constrain the aerial perspective effect to an area of a watershed, treating each area locally as it is done in Swiss-style manual relief shading. The results demonstrate eligibility of both global and local watershed approaches for quality relief representation. Although this is a step closer to a fully-automated method to create the aerial perspective effect, it still requires user-definable parameters. Nevertheless, this approach is quantitative, consistent, reliable, and more objective than older techniques.

Keywords: analytical relief shading, aerial perspective effect, contrast adjustment, watersheds, ArcGIS

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Dedicated to my mom

Chapter 1

Introduction

1.1 Relief Shading

Relief shading is a technique to depict topography on maps in a way that it is intuitively understood by the user (Jenny and Räber, 2002). Due to the importance of relief depiction on maps, relief shading is considered to be the framework for the rest of the elements of a map (Imhof, 1982).

For many years cartographers tried to produce shaded relief using diverse techniques. Fridolin Becker (1854-1922), being a prominent representative of the Swiss school of cartography, summarized a variety of techniques inherent to the Swiss cartography and introduced the so called Swiss style relief shading. These techniques are contrast enhancements for the higher elevations, decreasing the contrast towards the valleys, depicting the lowlands with a grey tone to connect different land forms with one another, and applying the aerial perspective effect (Jenny and Räber, 2002). The principles listed were later refined by another Swiss cartographer Eduard Imhof (1895-1986). In the following, the term manual relief shading will be regarded as Swiss style relief shading.

Whereas traditionally shaded relief was created manually based on the cartographer's interpretation of contour lines, nowadays digital elevation models (DEM) are employed instead, allowing the development of analytical (i.e., automatic) relief shading (Jenny, 2001b). The automation process is needed, as the analytical approach takes distinctively less time, resources and is more objective than manual relief shading. At the same time, it suffers in legibility, aesthetic quality and unnecessary greater level of detail (Jenny and Räber, 2002). Methods that exist cannot replace manual relief shading, they need first to be improved. As long as there is no real alternative to replace manual relief shading, it inalterably serves as a pattern to compare to. Therefore, computers should not only be used to speed up the production process, but also to simulate manual relief shading as precisely as possible.

1.2 Aerial Perspective Effect

Aerial perspective is determined by the presence of atmospheric haze over the landscape, caused by the particles of water, and results in diminishing of contrast with the distance from the object. This effect notably contributes to the three-dimensional appearance of relief. The key practical advantage the user gains from a good-quality aerial perspective simulation is a better visualization of relief. Besides increasing three-dimensionality, simulation of the aerial perspective promotes interrelationships between different landforms and prevents the user from perceiving the relief inversely (Imhof, 1982).

This particular aspect is of importance, as the atmospheric perspective is one of the key components of the manual relief shading. Together with contrast corrections, it is important to take into consideration the topography of the terrain.

Accordingly, there is obviously a need to consider major structures of relief. First, contrast adjustment within the particular relief form can make visible the difference in height of different peaks or valleys. Extraction of watersheds from the terrain can help to define the light direction that would emphasize specific landforms, which were not depicted properly before. For instance, Brassel (1974) manually created a draft of ridges and ravines in order to adjust the horizontal angle of illumination to stress specific landforms.

1.3 Objective

The aim of this Master thesis is to develop a method that would allow automatic enhancements of the aerial perspective effect in relief shading. Specifically, the following two improvements will be made: (1) emphasized sharpness of ridges and (2) haze effect in the lower elevations.

As a first step in developing a novel method, the existing approaches and models described above will be implemented in a Geographic Information System (GIS) environment. In the times those models were created, GIS systems were less flexible and functional than nowadays. Thus their implementation in a GIS environment today may not only bring better understanding of theory behind different methods, but also evoke new ideas and approaches to develop. As a second step, the novel method based on watershed approach will be implemented in the same GIS environment.

1.4 Outline of the Thesis

This thesis is structured as follows: this chapter comprises the introduction to the subject and an overview of the problem and the objectives. In chapter 2 the literature overview of existing methods and basic concepts necessary for the development of a new approach are provided. Chapter 3 describes the methods chosen for the analysis, their implementation and results. The detailed description of the new approach is provided in chapter 4, whereas its results are given separately in chapter 5. Finally, the discussion section brings the evaluation of the results and gives a critical view on the work done, concluding with an outlook on open research questions and next steps in automated relief shading.

Chapter 2

Literature Overview

Nowadays analytical relief shading is used for topography visualization more than any other method (Zakšek et al., 2011). Derived from a digital elevation model (DEM), it is presented in a raster format and composed of grey values, which are determined by different algorithms based on a DEM and a light source (Jenny, 2001b).

2.1 Local Adaptation of Illumination

Methods to mathematically describe spatial surfaces started to appear since the end of the 19th century, primarily through applying Lambert's Cosine Law to calculate illumination of a light source at a discrete point on a surface (Wiechel, 1878; Moellering, 2012):

$$Intensity = cos(e) = cos(a) \cdot cos(b) + sin(a) \cdot sin(b) \cdot cos(c) \tag{2.1}$$

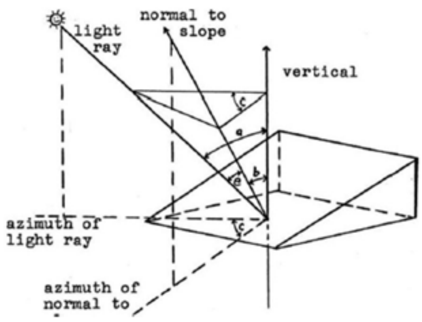

Figure 2.1: Analytical point illumination by Wiechel (1878) (Moellering, 2012, p.3)

Based on this, the light intensity is proportional to the cosine of the angle of incident light and is a function of the steepness (slope) and orientation (aspect) (figure 2.1). The

Lambertian model was first employed by Yoëli in his research (Yoëli, 1959, 1965, 1966). Whereas Wiechel proposed to calculate light intensities in a number of points with a further interpolation, Yoëli applied vector analysis to a surface divided into small plane-area elements, calculating their intensities and projecting them orthogonally on a plane. Using smaller cells allowing more continuous and natural shading led to automatization of these approaches (Yoëli, 1967b).

Based on Yoëli's experiments with local adjustments of light directions (Yoëli, 1967a), Brassel (1973, 1974) developed a more complex approach, which combines basic parameters of the Swiss style relief shading (Imhof, 1982) and intends to imitate the whole process of manual shading. Adjustments of the vertical and horizontal angles of illumination to the local terrain prevent the disappearance of terrain features located along the direction of the light source and the exaggeration of other terrain forms. Recently Jenny (2000, 2001a,b) developed a framework to define grey values of the image by applying aspect-based shading for steep regions, diffuse reflection for low areas and grey tones for flat areas. Local adaptations of light direction, vertical exaggeration, brightness and tone are used for flat areas within a manually fenced area. This combination of operations enhances visual appearance of the shaded relief, but because it is not automatic, manual adjustments throughout an image are required, which are time consuming and dependent on the user's decisions.

Another approach to locally adapt the light direction (Zhou and Dorrer, 1995) retrieves correction for the main light source from a DEM wavelet transform.

2.2 Aerial Perspective

The aerial perspective effect implies contrast reduction depending on the distance from the viewpoint (Imhof, 1982). It is employed in several existing models, the best-known of which are described in the following.

Brassel's model (Brassel, 1973, 1974) applies the atmospheric perspective effect by accentuating the tonal contrast in upper elevations and reducing it in lower elevations. It includes two algorithms: the first one applies the weights along the slope curve to the grey values of cells and results in darker cells in the upper areas and lighter cells in the lower elevations and flat areas (figure 2.2), while the second correction generally changes tonal values of all the cells, which finally introduces haze effect to the terrain. Deployed in an ArcGIS model, the two corrections with different starting parameters demonstrate fairly good results, which brings us to the conclusion that the local weights should be applied in the process of atmospheric correction.

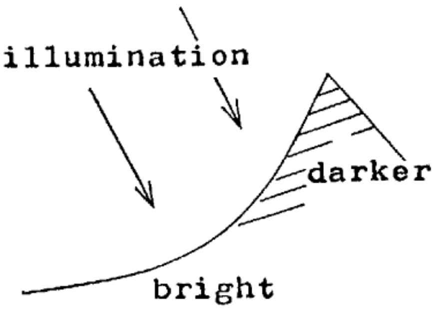

FIGURE 2.2: The slope curve for contrast adjustment (Brassel, 1974, Fig. 2)

The Shadow software developed by Jenny (2001b) simulates the aerial perspective by transforming the relative elevation, the orientation of the slope and the relative position on the slope to weights and applying them to the grey values calculated before. As in the case of Brassel's model, this process is not fully automatic and requires the user to define several parameters, such as the minimum length of the slope line and the degrees of both contrast reduction and aerial perspective, which are applied to reduce the contrast of grey values. Thus, the involvement of the user in the process, the need to control the output and to change parameters if needed is a major deficiency of the two methods described above.

Within the current GIS environment, atmospheric correction can to a certain degree be performed by the built-in ArcGIS Hillshade function, which through a series of calculations acquires illumination values of each cell in relation to neighboring cells (ESRI, 2009; Jenness, 2013). Despite a certain enhancement of visualization of the surface achieved by median filtering, this method produces results that are not even close to manual relief shading, as it does not support local light changes and does not consider a cell as a part of major relief forms. The effort to introduce several light sources, i.e., multidirectional shaded relief image, was done within developing another approach, also embedded into the ArcGIS Hillshade model and called Multiderictional, oblique-weighted (MDOW) model (Mark, 1992; ESRI, 2009; Jenness, 2013).

2.3 Other Approaches

For a long period of time, the relief of a terrain was illustrated by means of contour lines starting from older investigations (Tanaka, 1950) to more recent ones (Hobbs, 1995). However, using contour lines was not always natural for the viewer to perceive three-dimensionality of the terrain (Marsik, 1971). Nowadays contour lines can be easily derived from a DEM using a GIS package.

Slope-aspect mapping (Kimerling and Moellering, 1989; Moellering and Kimerling, 1990) is another approach to simulate relief shading. Developed in the late 80s, it presents terrain using colours for aspect classes and saturation for the slope. The resulted aspect-slope map (ArcGIS Resources, 2008a) makes an attempt not only to visualize relief in a different way, but also to retrieve the underlying landforms.

Other approaches include producing shaded images of curved surfaces (Gouraud, 1971), grid-based terrain analysis which allows computing of the slope, aspect, curvature and other attributes for every cell of a DEM (Gallant and Wilson, 1996), calculation of the hill slope algorithm employed in DEM (Jones, 1998), logarithmic and sub-pixel approach (Katzil and Doytsher, 2003), displaying shading with curvature (Kennelly, 2008, 2009), varying luminosity of colours based on the aspect and using layer tints(Kennelly, 2009; Kennelly and Kimerling, 2001), illuminating terrain with multiple light sources (Lukas and Weibel, 1995; Kennelly, 2009; ESRI, 2009). Some more methods are represented by creation of hillshading by combining different lighting directions (Loisios et al., 2007), applying sky models on hill shading (Kennelly and Kimerling, 2004), hillshading with cast shadows (Ware, 1989), using the light vector instead of a constant vector and other modifications done for existing models by Tutić et al. (2007), utilizing the sky-view factor, which relates to a visible part of sky limited by relief together with diffuse illumination and filtering (Zakšek et al., 2011), an algorithm taking into account changes of sun position (Zhou, 1992), etc.

Other approaches to render shaded relief have been developed in parallel with cartography areas, such as photogrammetry, remote sensing and machine vision. As shading in general is a cue for shape reconstruction, shape from shading has been employed by Batson et al. (1975) and Horn (1981). In the late 70's Horn (1981) recognized the dependence of brightness on surface orientation (aspect) using a reflectance map, which introduces radiance as a function of the gradient and brings relation between intensity and shape (Horn and Sjoberg, 1979). Modeling illumination by using three coloured (RGB) diffused light sources by varying the width of the light beam, sequence of colours and inclination of the light sources, prevents the terrain from being partially depicted (Hobbs, 1999).

One of the latest algorithms developed for computer graphics applications applied in analytical relief shading is the diffusion curves algorithm (Orzan et al., 2013; Association of American Geographers, 2014). It is applied to ridge lines and produces smooth-shaded images called diffusion curves, which partition the space and define different colours on either side. Another novel method called multidirectional visibility index has been shown to accentuate visualization of terrain features (Podobnikar, 2012).

Analytical relief shading can also be enhanced with graphic and other software comprising mainly of filtering, texturizing and manual adjustments done with a digitizer, for instance, in Adobe Photoshop (Jenny and Räber, 2002; Patterson, 2014; Patterson and Jenny, 2010; Jenny, 2009; Robinson and Thrower, 1957). Coloured shaded relief can be generated with a digital method of colourizing grey-shaded relief by assigning colours according to elevation and exposure to modulation (Jenny and Hurni, 2006). Guidelines on creating cliff drawings are described by Hurni et al. (2001); Hurni (2008); Jenny et al. (2014).

Without prior generalization shaded relief does not successfully portray the main structures of a terrain. Significant research in this area includes methods developed by Brassel and Weibel (1988), Weibel (1989), Weibel (1992), Poiker and Poiker (1997), and Guilbert et al. (2014). One of the latest software applications aiming both to generalize the DEM and apply the principal rules described by Imhof (1982) is Terrain Sculptor (Leonowicz et al., 2010b), performing very well at small and medium scales. As described by Leonowicz and Jenny (2010) and Leonowicz et al. (2010a), the general principle of the software's work consists in dividing the terrain into mountainous and lowland areas and treating them in different ways, i.e. to generalize them separately and afterwards to recombine them again into one elevation model. This idea was formulated by (Imhof, 1982) for manual relief shading.

2.4 Watershed Approach

A watershed may be regarded as

> 'a tessellation or subdivision of a basin into drainage areas selected for a particular hydrologic purpose' (Maidment, 2002, p.200)

Large watersheds consist of smaller ones, as it can be seen in figure 4.1.

Techniques with regards to watersheds started to appear in 1950s and 1960s. One of the primary models was the Stanford Watershed Model (SWM) aimed to substitute manual computations done by hydrologists in order to perform streamflow forecasts (Donigian Jr and Imhoff, 2006).

2.5 Summary and Challenges

Nowadays many GIS packages allow generation of shaded relief. Nevertheless they generally do not follow the principles developed for manual relief shading, which universally serves as a pattern. Therefore, there is a high demand to automate analytical relief shading in a GIS environment considering the guidelines for hand-shaded relief.

Automatic adjustment of image sharpness and automated local adjustments of the light direction are the focus of the current research. Methods of weighting and generalization to a large extent correspond to subjective decisions of cartographers characteristic of manual relief shading, thus can be a part of a new method. One straightforward approach is to use watersheds to divide a given area into separate landforms, which are then processed independently, to prevent minor slopes from looking feeble in contrast with the steeper slopes. Global and local weights and transitional thresholds, corresponding to the altitudes within the given area, could then be applied in order to preserve accurate terrain representation.

Chapter 3

Methods

The following chapter provides a detailed description of the currently existing methods for computing the aerial perspective effect employed in this Master thesis, their step-by-step implementation and results.

3.1 Data and Software

Analytical shaded relief is generated using a digital elevation model (DEM) (Jenny and Räber, 2002). For the Master thesis, a DEM was downloaded in an Esri Grid format ASCII, which is a non-proprietary raster file format developed by the Environmental Systems Research Institute (ESRI) (ESRI, 2009).

The hydrology network served as basis for the extraction of watersheds for the test area. Automatically created shaded reliefs were visually analyzed against manual shaded reliefs for the same area available at the scales 1:25000, 1:50000, 1:100000 and 1:200000 (see Appendix A.1).

All the test data were provided by the GeoVITe platform (ETH Zurich, 2009). A 2 m resolution digital terrain model (DTM) can be found at the Dataset Digital Elevation Models - DTM-AV with the maximum area to download equal to 120 km^2. It was downloaded in several parts and downsampled to 10 m resolution to decrease the error above 2000 m, where the DTM was resampled from 25 m resolution. The downsampling of the DTM also allowed to decrease the computational time. The hydrology network at the scale 1:200000 was download from the Dataset called Topographic Vector Maps.

3.1.1 Selection of Test Area

The test area of approximately 440 km^2 is located in the Lepontine Alps on the south of Switzerland. The main reason for choosing this specific area was that it is topographically heterogeneous, having both wide and narrow valleys and peaks of different orientation relative to the light source. Accordingly, it should be sufficient to try the method on this area only, as it gives a diverse sample of landforms.

One feature that made this particular region challenging for trying the enhancement of analytical relief shading was that one of the peaks, Pizzo Erra (2416 m), stretches from the Northwest to the Southeast, i.e., parallel to the Northwest light direction (generally recognized as a standard light direction). Such orientation usually results in a very similar grey tone on both sunlit and shadowed sides of the ridge. As a consequence, its elevation visually seems lower compared to neighboring peaks, whereas in reality they all are approximately of the same height. Adjustments of sharpness to implement within the area are aimed at contrast enhancements at the shadowed slopes, especially those oriented in parallel to the light direction, to differentiate the two slopes and enhance visual appearance of relief on the whole.

The large valleys Levantine and Blenie spanning across the city of Biasca and to the North of it also draw attraction to its depiction in analytical shaded relief. As it can be seen in the subsection 5.1.5, traces of human activity present on high resolution DEM not only distract attention but may also cause obstacles when it comes to watersheds extraction.

3.1.2 Software

Since the automation process is targeted at the ESRI ArcGIS software package, the primary tools for its development are considered to be ArcGIS built-in functions, ModelBuilder and Python programming language. SAGA GIS and QGIS served as supplementary software in attempts to define position within a slope for calculating a weight of relative position within the hillshade introduced by Jenny (2001b).

ArcGIS ModelBuilder is an application that assists in combining geoprocessing tools together and designing a separate workflow. It allows the creation of a new tool and enables integration of ArcGIS with other applications (ESRI, 2009).

The module ArcHydro was separately installed within ArcGIS to proceed with the extraction of watersheds and their analysis based on the hydrology network available from GeoVITe. These tools for surface water analysis are readily available and well documented (ArcGIS Resources, 2011).

3.2 Aerial Perspective Effect in ArcGIS

It is possible to simulate the aerial perspective effect with the help of an existing ArcGIS toolbox. The current workflow generates shaded relief using ArcGIS built-in Hillshade function and succeeding operations to imitate the aerial perspective effect using a model designed in frame of the ArcGIS Hillshade Toolbox.

This model is the only one to produce aerial perspective effect in ArcGIS that is currently available for users worldwide. The following sections thoroughly discuss the toolbox, its elements and their use.

3.2.1 ArcGIS Hillshade Function

Apart from elevation as the basic characteristic, which can be extracted from DEM, the other two important features are slope and aspect angles (Jenny and Räber, 2002). The slope of a topographic surface is usually defined as

> 'an angle G between the tangent plane P and the horizontal plane S at the given point S of the topographic surface' (Florinsky, 2012, p.12) (figure 3.1, left),

and aspect as

> 'a clockwise angle α from north to a projection of the external normal n to the horizontal plane S at the given point A of the topographic surface' (Florinsky, 2012, p.12) (figure 3.1, right).

Both angles can be computed in many GIS applications.

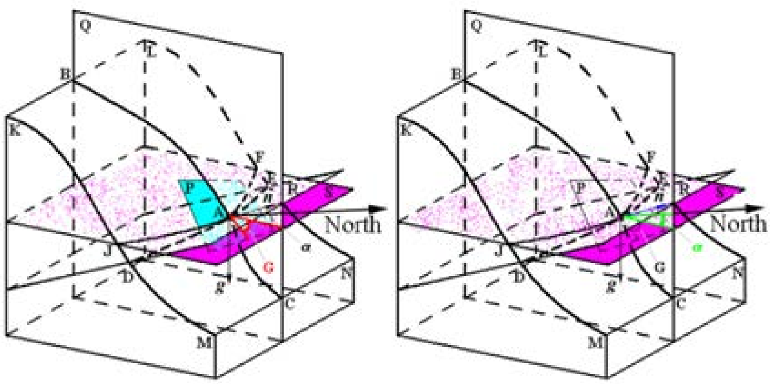

FIGURE 3.1: Slope (left) and aspect (right) (Florinsky, 2012, p.12)

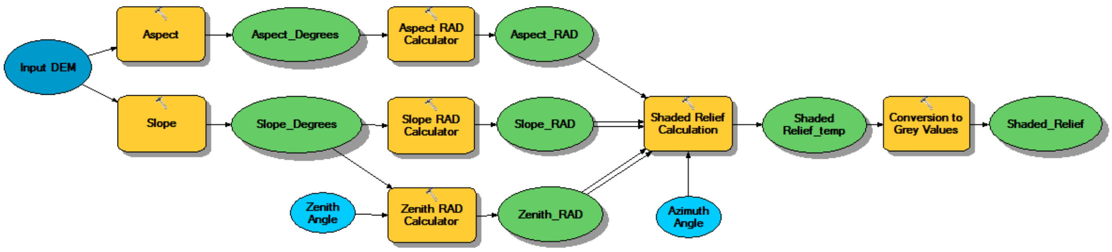

FIGURE 3.2: Model of hillshading equation

The Hillshade function makes it possible to define illumination values for every single raster cell with respect to the neighboring cells by placing a fictional light source and thereby refining the terrain's appearance (ESRI, 2009). Based on the Cosine law (equation 2.1), the algorithm to compute analytical shaded relief in ArcGIS looks as follows:

$$\begin{gathered} Hillshading = 255.0 \cdot ((cos(zenith) \cdot cos(slope))+ \\ (sin(zenith) \cdot sin(slope) \cdot cos(azimuth - aspect))), \end{gathered} \tag{3.1}$$

where *slope* and *aspect* are computed automatically for each raster cell using corresponding built-in ArcGIS functions from 3D Analyst Tools - Raster Surface, *azimuth* is the light vector direction, and *zenith* is the angle of inclination. All the values above are required to be converted into radians. Finally, with multiplying by 255 the shaded relief is converted into a greyscale image.

According to ESRI (2009), illumination angle (zenith) is defined by substracting altitude values from 90° (i.e., from the normal to the surface); illumination direction is specified by switching from geographic azimuth to a mathematical angle, i.e., $azimuth_{math} = 360 - azimuth + 90 = 360 - 315 + 90 = 135$, and values of slope and aspect newly computed by using filtering mechanism with a 3-by-3 moving window, aggregate values of their 8 neighboring cells each.

The steps described above are put together in the model displayed in figure 3.2.

Both azimuth and zenith angles here are variants, set to 315° and 45°, respectively, as specified above. Shaded Relief Calculation and Conversion to Grey Values calculators comprise equation 3.1 and are expressed using Python syntax.

3.2.2 The Swiss Hillshade Model

The Swiss Hillshade model (ArcGIS Resources, 2008c) is a part of the ArcGIS Hillshade Toolbox freely accessible at ArcGIS Resources (2008b) (figure 3.3).

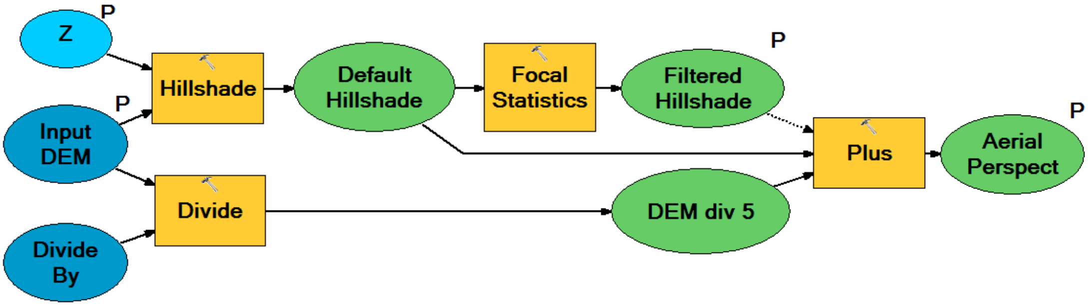

FIGURE 3.3: Swiss Hillshade Model

The model claims to represent Swiss hillshade effect by overlaying two adjusted hillshades: the first generalized by means of median filter (figure 3.4, left) and the second one generated from the original DEM and the default hillshade to lighten up the peaks and to darken low elevations (figure 3.4, right). Combined together with a certain degree of transparency, the hillshades produce the effect of atmospheric perspective, though in inverse way.

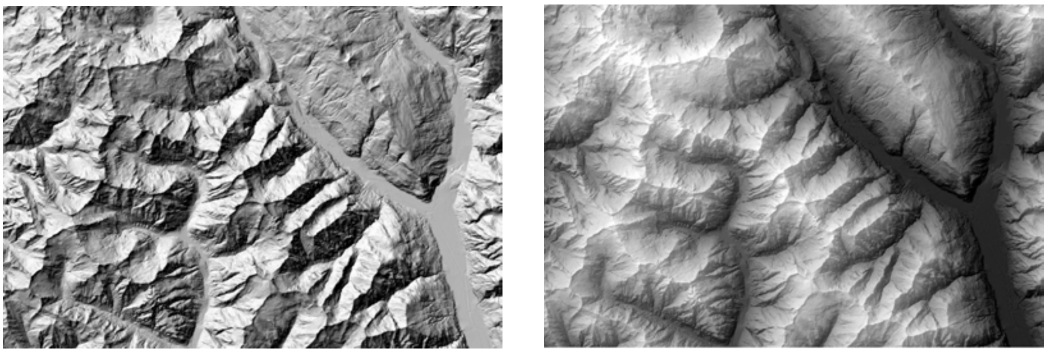

FIGURE 3.4: Generalized (smoothed) hillshade produced by using a median filter (left). A modified hillshade simulating aerial perspective effect in an inverse way (right).

3.3 Brassel's Method

The method described in this section was developed 40 years ago by Kurt Brassel (1974) in his PhD thesis at the University of Zurich. The model presented in the article comprises both contrast corrections and adjustment of the light direction. All these corrections amount to basic parameters of the Swiss style of relief shading and are targeted at employing computer for the whole chain of operations to deliver shaded relief comparable in quality with hand-shaded relief. In this section, however, only his findings related to imitation of the aerial perspective effect are introduced.

3.3.1 Method Description

Changes of the tonal values in the image are a central element of the method. The contrast corrections are accomplished by accentuating the tonal contrast for upper regions and its reduction in the lower areas, as it is defined by the commonly recognized rules for manual relief shading (Imhof, 1982).

According to Brassel (1974), there are two stages to achieve the desired effect. The first one targets the contrast changes depending on the altitude, whereas the next step applies overall changes of the grey values of the image.

Alterations of contrast are done in accordance with the following equation:

$$R_{new1} = (R_{old} - R_n\psi) \cdot e^{Z^*} \cdot 1^{nC_1} + \dot{R_n}\psi, \tag{3.2}$$

where R_{new1} is the reflection value to compute, R_{old} is the initial, prior to correction reflection value, $R_n \cdot \psi$ is the reflection of the surface according to the angle ψ, and $C_1 \geq 1$ illustrates the rate of the contrast changes. Independently of the parameter C_1, 1^{nC_1} always stays 1. Z^* is the weight for the altitude changes, which is in turn calculated as follows and may take values in the range of $-1 \leq Z^* \leq 1$:

$$Z^* = \frac{(Z - \frac{Z_{max}+Z_{min}}{2})}{\frac{Z_{max}-Z_{min}}{2}}, \tag{3.3}$$

where Z_{max} and Z_{min} are the maximum and minimum elevations within the area, respectively.

This mechanism is demonstrated in figure 3.5, where the tonal values in the middle stay the same, while at the higher elevations reflection values increase and grey values become darker enhancing the contrast. At the lower elevations contrast is reduced, which introduces the slight effect of haziness. This middle line can be shifted upward or downward. In this study the line was lowered (the denominator 2 in equation 3.3 was replaced by 1.5) in order to prevent the aerial perspective effect from appearing too strong.

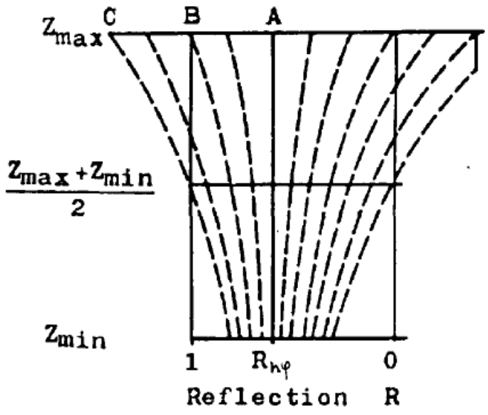

FIGURE 3.5: Change of contrast (Brassel, 1974, Fig. 6)

Reflections values out of range of [0 .. 1] are normalized so that negative values are equal to 0, and values bigger than 1 are defined as equal to 1 (figure 3.5).

The second stage of correction is done using the following equation:

$$R_{new2} = R_{new1} + \frac{C_2 \cdot (Z^* - 1)}{2}, \tag{3.4}$$

where R_{new2} is the reflection value to compute, R_{new1} is the reflection value before the second correction, Z^* is the weight for the altitude changes, and C_2 is a parameter indicating the rate of clearing or obscuring. To brighten the image, negative values from -1 to 0 for C_2 should be chosen, whereas to darken the image the parameter should be in the range between 0 and 1.

3.3.2 Implementation in ArcGIS

In order to visualize the effect described above, all the listed equations were incorporated into the ArcGIS model illustrated in figure 3.6.

Both corrections are applied to the shaded relief with fixed azimuth and zenith. The maximum and minimum values to calculate the altitude weight and to normalize the final image, i.e., to convert it into greyscale image, are computed with the Calculate Statistics function.

3.4 Jenny's Method

Another technique to simulate the aerial perspective effect in a quantitative way was offered and implemented in the Shadow software by Bernhard Jenny (2001b) implemented

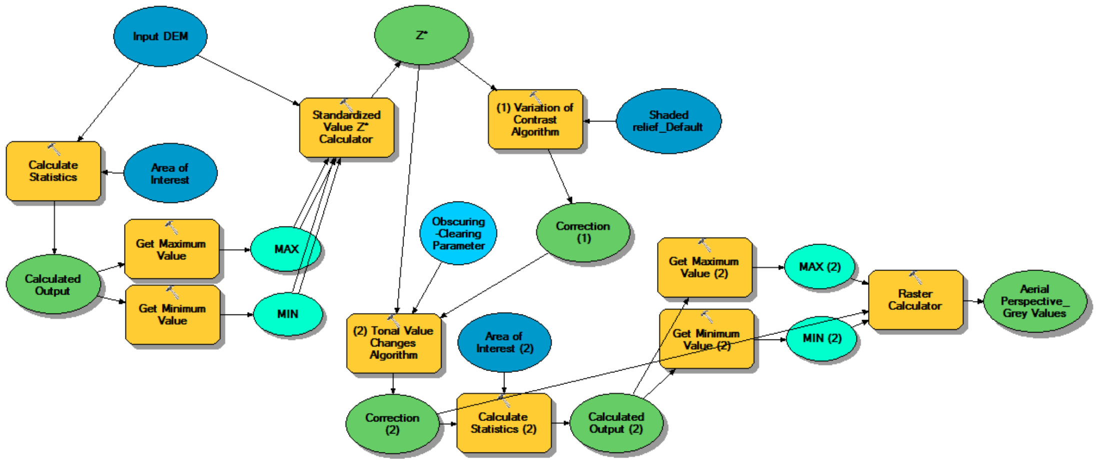

FIGURE 3.6: Aerial perspective effect according to Brassel

in the scope of his Diploma thesis at the ETH Zurich. The Shadow software was designed in a way to enable users to perform all the steps developed for manual relief shading: to calculate grey values employing both aspect-based shading for mountainous regions and diffuse reflection for low areas, to apply a grey tone for the valleys, to interactively adjust the light direction and to apply the aerial perspective effect. This software is not widely used anymore, as it requires Mac OS 9 to run it (Jenny, 2014).

3.4.1 Method Description

Similarly to Brassel, Jenny also transformed some corrections into weights. The first weight is the relative elevation weight, which is similar to the Brassel's first correction. It is calculated using the following equation:

$$w_h = \frac{h_p - h_{min}}{h_{max} - h_{min}}, \tag{3.5}$$

where w_h is the weight of the altitude between 0 and 1, h_p is the elevation of the point, and h_{min} and h_{max} are minimum and maximum elevations of the DEM within the specific area.

The weight of the orientation of the slope is computed based on the aspect:

$$w_a = \cos a, \tag{3.6}$$

where w_a is the weight of aspect in the range between -1 to 1 and a is the angle between the aspect and the azimuth of the light direction.

The third weight relates to the relative position on the slope using slope lines. The slope line below the point is defined by the line of the steepest slope, which is the direction of the aspect, till it meets the flat area. The slope line above the point is defined by tracing along the line until slope decreases below a defined threshold. This weight cannot be calculated within ArcGIS, unless it is programmed to be computed. As the idea is to implement the whole workflow in ArcGIS, it was decided to omit this weight.

Prior to employing the weight, the contrast was reduced using the following equation:

$$grey_{new} = grey \cdot (1 - m \cdot n) + \frac{m \cdot n}{2}, \tag{3.7}$$

where $grey_{new}$ are grey values after contrast reduction, $grey$ are initial grey values, m is the contrast reduction parameter, and n is the aerial perspective parameter. Both m and n are user-definable parameters, which makes this method, as Brassel's, not entirely automatic.

The contrast reduction is followed by applying the aerial perspective effect:

$$grey_{new2} = grey_{new} + w_h \cdot w_a \cdot w_p \cdot n, \tag{3.8}$$

where $grey_{new2}$ are the final values with aerial perspective.

3.4.2 Implementation in ArcGIS

A model based on Jenny's algorithm (Jenny, 2001b) for the aerial perspective effect weights was also integrated with the ArcGIS ModelBuilder (figure 3.7).

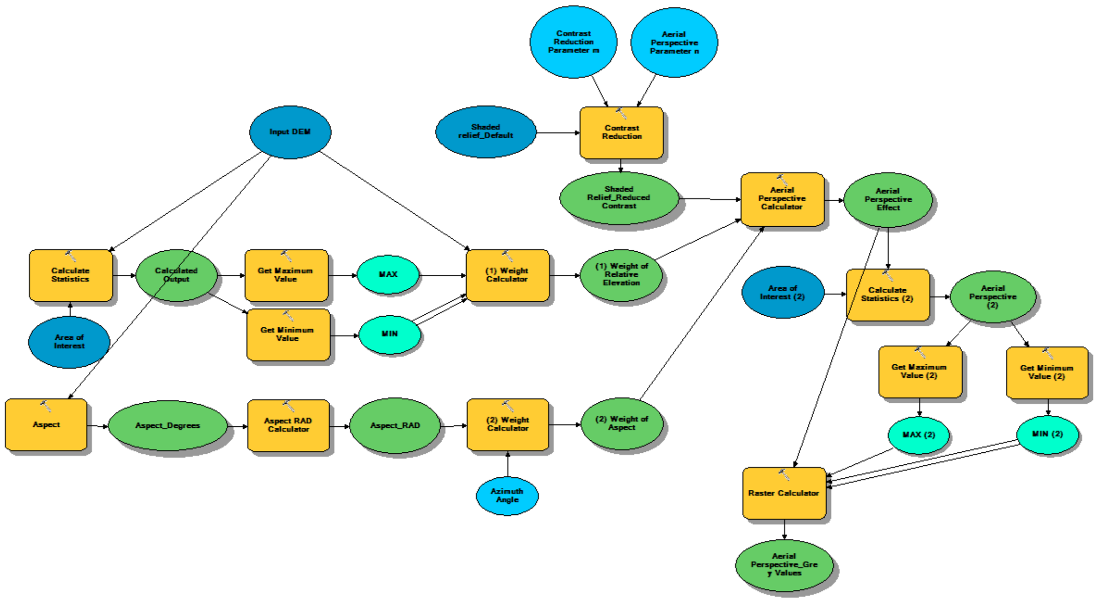

FIGURE 3.7: ArcGIS model for the aerial perspective effect according to Jenny (2001b)

Chapter 4

Applying the Watershed Method to Analytical Relief Shading

In the following chapter, the motivation for a novel approach is given, based on the idea of constraining the aerial perspective effect to an area of a waterhsed, the process of deriving watersheds with the help of ArcHydro tools is described and its implementation in ArcGIS is presented.

4.1 Novel Approach

The idea to take watersheds into account when changing the contrast or adapting the light direction comes from considering the fact that when depicting relief manually cartographers not only perform excellent generalization of relief, but at the same time manage to regard each landform as a separate and all-sufficient element of the terrain. The landforms differ from one another morphologically, and due to their different steepness, maximum and minimum elevation, and orientation to the light source they are depicted with a different grey tone and contrast. Furthermore, orientation of rivers and channels as the base elements of the watersheds can be used to determine orientation of the watershed and azimuth. This realization gave the motivation to review the current results, to constrain the changes of the light and contrast to an area of a watershed and to reconstruct the models accordingly.

This approach requires watershed boundaries and calculations for contrast and light adjustments. For the Master thesis, boundaries of watersheds were derived from the hydrology network of the scale 1:200000 provided by GeoVITe platform (ETH Zurich,

2009) and calculations for contrast adjustments were taken from the models described in Chapter 3.

4.2 Deriving Watersheds with ArcHydro

To perform all the operation within a single software package, ArcHydro Tools v2.0, available at ArcGIS Resources (2011), were chosen to retrieve watershed boundaries from the hydrology network available. As stated in the corresponding tutorial, Microsoft.Net Framework 3.5 for ArcGIS 10 (ESRI, 2011), the Spatial Analyst extension and the Water Utilities Application Framework (ApFramework, automatically installed with ArcHydro) are required for running ArcHydro Tools version 2.

According to ESRI (2011), watershed analysis with ArcHydro includes the steps terrain preprocessing, terrain processing and watershed processing.

First, the following manipulations were performed on the DEM. Changing of leveling the raw DEM in a way that the cells under lake polygons acquire specific constant height values was followed by reconditioning of DEM (a modification of a DEM by burning a streams on it). Then relative slopes were assigned to the streams and their following burning with slopes was done. Next, area boundaries served as a base to build outer walls, lakes as inner walls and streams as breaches. The sequent sink prescreening helped to avoid emerging of too many small sinks by specifying the threshold for potential ones. Afterwards, evaluation of sinks was performed with the aim to define the flow direction and to create drainage areas matched to the sinks. Later sinks should be filled in two steps, first all of them to establish a filled grid, second the sinks except those, which were already determined as grids.

As soon as the DEM is properly preprocessed, the workflow is continued with delineation: flow direction was defined for a grid and adjusted for streams, after the entirely filled DEM was employed in the process of creation of flow accumulation. Based on the created grid and a threshold, defined by the user, stream grid was generated. Choice of the threshold appears to be the key step, as it defines the dimension or scale of the watersheds later. As the next steps, streams were divided into segments, a grid was created with the values of each cell belonging to a specific catchment, followed by transformation of this grid into a polygon feature class.

As a result, different dimensions of watershed polygons were generated. Combined with the corresponding streams network, they are displayed in figure 4.1.

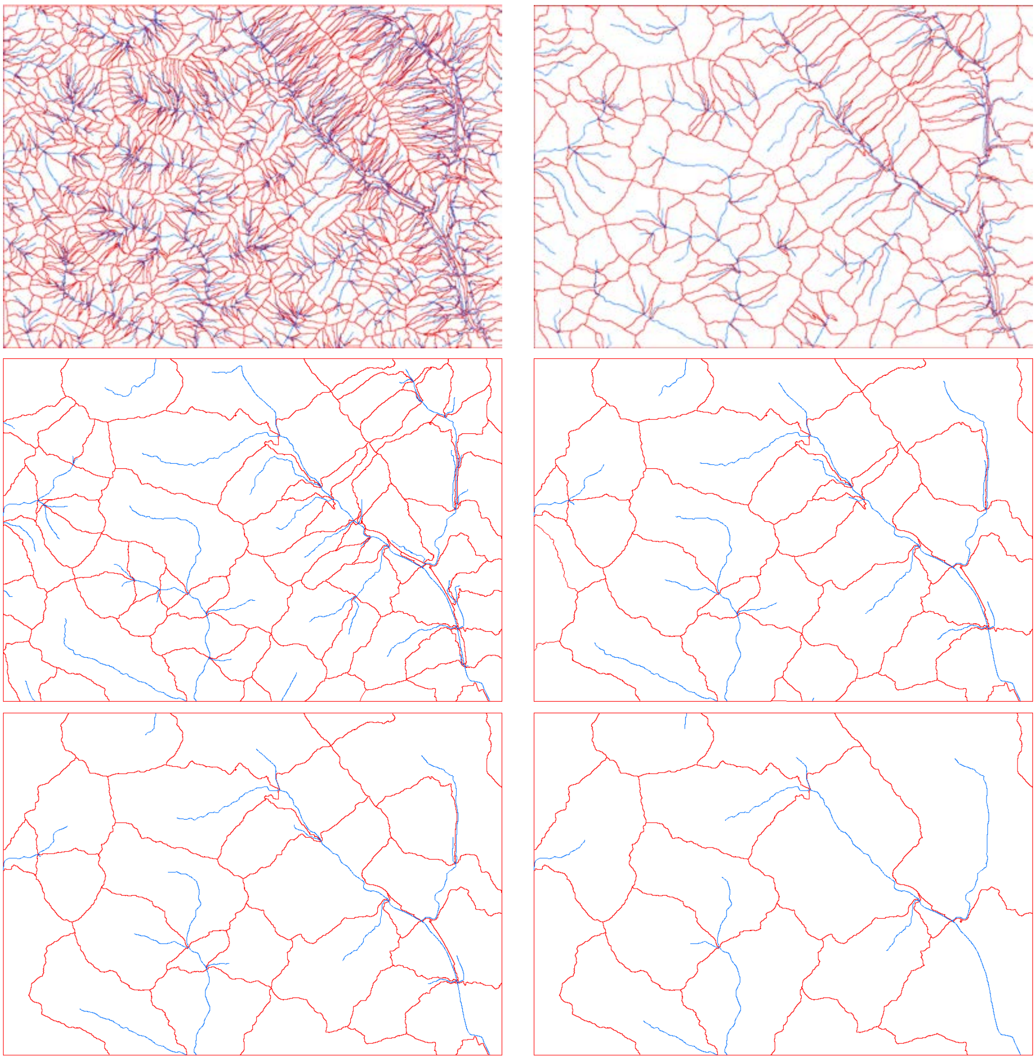

FIGURE 4.1: Different density of watersheds in combination with streams network corresponding to specific thresholds

The dimension of the watersheds depends on the size of polygons, which in turn is determined by a user-defined threshold. The aerial perspective effect resctricted to watersheds it tested on all the dimensions in chapter 5.

4.3 Implementation in ArcGIS

The watershed approach described in the previous section was implemented as two ArcGIS models in accordance with Brassel's and Jenny's equations for the aerial perspective effect (see sections 3.3.1 and 3.4.1). Below there are explicit guidelines given what input data are needed, how to run the tool, what output data to expect, and recommendations for how to speed up the process in cases of big volumes of data.

Before running the tool, it is necessary to find out the version of ArcGIS installed. The tool's version normally corresponds to the version of ArcGIS. In case of mismatch of the versions, the toolbox either could not be opened or not all of its functions would perform properly. The toolbox is designed in ArcGIS 10.2. In case ArcGIS installed on the user's PC is of a lower version than 10.2, the user should work with an appropriate version of the toolbox.

4.3.1 Input Parameters

Before running the model, the user needs to define the input parameters, which are listed below.

There are three input parameters to choose for the model based on Brassel's equations (figure 4.2). These are input DEM in ESRI ASCII grid format, a shapefile containing watershed boundaries as polygons and the Clearing-obscuring parameter. The parameter is user-definable and should be chosen in the range of [-1 .. 1], where -1 corresponds to the maximum clearing, 1 to the maximum obscuring and excluding a zero value, that is when the aerial perspective is not applied.

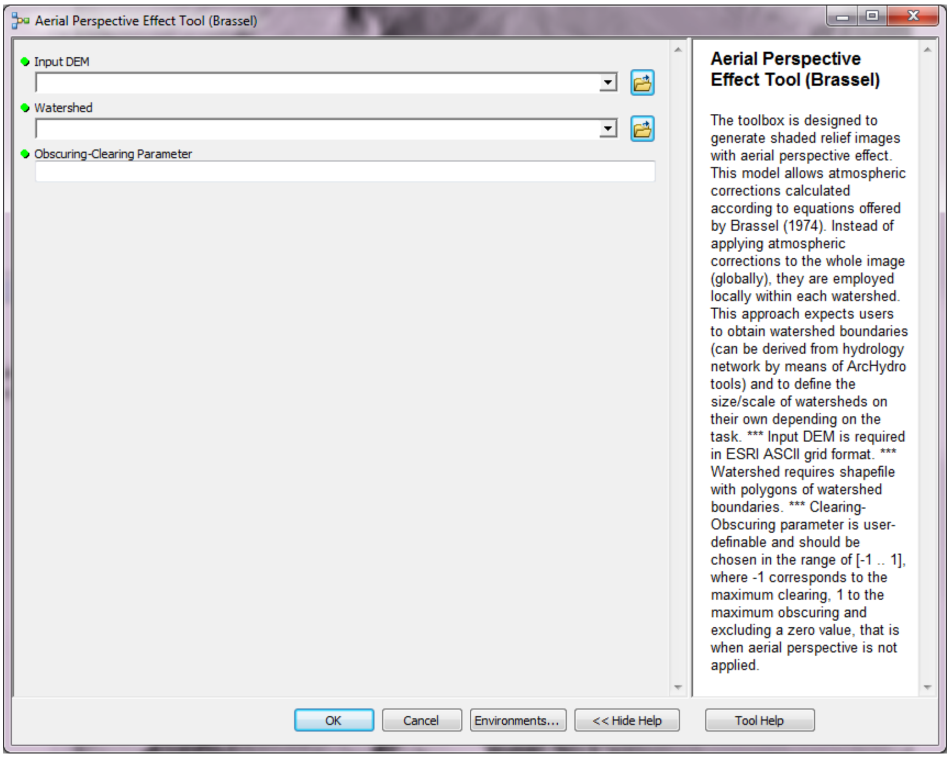

FIGURE 4.2: Input parameters to define for the watershed tool based on Brassel's equations for aerial perspective effect

To apply atmospheric corrections with Jenny's method, the user should define four input parameters: the input DEM in ESRI ASCII grid format, a shapefile containing watershed boundaries as polygons, and two parameters (figure 4.3). Intensity of both contrast reduction, which should be done prior to applying the weights to the default shaded relief, and aerial perspective should be defined by the user. They should be chosen in the range of [0..1] except a zero value, that is when the aerial perspective is not applied.

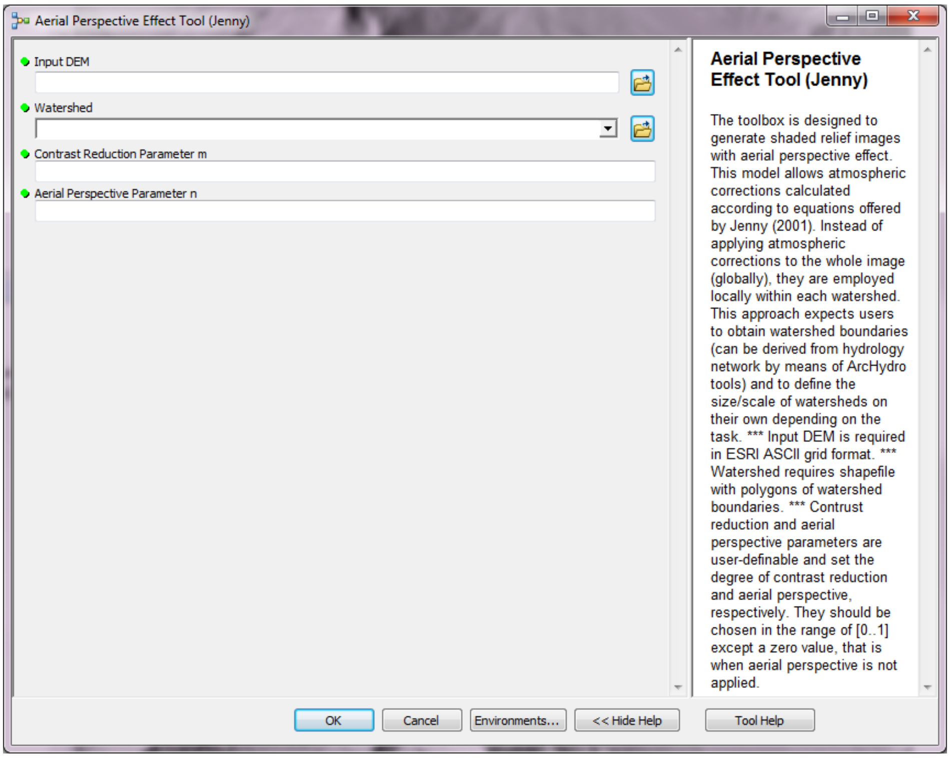

FIGURE 4.3: Input paramaters to define for the watershed tool based on Jenny's equations for aerial perspective effect

4.3.2 Workspace Settings

Along with the input parameters, the user should specify the workspace for the output files. By default, both *Current Workspace* for inputs and the *Scratch Workspace* for outputs are set to the default geotadabase automatically generated in the ArcGIS folder in the user profile. All the intermediate output data in the model are stored to the *Scratch Workspace* with the Python syntax %scratchworkspace% followed by the output name. To properly specify destination for the output data, the user should perform the following operations: right-click the model in the ArcToolbox, click *Edit*, inside the ModelBuilder click *Model - Model Properties - Environments* - flag *Workspace - Values - Workpace* - replace the current paths for **both** *Current Workspace* and *Scratch Workspace* with the path to the existing folder to store the output and press *Apply*.

4.3.3 Intermediate Data

Output data are produced after each process in the model. Some intermediate data are not of importance and can be deleted in the end automatically not to overload the output folder with data of no use and to speed up the process. For instance, clipped DEM, clipped shaded relief, clipped weights and corrections sum up to hundreds of MByte. To automatically delete them when the process is over, those output files are defined as *Intermediate*. The user can specify on his or her own which outputs to keep by right-clicking on the model and activating the editing mode, then right-clicking on any of the outputs in the model which are usually coloured green and leaving *Intermediate* unflagged. By default, all the outputs in the models of the toolbox are set to be intermediate. When starting the model not from ArcToolbox, but from the ModelBuilder itself (by right-clicking on the model and choosing *Edit*), all intermediate outputs are kept and can be deleted if desired by clicking *Model - Delete Intermediate Data* (ESRI, 2009). When running the model from ArcToolbox, the only output the user will find in the destination folder is the final output.

4.3.4 Workflow

The mechanism of the watershed approach is applied to the methods of Brassel and Jenny separately to see the differences in aerial perspective effect appearance. The whole models are given in the Appendix A.2. The execution time of the Watershed model iterating over the smallest amount of polygons (that is, 17) was approx. 2 min on an Intel(R) Xeon(R) CPU with 3.30GHz and 8.00 GB RAM with Windows 7 64-bit operating system.

The steps are described in more detail in the following subsections.

4.3.4.1 Iteration

The iteration over watershed polygons in the watershed shapefile is executed with the help of *Iterate Feature Selection* and *Get Field Value* tools to get OBJECTID field from a table and iterate over watersheds by OBJECTID. The mechanism is the same for the two models and is graphically represented in figure 4.4. The outputs of iteration tools, namely amount of watershed polygons and OBJECTID serve precondition for clipping, calculating weights and creating mosaic and determine the proper order of operations to be performed.

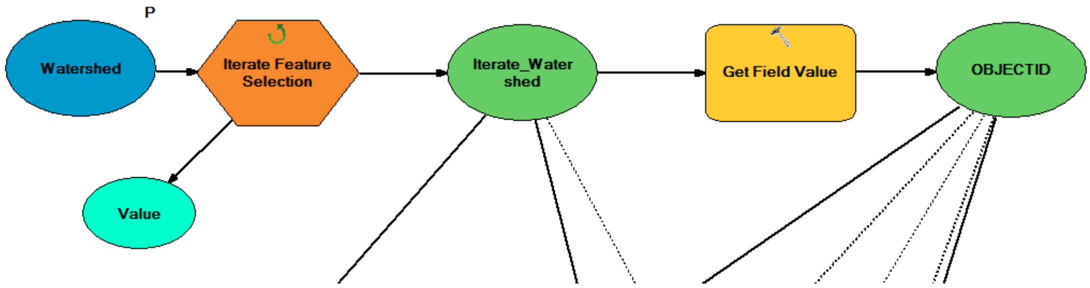

FIGURE 4.4: Iteration over watershed polygon

4.3.4.2 Generation of Shaded Relief

Before proceeding with clipping the rasters by watersheds so that to apply the corrections to the clipped raster files, both raster files (DEM and shaded relief) should be ready. The DEM is available as the input file. The shaded relief should first be generated (figure 4.5). Therefore shaded relief with standard azimuth and zenith values is computed using Hillshade function, as already described in Chapter 3.

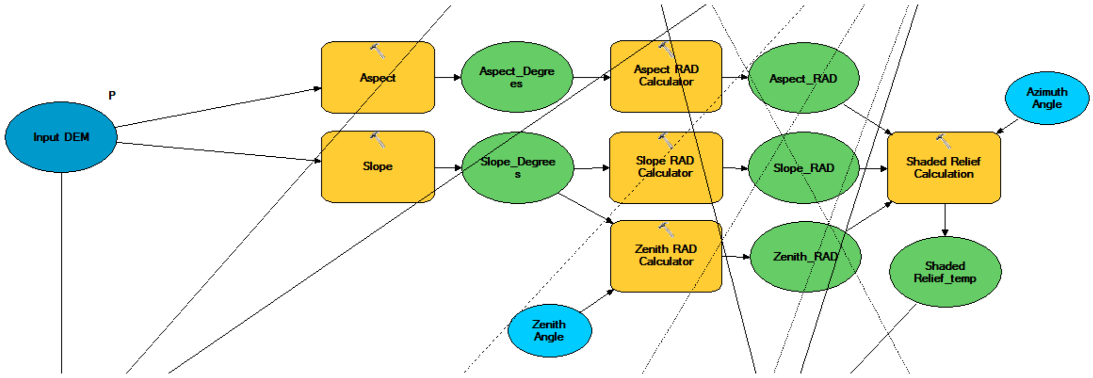

FIGURE 4.5: Calculation of shaded relief prior to clipping it by watershed polygons

4.3.4.3 Clipping DEM and Shaded Relief

To apply the weights within the watersheds, the entire raster images of the DEM and shaded relief should be clipped by polygons. This was done using *Clip* tool within *Data Management toolbox - Raster toolset - Raster Processing toolset*. The DEM and newly computed shaded relief should serve input raster, whereas iteration output data should be chosen as output extent. To create many raster files all with unique names, OBJECTID should be integrated into the output raster name and the extension should be specified in the following way, e.g. dem'%OBJECTID%'.tif.

4.3.4.4 Aerial Perspective Effect

At the next step, atmospheric corrections are calculated in the very same way it was done in the Chapter 3 with the only difference that this time when calculating weights, maximum and minimum tonal values of watersheds are taken into consideration, and not of the whole image (figure 4.6, figure 4.7).

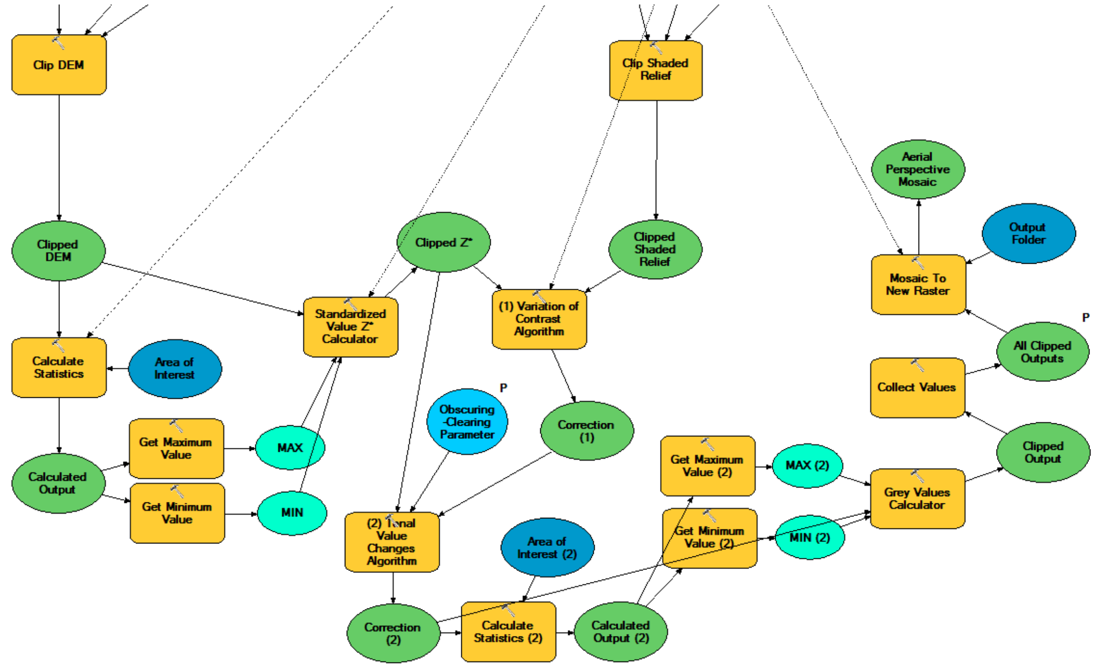

FIGURE 4.6: Applying atmospheric corrections described by Brassel to the watersheds

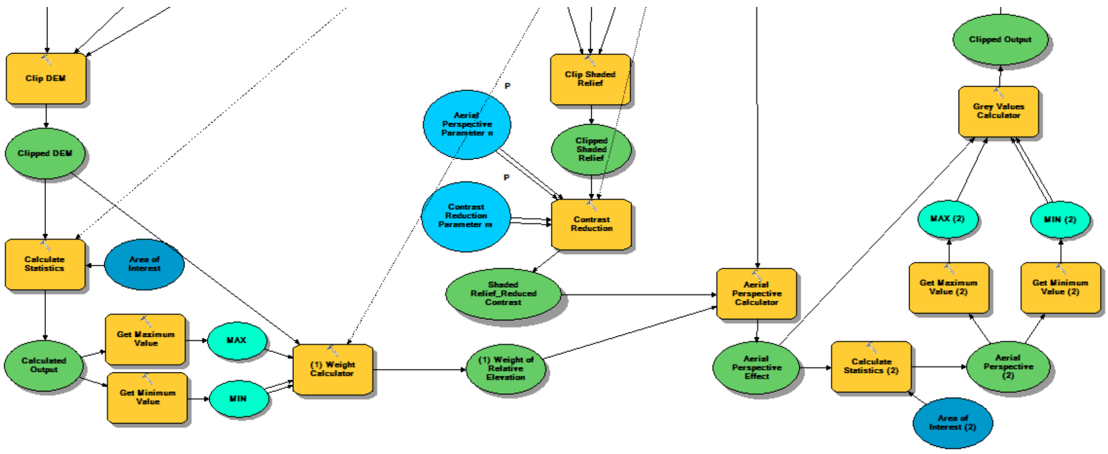

FIGURE 4.7: Applying atmospheric corrections described by Jenny to the watersheds

4.3.4.5 Creating Mosaic

The output data after applying aerial perspective effect and conversion into greyscale are clipped raster files, their number corresponds to the number of features in the watershed shapefile. In order to represent all of them as the one raster file, they should be collected into a mosaic. To gather all the outputs of the iterator to use them as input for mosaic tool, *Collect Values* tool is used. The collected values are specified as model parameter. *Mosaic To New Raster* tool combines multiple rasters into a new raster dataset (ESRI, 2009). The following parameters are set to create mosaic: Pixel Type 32 BIT UNSIGNED and number of bands 1 (as they appear to be the pixel type and number of bands of the outputs), BLEND as Mosaic Operator and default Mosaic Colormap Mode. Creation of mosaic is graphically represented by figure 4.6 on the right.

Chapter 5

Results

This chapter provides results acquired with the ArcGIS models designed within this Master thesis. The models were run for different scales of watersheds. In the end of this chapter, the final results are demonstrated followed by description of possible enhancements and concluded with discussion.

5.1 Intermediate Results

In this section results of different existing methods applied within this Master thesis are presented.

5.1.1 ArcGIS Hillshade Function

Figure 5.1 (left) illustrates how shaded relief looks when azimuth and zenith are restricted to fixed values. Atmospheric corrections for both global and local approaches in this work were applied to the shaded relief generated with Hillshade function.

5.1.2 The Swiss Hillshade Model

The filtered hillshade is intended to accentuate major terrain features. However, as the figure 5.1 (right) illustrates, a certain level of noise, namely traces of a transportation network, is still there in the valley. The bright peaks and dark valleys demonstrate the opposite effect of those meant by the Swiss style relief shading. The transitions between valleys and slopes are not smooth and foggy enough, which indicates that this method should be improved. The objective was to imitate the Swiss style relief shading, whereas

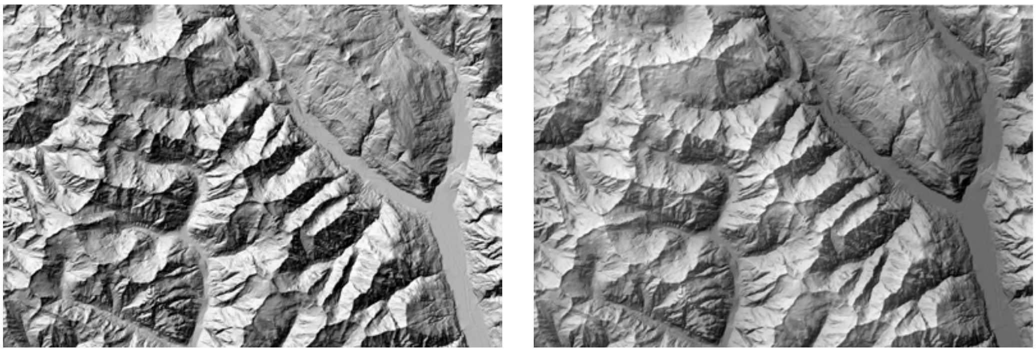

FIGURE 5.1: Shaded relief generated using hillshade function with 315° azimuth and 45° zenith (left). Shaded relief generated using the Swiss Hillshade model with 50% transparency of the hillshade image simulating aerial perspective effect (right)

this tool is not close in doing so. As a result, there was an attempt made to employ equations from two articles on the subject (Jenny, 2001b; Brassel, 1974) into ArcGIS, which prove to be capable of imitating the aerial perspective effect in a quantitative and consistent way.

5.1.3 Brassel's Method

Figure 5.2 (right) demonstrates the tonal changes when the first correction comes to the effect and is compared to the shaded relief produced with default settings.

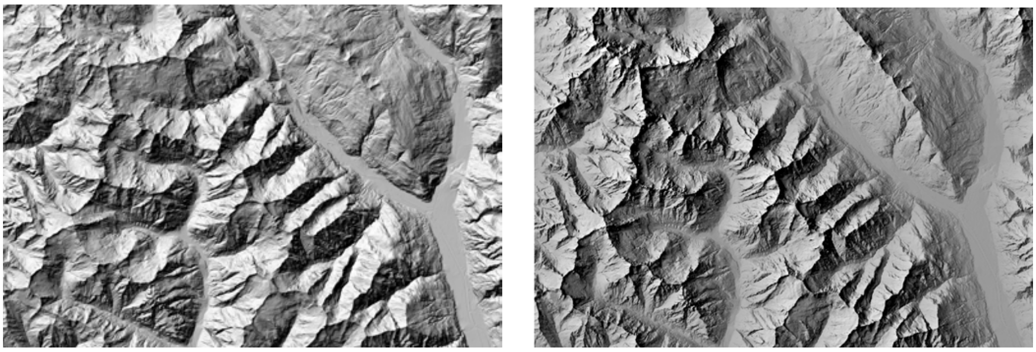

FIGURE 5.2: Shaded relief generated using default settings (left). Shaded relief after the first correction (Brassel, 1974) (right)

As mentioned before, the second correction is user-dependentdue to the presence of the parameter C_2. Figure 5.3 shows what the output shaded relief looks like when different values of the parameter C_2 are applied.

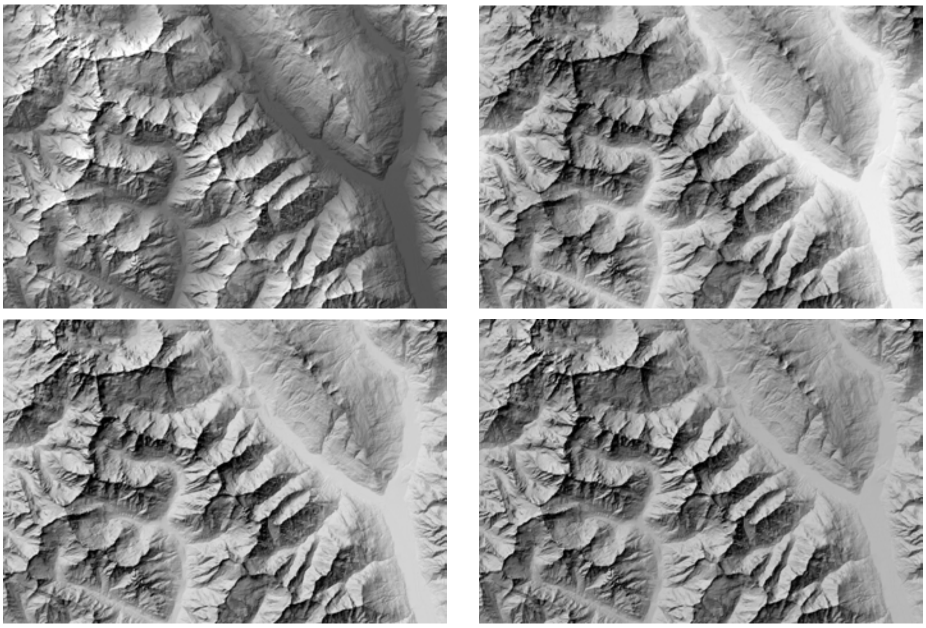

FIGURE 5.3: Aerial perspective effect by Brassel (1974), with user-definable parameter C_2 equal to 1 (maximum obscuring, top left), -1 (maximum clearing, top right), -0.5 (bottom left) and -0.3 (bottom right)

5.1.4 Jenny's Method

Using different combinations of user-definable parameters m (contrust reduction) and n (aerial perspective), the following results can be achieved (figure 5.4).

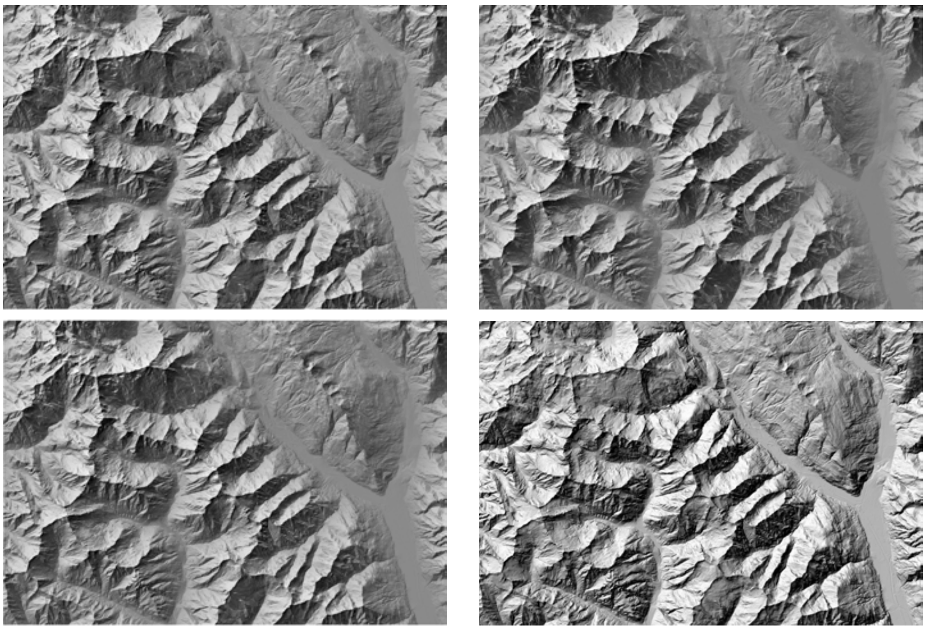

FIGURE 5.4: Aerial perspective effect by Jenny (2001b), using different combinations of user-definable parameters m and n (0.1, 0.1 - upper left, 0.9, 0.9 - upper right, 0.5,0.9 - lower left) compared to the shaded relief generated using default settings

5.1.5 Watershed Method

The watershed method brings different in quality results depending on the scale of the watersheds. The reason is that when the DEM is split by the smallest watersheds, the range of grey values within each watershed is not that big compared to the whole area of an image, but the values of the watersheds between one another may differ a lot. These tonal differences are shown in figure 5.5.

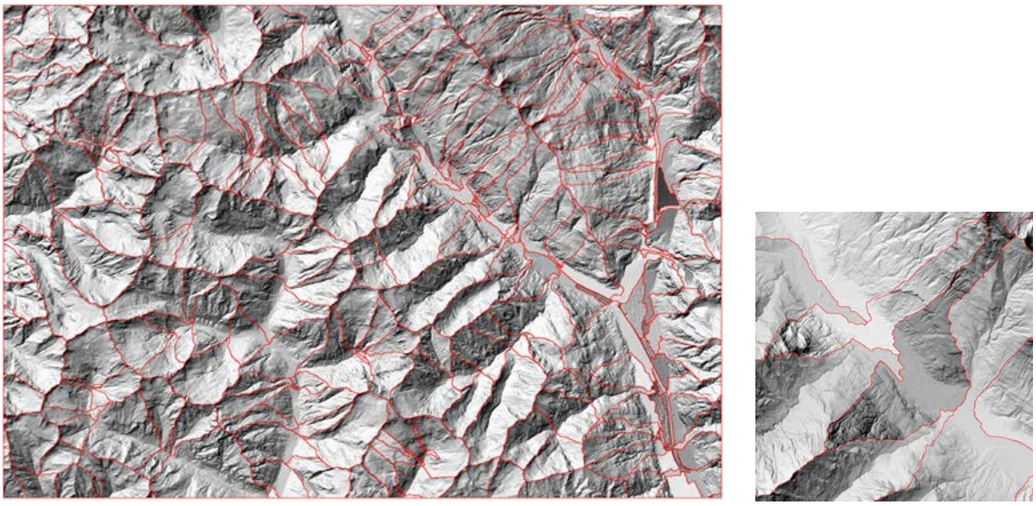

FIGURE 5.5: Clipped shaded relief with altitude weight (Brassel, 1974) applied within watersheds and overlayed with the boundaries of watersheds (left). Transitions between tonal values of adjacent watersheds caused by weights constrained to the watersheds (right)

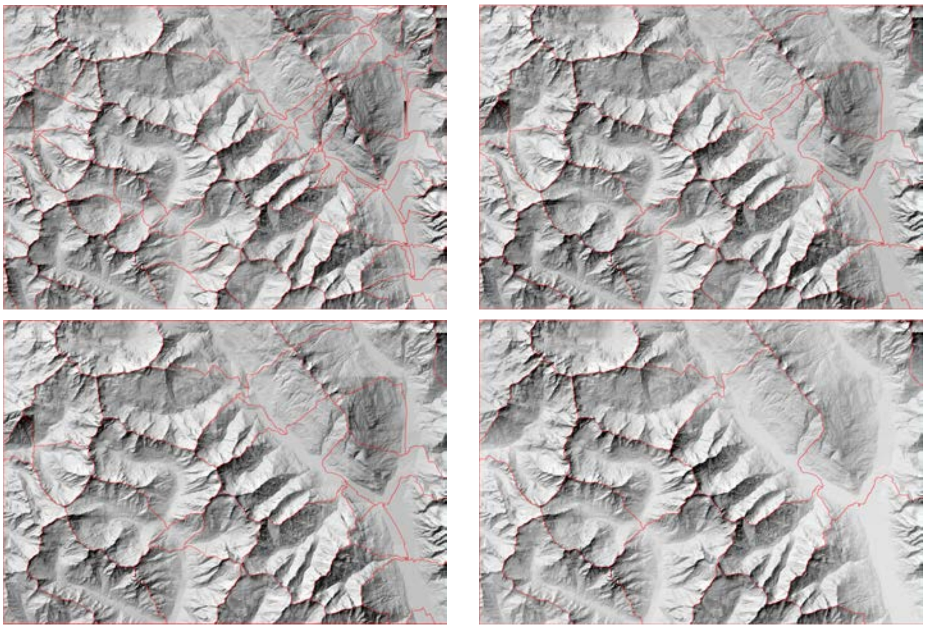

FIGURE 5.6: Aerial perspective effect by Brassel (1974), calculated for different scales of watersheds and collected into mosaics with BLEND operator

When collected into a mosaic, clipped parts of shaded relief have smoother transitions of tonal value. Nevertheless the smaller the watersheds are, the more observable boundaries of clip extents even in mosaic are, and none of mosaic operators can totally prevent images from having tonal transitions as in figure 5.6.

Another problem may cause when ArcHydro algorithm sometimes recognizes the men-made structures such as railways or highways (or their parts) as streams or channels. In case this happens, the solution could be to replace a fine resolution DEM by the one, which was downsampled to overcome some consequences of the algorithm.

5.2 Final Results

As illustrated in the previous section, not all the scales of watersheds deliver equally good results. Based on the results delivered, it can be concluded that the larger watersheds are, the better visualization of the aerial perspective effect constrained to those watersheds is. For this reason, here only results for the largest available watersheds are presented.

5.2.1 Results of the Watershed Method based on Jenny's equation

After the contrast reduction and applying two weights, the resulting shading looks as depicted in the figure 5.7.

The obscuring effect may be a consequence of either the contrast reduction or incomplete weights applied. As it was mentioned in Chapter 3, only two out of three weights introduced by Jenny could be applied using ArcGIS.

5.2.2 Results of the Watershed Method based on Brassel's equation

Similar effect of obscuring emerged when a positive value of the clearing-obscuring parameter in Brassel's equation was chosen (figure 5.8). But together with positive values, the clearing-obscuring parameter also accepts negative values in the range of [-1 .. 0] to brighten the image. The most suitable values proved to be in the range of [-0.3 .. -0.1].

The increased brightness of the Brassel's results (figure 5.9) may be caused either by the clearing parameter or by the altitude weight, which is in these models calculated in a way to shift the aerial perspective downward towards the valley, i.e., to diminish it (the denominator 2 in the equation 3.3 was replaced by 1.5).

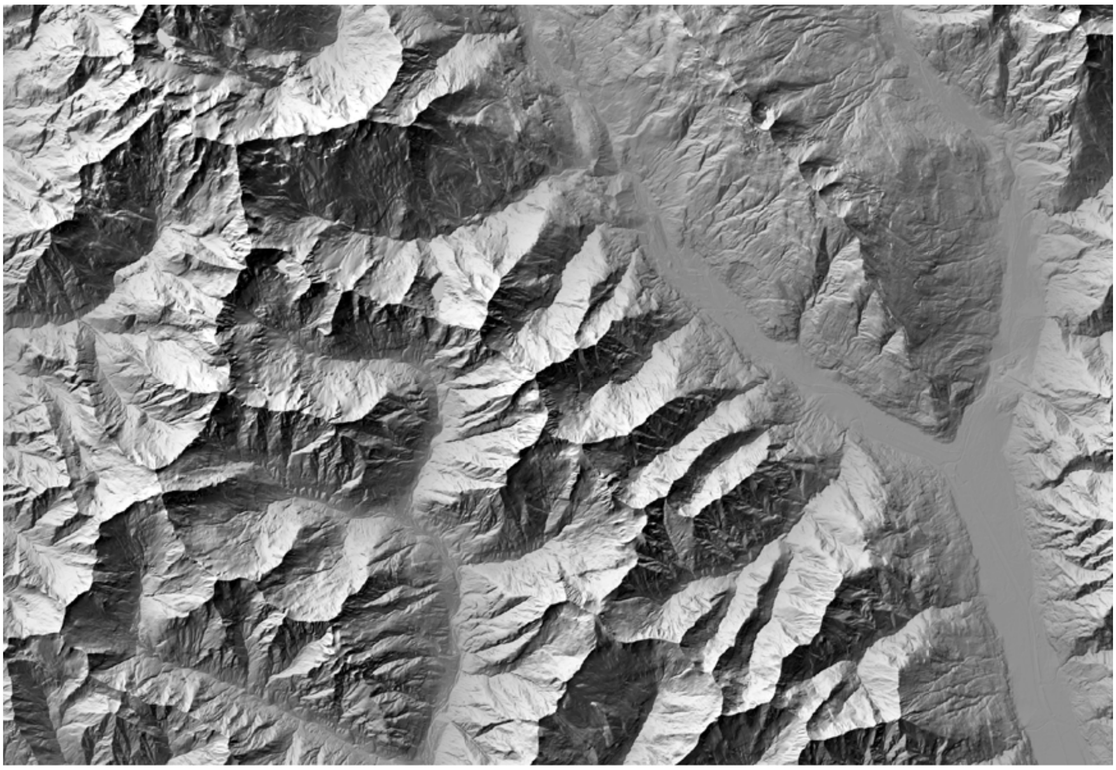

FIGURE 5.7: Constrained to the watersheds aerial perspective effect by Jenny (2001b) (contrast reduction parameter m = 0.5, aerial perspective parameter n = 0.5, Mosaic Operator BLEND)

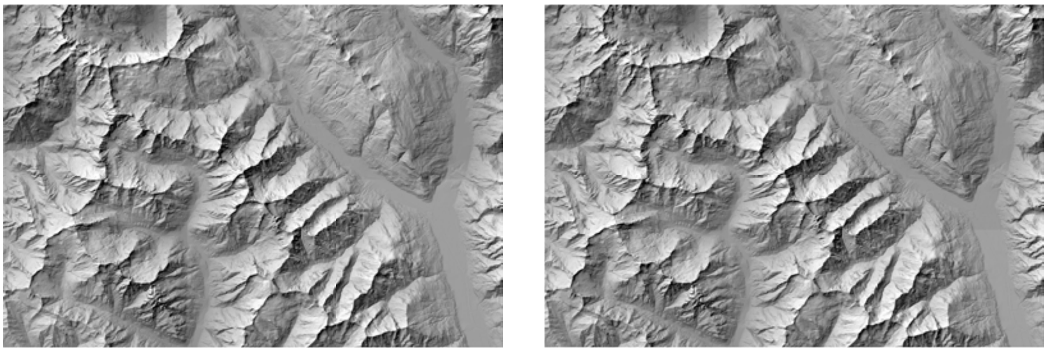

FIGURE 5.8: Constrained to the watersheds aerial perspective effect by Brassel (1974) (Obscuring parameter 0.3, Blend (left) and MEAN (right) Mosaic Operator

Below is a comparison between the default shaded relief (generated with the help of the Hillshade function with default parameters – constant NW illumination and inclination of 45°) and the same shaded relief but with aerial perspective effect generated based on Brassel's equations (figure 5.10).

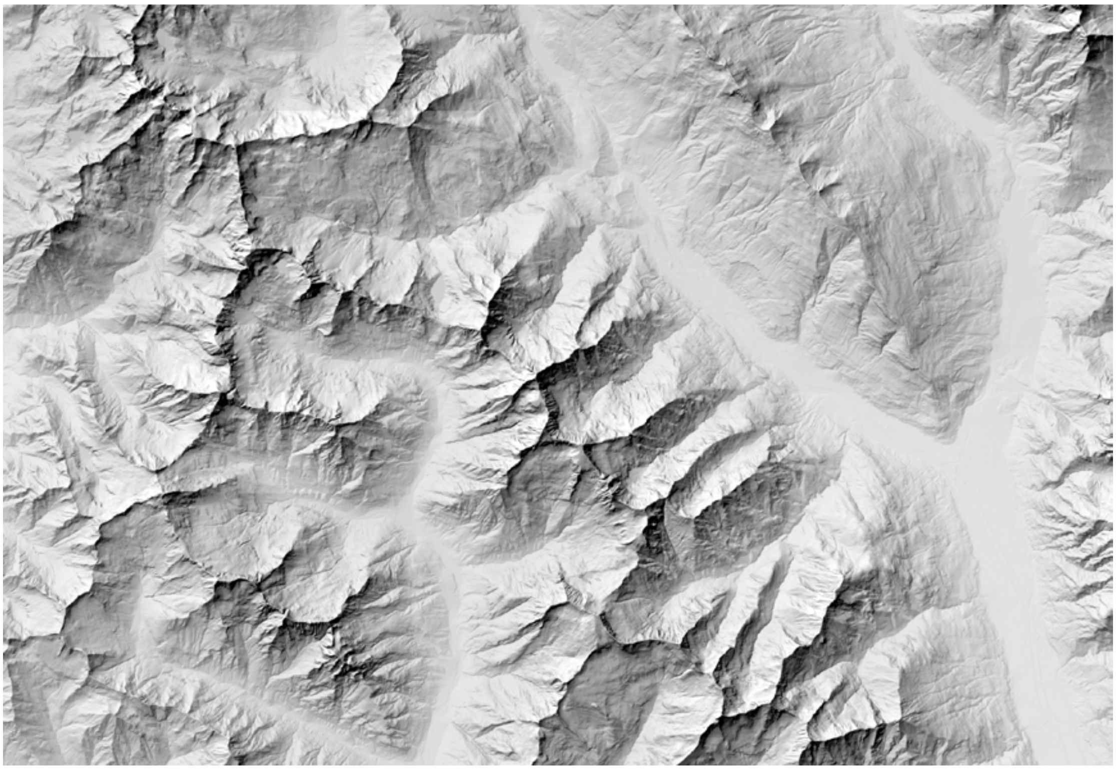

Figure 5.9: Constrained to the watersheds aerial perspective effect by Brassel (1974) (Clearing parameter -0.3, Mosaic Operator BLEND)

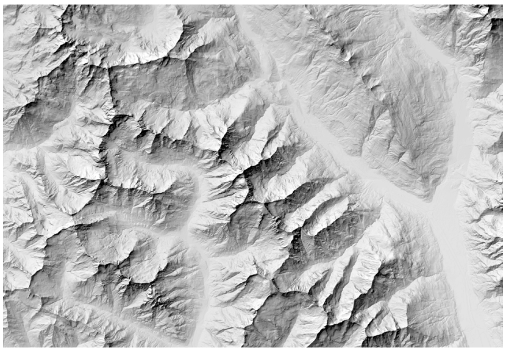

Figure 5.10: Default shaded relief (left) and the same shaded relief with aerial perspective effect by Brassel (1974)

5.3 Enhanced Results

As the aerial perspective effect is not the only component of relief shading, it is possible to enhance the appearance of the shaded relief by changing also the light direction within a watershed.

There is a framework in the process of development at the Institute of Cartography and Geoinformation (IKG). Its target is to design a tool to enhance the appearance of shaded relief by applying basic components of the Swiss style of relief shading. Therefore, one of them, that is light direction adjustment, was implemented as a model in ArcGIS by

Dr. Fabio Veronesi. Due to the known orientation of the streams within watersheds, it became possible to adjust the light direction within watersheds and to set an extra light source perpendicular to the standard light direction to accentuate the slopes which stretches from the Northwest to the Southeast (figure 5.11).

5.4 Discussion

Both the aerial perspective models by Brassel (1974) and Jenny (2001b) demonstrate the presence of haze over the lowlands and enhanced contrast over the peaks of the mountains. As a positive consequence of applying aerial perspective effect, noise is reduced leading to less visual distraction in the valleys. At the same time the ridges oriented parallel to the light direction are still depicted with similar grey tone and look indistinct, unless changes of light direction are applied (figure 5.11, down).

Taking into consideration the darkness of the output images of Jenny's model after reducing the contrast, Brassel's model looks more favorable, in author's opinion, as it offers brightening the image by using the negative parameter C_2.

It is important to consider that there are different scales of the watersheds and by choosing small watersheds as input, the user would be able to see men-made elements in the DEM. Line artefacts and mean grey values may also be caused by using a specific Mosaic operator.

To conclude, aerial perspective effect proved to work both globally and locally with certain limitations stated above. When combined with another methods, e.g., with the lighting model, the influence of the effect may be decreased.

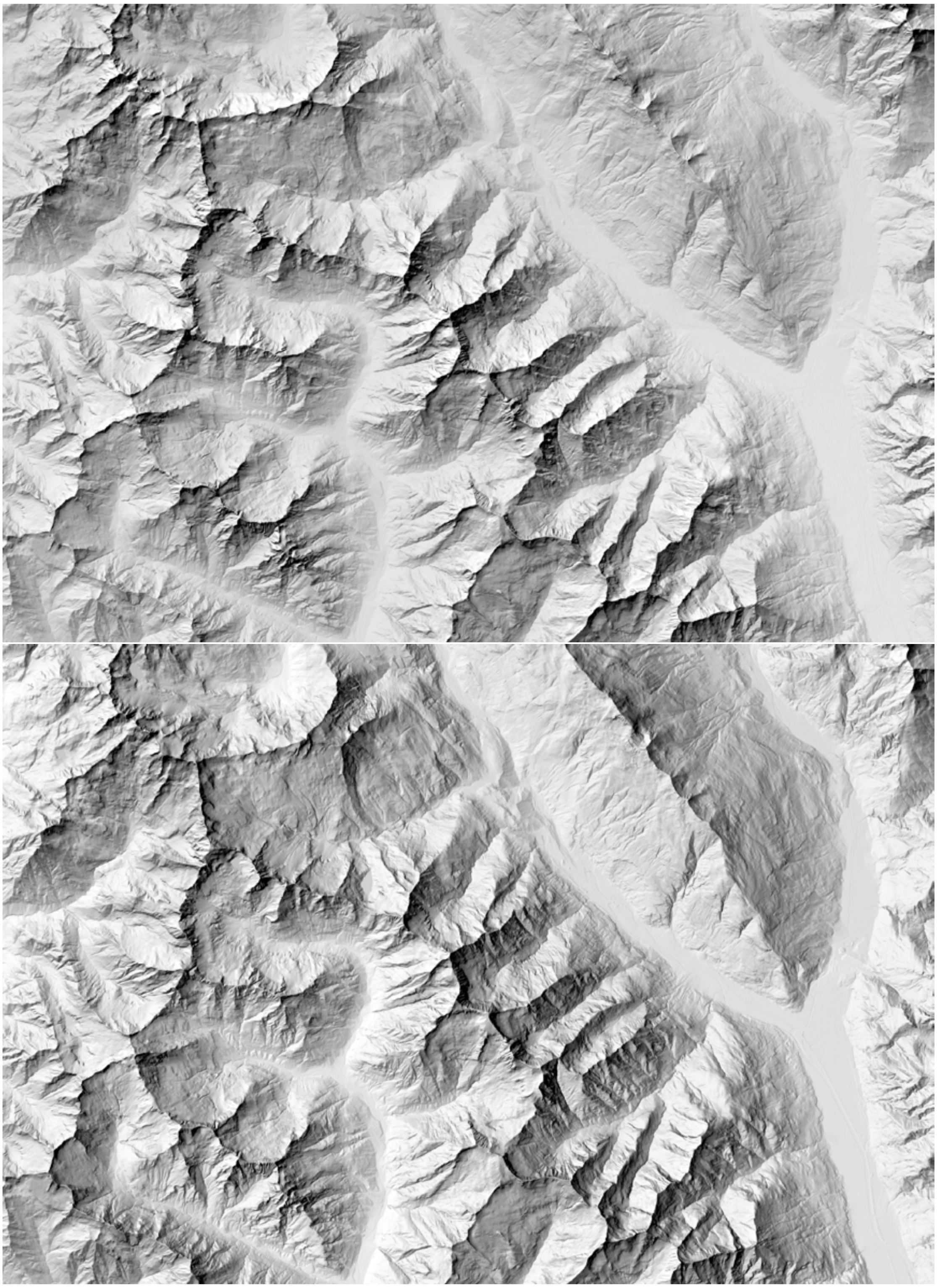

FIGURE 5.11: Shaded relief generated using the Hillshade function combined with aerial perspective effect (Brassel, 1974) calculated within watersheds (top). Shaded relief generated using the Hillshade function combined with aerial perspective effect (Brassel, 1974) calculated within watersheds, complemented with light changes within watersheds and the light sources originating from the Southwest (bottom)

Chapter 6

Conclusion and Outlook

6.1 Discussion

This Master thesis started with the idea to automatically adjust image sharpness in relief shading by applying an aerial perspective effect. The simulation of aerial perspective effect is one of the key components of the Swiss style relief shading. However, so far there was no tool available to perform it in GIS standard software, such as ArcGIS.

Based on two approaches by Brassel (1974) and Jenny (2001b), two models were created in ArcGIS ModelBuilder, each calculated in a different way, respectively.

In a second step, a novel approach based on considering watersheds when accentuating the contrast of the higher peaks and diminishing the contrast in the lower elevations was proposed, which uses the two basic methods by cutting the input DEM and the shaded relief by watershed boundaries and applying the aerial perspective locally within an area of a watershed.

The developed methods were tested on the following dataset: a 2m DEM in ASCII format downsampled to 10 m resolution in order to diminish the error above 2000 m and the hydrology network at the scale 1:200000 used to derive watershed boundaries from it. The test area was chosen to be topographically heterogeneous and to comprise features like the ridge oriented parallel to the standard NW-SE light direction, which is difficult to properly depict in relief shading using the standard light direction.

The results showed that both global and local watershed approaches deliver aerial perspective effect, enhancing the contrast of the higher peaks and placing a haze in the lower elevations. As for the scale of the watersheds, the bigger the size of a watershed, the better resulting image with aerial perspective effect looks.

Though methods proved to demonstrate aerial perspective effect, there are certain limitations and drawbacks. The watershed algorithm embedded in ArcHydro requires the user to choose thresholds in order to define the length of a stream and, in turn, to determine the scale of the output watersheds. The scale term in this case refers to the size or dimension of the watersheds. It is not completely clear how to choose the minimum threshold for a stream. The algorithm produces watersheds of arguable shape, when an area lies in a valley or crosses it. Due to the disputable boundaries formation, the applied weights for the altitude and contrast changes cause transitions in tonal values of neighboring watersheds and, as a consequence, irregular grey values in plain parts, specifically in valleys.

As mentioned before, the work is resulted with the two models described in sections 3.3.1 and 3.4.1. Their key advantage is that implementation of aerial perspective equations was not done in the ArcGIS models before, and from now on the models are available for users. The equations to calculate aerial perspective effect were written using Python syntax, which means that models can be intuitively understood by the user and can be converted to the other programming language or used in another software. This work is an attempt to bring the manual technique into automatic, to accentuate major landforms just as it is normally done in manual relief shading, but in a quantitative way, reproducible in GIS.

6.2 Outlook

While this thesis has taken further steps towards a full automation of relief shading, specifically applying the aerial perspective effect in an automated way, results are not yet of as high quality as the "gold-standard" of manually shaded reliefs.

Attempts to treat each form of relief separately as it is done manually generally fails in analytical relief shading. Computers can deal with a bunch of complex computations, yet they can hardly imitate hand-shaded relief due to subjectivity and certain degree of randomness of contrast distribution and local light adaptations in manual relief shading.

The results achieved in this work are a step forward. It is hardly possible to completely solve the problem in four months, as many people have been working on it for decades. But this is an attempt to implement one of the key components of the manual relief shading in an automated way. Together with changes of the light direction constrained to watersheds developed within a framework at IKG group, these components are the basic components implemented in ArcGIS to automatically simulate relief shading.

One obvious next step would be to further explore the influence of the used watershed polygons on the result. For instance, one could allow for a manual adjustment of the polygons, i.e., for merging or dividing them in a sensible way. While this would require more manual intervention than the approach suggested here, the result can be expected to be of higher quality.

The other solution could be to include terrain segmentation methods to derive valleys, as they contain most of the artefacts caused by the algorithm. It is rather a complex task, however, because while for a human it may be easy to visually extract boundaries between the valley and the slope, it is probably much more difficult for an algorithm.

Finally, a semi-automated approach appears to be right now the best solution. To reach a compromise, there is still manual intervention needed from the cartographer.

Bibliography

ArcGIS Resources (2008a). Aspect-slope map. `http://blogs.esri.com/esri/arcgis/2008/05/23/aspect-slope-map/` (last accessed: 7 April 2014).

ArcGIS Resources (2008b). ESRI Mapping Center. `http://mappingcenter.esri.com/index.cfm?fa=arcgisResources.modelsScripts` (last accessed: 25 June 2014).

ArcGIS Resources (2008c). Updated hillshade toolbox. `http://blogs.esri.com/esri/arcgis/2008/10/07/updated-hillshade-toolbox/` (last accessed: 25 June 2014).

ArcGIS Resources (2011). Surface Water. `http://resources.arcgis.com/en/communities/hydro/01vn00000010000000.htm` (last accessed: 30 June 2014).

Association of American Geographers (2014). AAG Annual Meeting. `http://meridian.aag.org/callforpapers/program/AbstractDetail.cfm?AbstractID=55848` (last accessed: 10 April 2014).

Batson, R. M., Edwards, K., and Eliason, E. M. (1975). Computer-generated shaded-relief images. *Journal of Research of the US Geological Survey*, 3(4):401–408.

Brassel, K. (1973). *Modelle und Versuche zur automatischen Schräglichtschattierung (Ein Beitrag zur Computer-Kartographie)*. PhD thesis, Universität Zürich. 111 pages.

Brassel, K. (1974). A model for automatic hill-shading. *The American Cartographer*, 1(1):15–27.

Brassel, K. E. and Weibel, R. (1988). A review and conceptual framework of automated map generalization. *International Journal of Geographical Information System*, 2(3):229–244.

Donigian Jr, A. S. and Imhoff, J. (2006). History and evolution of watershed modeling derived from the stanford watershed model. *Watershed models*, pages 21–45.

ESRI (2009). ArcGIS Desktop Help 9.3. `http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?TopicName=welcome` (last accessed: 28 June 2014).

ESRI (2011). ArcHydro Tools - Tutorial, Version 2.0. `http://resources.arcgis.com/en/communities/hydro/01vn00000010000000.htm` (last accessed: 30 June 2014).

ETH Zurich (2009). ETH Geodata Portal. `https://geodata.ethz.ch/geovite/geovite_index.jsp` (last accessed: 30 June 2014).

Federal Office of Topography swisstopo (2014). Federal administration admin.ch. `http://www.swisstopo.admin.ch` (last accessed: 22 June 2014).

Florinsky, I. V. (2012). *Digital terrain analysis in soil science and geology.* Academic Press.

Gallant, J. C. and Wilson, J. P. (1996). TAPES-G: a grid-based terrain analysis program for the environmental sciences. *Computers & Geosciences*, 22(7):713–722.

Gouraud, H. (1971). Continuous shading of curved surfaces. *Computers, IEEE Transactions on*, 100(6):623–629.

Guilbert, E., Gaffuri, J., and Jenny, B. (2014). Terrain generalisation. In *Abstracting Geographic Information in a Data Rich World*, pages 227–258. Springer.

Hobbs, K. F. (1995). The rendering of relief images from digital contour data. *The Cartographic Journal*, 32(2):111–116.

Hobbs, K. F. (1999). An investigation of RGB multi-band shading for relief visualisation. *International Journal of Applied Earth Observation and Geoinformation*, 1(3):181–186.

Horn, B. K. P. (1981). Hill shading and the reflectance map. *Proceedings of the IEEE*, 69(1):14–47.

Horn, B. K. P. and Sjoberg, R. W. (1979). Calculating the reflectance map. *Applied Optics*, 18(11):1770–1779.

Hurni, L. (2008). Cartographic mountain relief presentation: 150 years of tradition and progress at ETH Zurich. In *Proceedings of the 6th ICA Mountain Cartography Workshop, Mountain Mapping and Visualisation*, pages 85–91.

Hurni, L., Jenny, B., Dahinden, T., and Hutzler, E. (2001). Interactive analytical shading and cliff drawing: Advances in digital relief presentation for topographic mountain maps. In *Proceedings of the 20th International Cartographic Conference*, volume 5, pages 3384–3391.

Imhof, E. (1982). *Cartographic relief presentation.* New York and Berlin: Walter de Gruyter.

Jenness, J. (2013). *DEM Surface Tools for ArcGIS Manual*. Jenness Enterprises. Available at `http://www.jennessent.com/arcgis/surface_area.htm/` (last accessed: 7 April 2014).

Jenny, B. (2000). Computergestützte Schattierung in der Kartografie. Diploma thesis, ETH Zürich.

Jenny, B. (2001a). Computergestützte Schattierung. *Kartographische Bausteine*, 18:61–69.

Jenny, B. (2001b). An interactive approach to analytical relief shading. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 38(1):67–75.

Jenny, B. (2009). Software for terrain mapping. `http://terraincartography.com/` (last accessed: 7 April 2014).

Jenny, B. (2014). Private communication.

Jenny, B., Gilgen, J., Geisthövel, R., Marston, B. E., and Hurni, L. (2014). Design principles for swiss-style rock drawing. *The Cartographic Journal*. in print.

Jenny, B. and Hurni, L. (2006). Swiss-style colour relief shading modulated by elevationand by exposure to illumination. *Cartographic Journal, The*, 43(3):198–207.

Jenny, B. and Räber, S. (2002). Relief shading. Institute of Cartography, ETH Zürich, `http://www.reliefshading.com/` (last accessed: 30 June 2014).

Jones, K. H. (1998). A comparison of algorithms used to compute hill slope as a property of the DEM. *Computers & Geosciences*, 24(4):315–323.

Katzil, Y. and Doytsher, Y. (2003). A logarithmic and sub-pixel approach to shaded relief representation. *Computers & Geosciences*, 29(9):1137–1142.

Kennelly, P. J. (2008). Terrain maps displaying hill-shading with curvature. *Geomorphology*, 102(3):567–577.

Kennelly, P. J. (2009). Hill-shading techniques to enhance terrain maps. In *Proceedings of the 24th International Cartographic Conference*, pages 15–21.

Kennelly, P. J. and Kimerling, A. J. (2001). Modifications of Tanaka's illuminated contour method. *Cartography and Geographic Information Science*, 28(2):111–123.

Kennelly, P. J. and Kimerling, A. J. (2004). Hillshading of terrain using layer tints with aspect-variant luminosity. *Cartography and Geographic Information Science*, 31(2):67–77.

Kimerling, A. J. and Moellering, H. (1989). The development of digital slope-aspect displays. In *Auto Carto 9: Ninth International Symposium on Computer-Assisted Cartography*, pages 241–244.

Leonowicz, A., Jenny, B., and Hurni, L. (2010a). Automated reduction of visual complexity in small-scale relief shading. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 45(1):64–74.

Leonowicz, A., Jenny, B., and Hurni, L. (2010b). Terrain sculptor: Generalizing terrain models for relief shading. *Cartographic Perspectives*, 67:51–60.

Leonowicz, A. M. and Jenny, B. (2010). Automated small-scale relief shading: a new method and software application. *Geographia Technica*, Special Issue:90–95.

Loisios, D., Tzelepis, N., and Nakos, B. (2007). A methodology for creating analytical hill-shading by combining different lighting directions. In *Proceedings of the 23rd International Cartographic Conference*.

Lukas, K. and Weibel, R. (1995). Assessment and improvement of methods for analytical hillshading. In *Proceedings of the 17th International Cartographic Conference*.

Maidment, D. R. (2002). *Arc Hydro GIS for Water Resources*. ESRI Press.

Mark, R. K. (1992). A multidirectional, oblique-weighted, shaded-relief image of the island of hawaii. U.S. Geological Survey Open-File Report 92-422, US Department of the Interior.

Marsik, Z. (1971). Automatic relief shading. *Photogrammetria*, 27(2):57–70.

Moellering, H. (2012). Perspectives on 3-D visualization of spatial geodata and future prospects. In *True-3D in Cartography*, pages 1–19. Springer.

Moellering, H. and Kimerling, A. J. (1990). A new digital slope-aspect display process. *Cartography and Geographic Information Systems*, 17(2):151–159.

Orzan, A., Bousseau, A., Barla, P., Winnemöller, H., Thollot, J., and Salesin, D. (2013). Diffusion curves: a vector representation for smooth-shaded images. *Communications of the ACM*, 56(7):101–108.

Patterson, T. (2014). Shaded relief: Ideas and techniques about relief presentation on maps. `http://www.shadedrelief.com/` (last accessed: 7 April 2014).

Patterson, T. and Jenny, B. (2010). Shaded relief archive. `http://shadedreliefarchive.com/` (last accessed: 7 April 2014).

Podobnikar, T. (2012). Multidirectional visibility index for analytical shading enhancement. *The Cartographic Journal*, 49(3):195–207.

Poiker, F. T. and Poiker, T. K. (1997). Simulating and displaying surface networks. *ACSM Technical Papers*, 5:387–396.

Robinson, A. H. and Thrower, N. J. W. (1957). A new method of terrain representation. *Geographical Review*, pages 507–520.

Tanaka, K. (1950). The relief contour method of representing topography on maps. *Geographical Review*, pages 444–456.

Tutić, D., Lapaine, M., and Poslončec-Petrić, V. (2007). Some experiences in analytical relief shading. In Petrovič, D., editor, *Proceedings of 5th Mountain Cartography Workshop, International Cartographic Association, Commision on Mountain Cartography, Ljubljana*, pages 249–258.

Ware, C. (1989). Fast hill shading with cast shadows. *Computers & Geosciences*, 15(8):1327–1334.

Weibel, R. (1989). *Konzepte und Experimente zur Automatisierung der Reliefgeneralisierung*. PhD thesis, Geographisches Institut der Universität Zürich. 218 pages.

Weibel, R. (1992). Models and experiments for adaptive computer-assisted terrain generalization. *Cartography and Geographic Information Systems*, 19(3):133–153.

Wiechel, H. (1878). Theorie und Darstellung der Beleuchtung von nicht gesetzmässig gebildeten Flächen mit Rücksicht auf die Bergzeichnung. *Civilingenieur*, 24:335–364.

Yoëli, P. (1959). Relief shading. *Surveying and Mapping*, 19(2):229–232.

Yoëli, P. (1965). Analytical hill shading. *Surveying and Mapping*, 25(4):573–579.

Yoëli, P. (1966). Analytical hill shading and density. *Surveying and Mapping*, 26(2):253–259.

Yoëli, P. (1967a). Die Richtung des Lichtes bei analytischer Schattierung. *Kartographische Nachrichten*, 2:37–44.

Yoëli, P. (1967b). The mechanisation of analytical hill shading. *The Cartographic Journal*, 4(2):82–88.

Zakšek, K., Oštir, K., and Kokalj, Ž. (2011). Sky-view factor as a relief visualization technique. *Remote Sensing*, 3(2).

Zhou, Q. (1992). Relief shading using digital elevation models. *Computers & Geosciences*, 18(8):1035–1045.

Zhou, X. and Dorrer, E. (1995). An adaptive algorithm of shaded-relief images from DEMs based on wavelet transform. In *Digital photogrammetry and remote sensing'95, SPIE Proceedings Series, volume 2646*, pages 212–224.

Appendices

A.1 Manual Shaded Reliefs

On the following pages of this appendix shaded reliefs of the test area performed manually at different scales by specialists from Swisstopo (Federal Office of Topography swisstopo, 2014) are presented. They were accessed through the GeoVITe portal (ETH Zurich, 2009) and serve as patterns to compare automatically created shaded reliefs to.

Figure 1: Manual shaded relief 1:25000

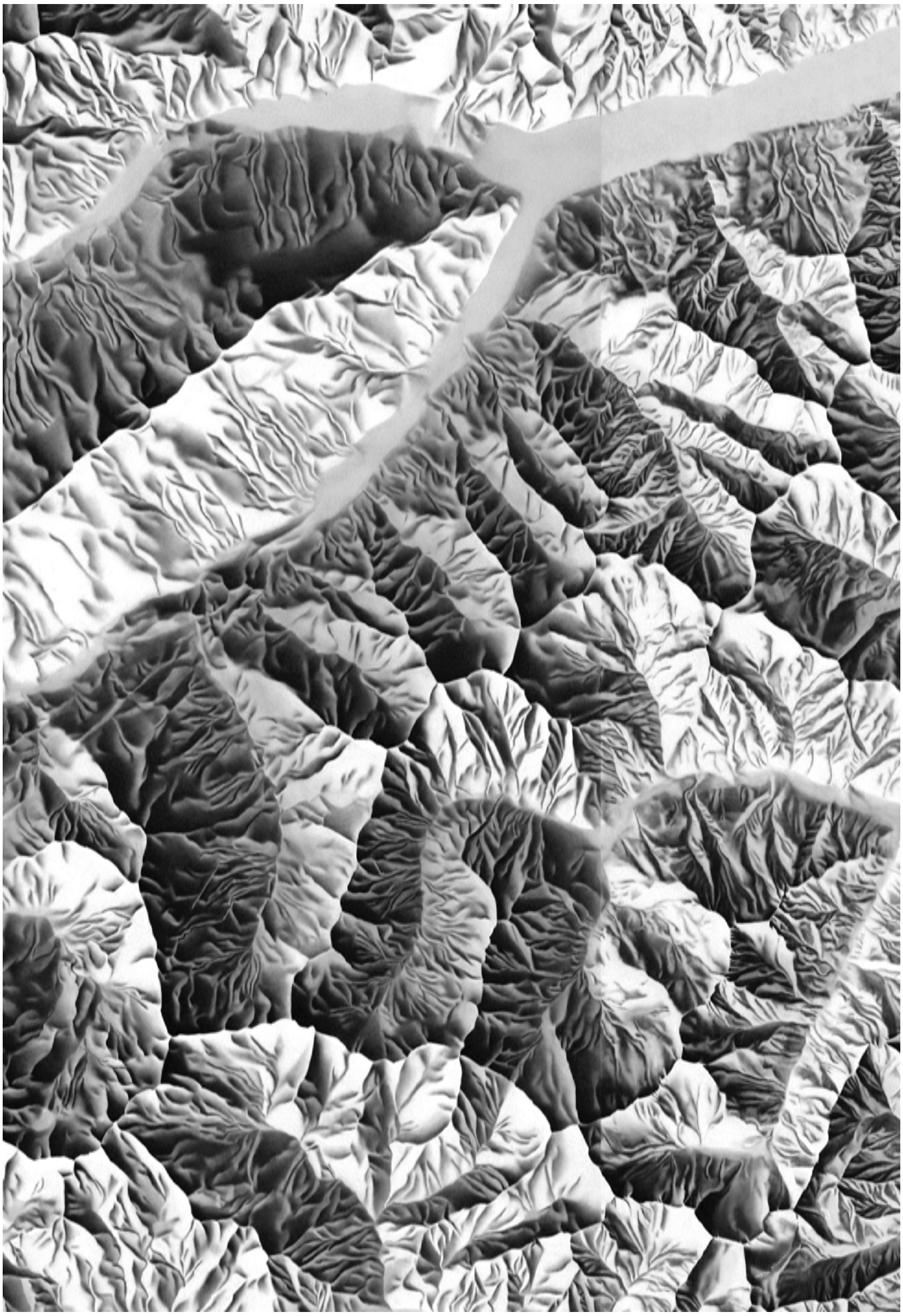

Figure 2: Manual shaded relief 1:50000

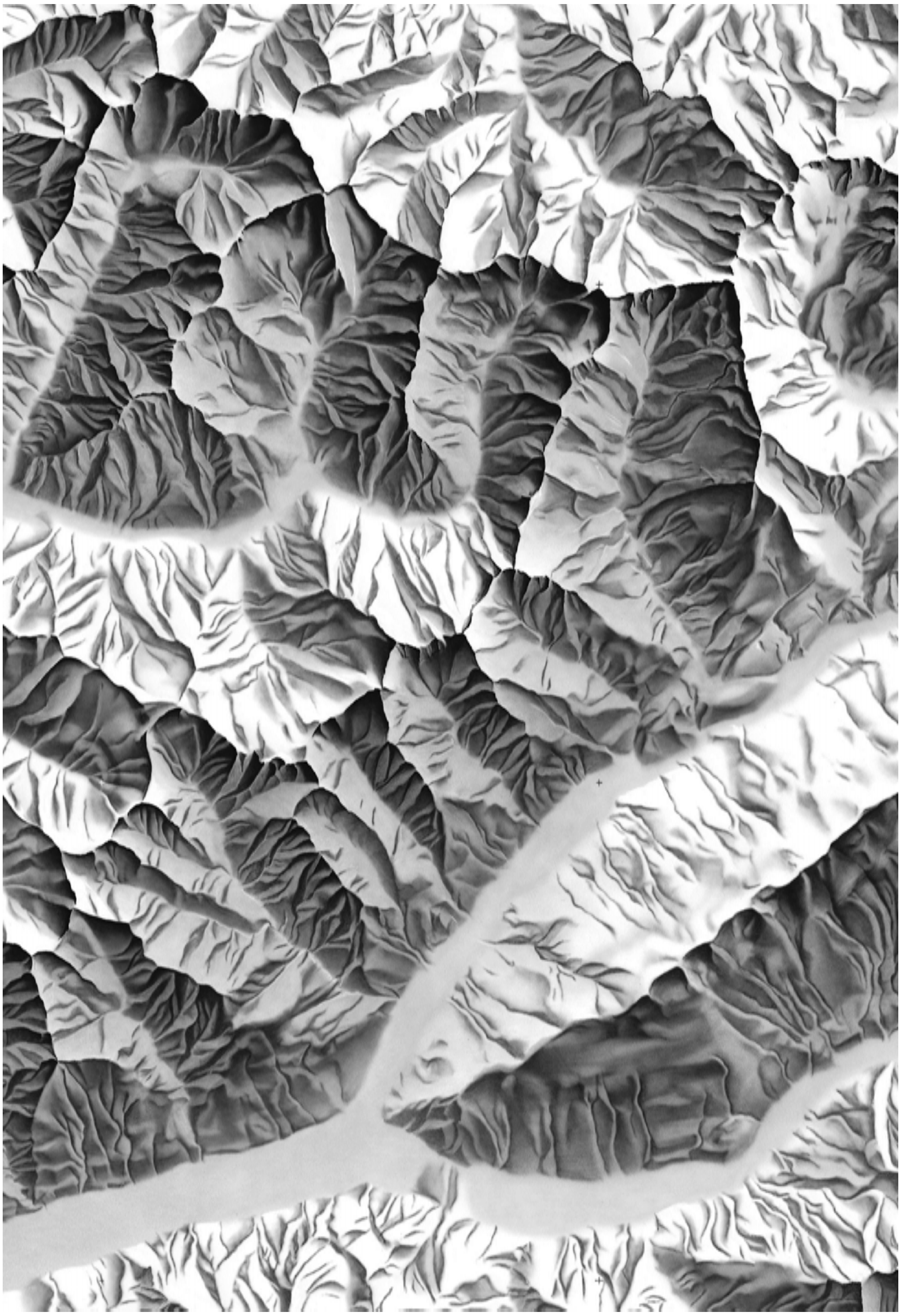

FIGURE 3: Manual shaded relief 1:100000

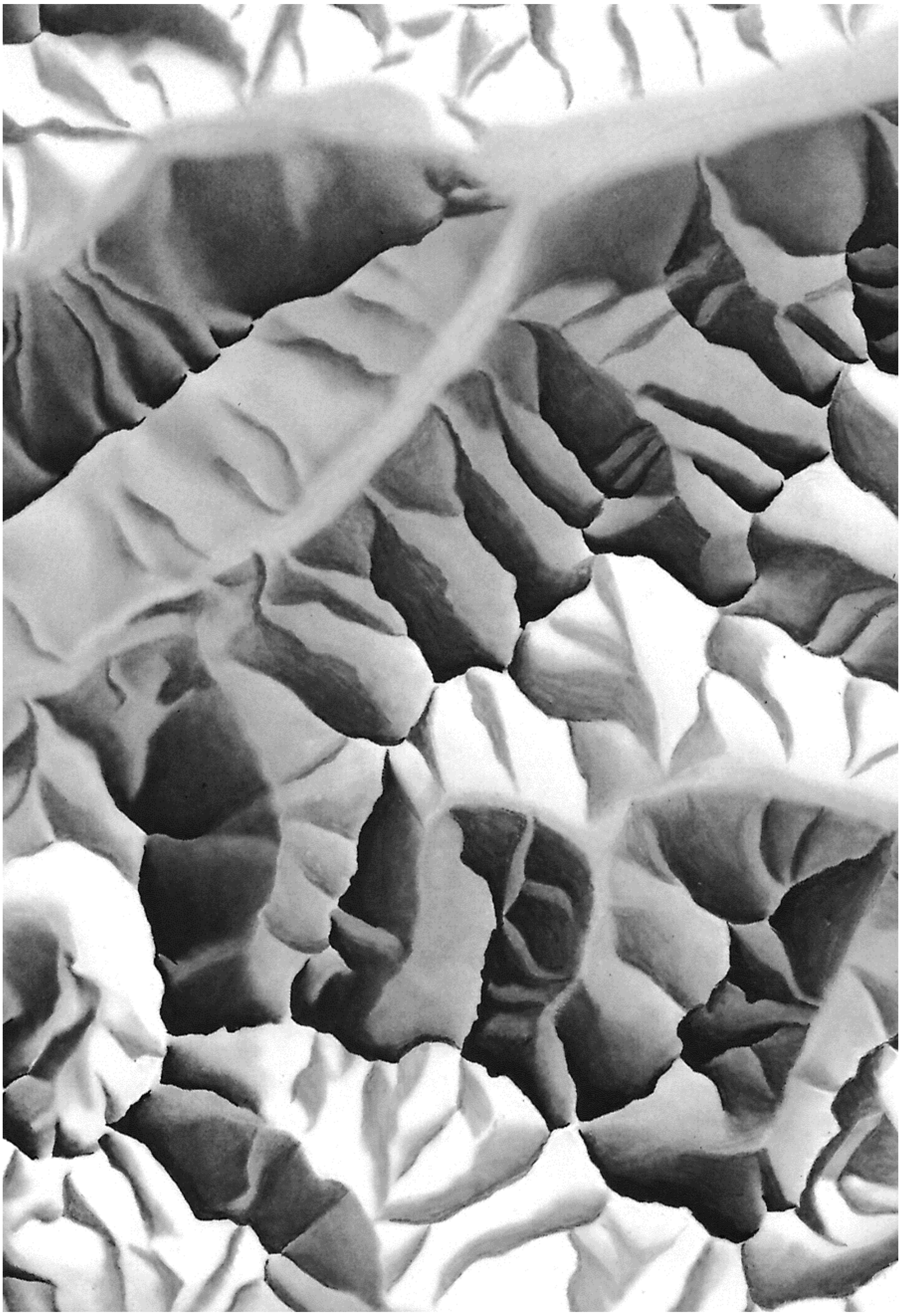

FIGURE 4: Manual shaded relief 1:200000

A.2 Watershed Models

This appendix contains watershed models developed in ArcGIS.

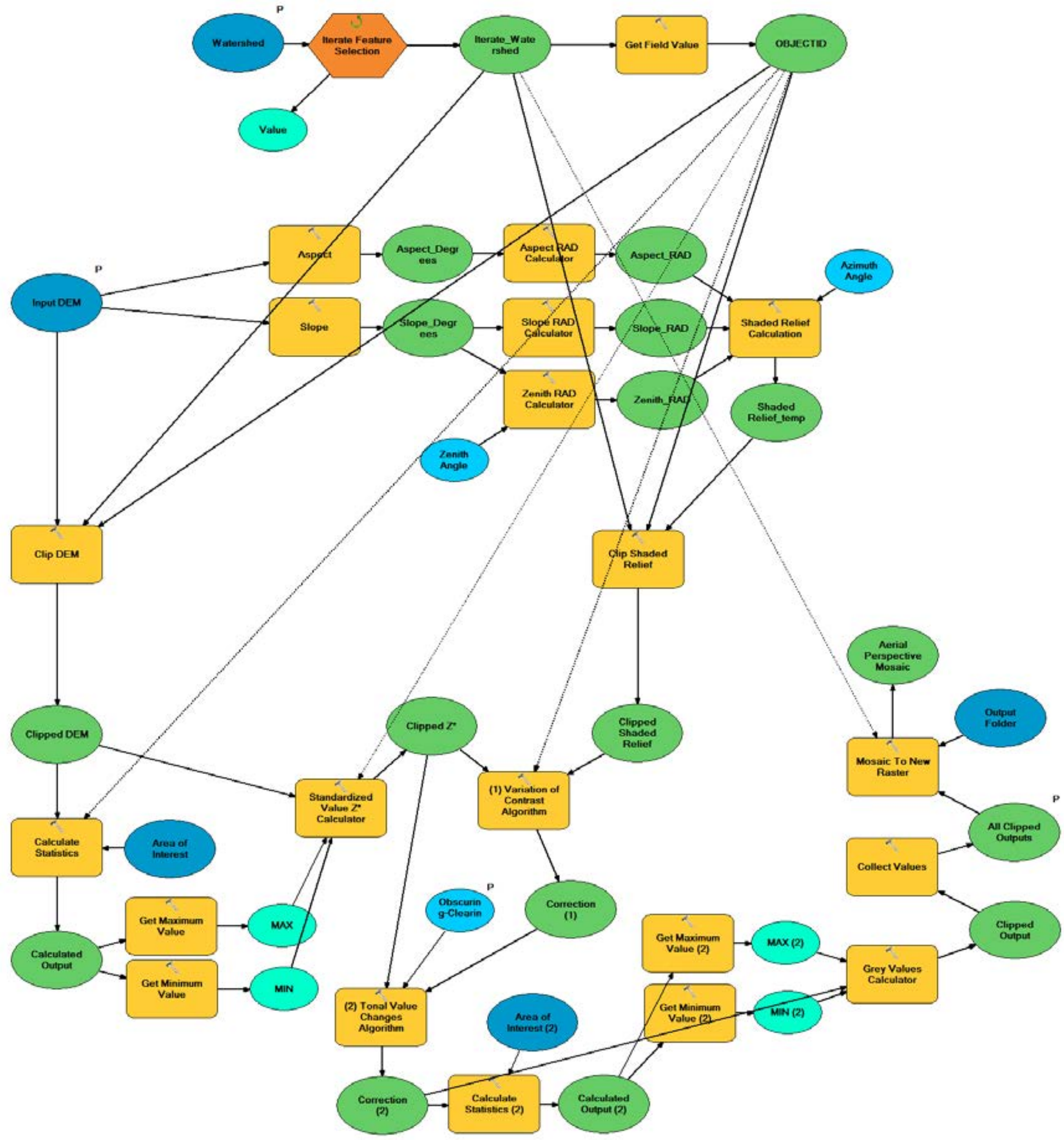

FIGURE 5: Watershed model based on Brassel's method

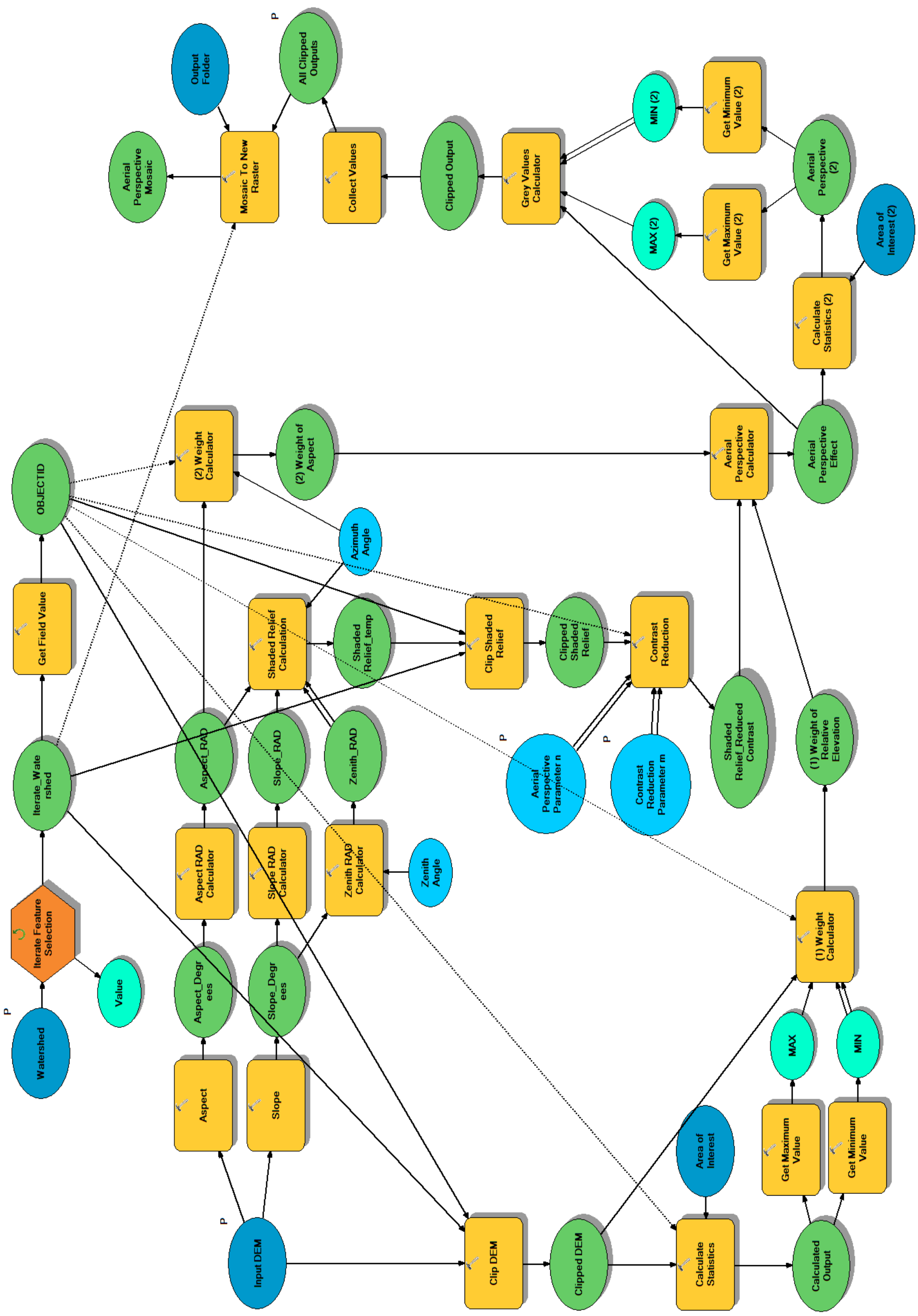

Figure 6: Watershed model based on Jenny's method

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