CHAPTER 10

Using Digital Elevation Models

Digital Elevation Models (DEM's) are digital representations of altitude. This can be the altitude of the terrain surface (also called *Digital Terrain Model*), or the altitude of soil-layers, contact of soil-rock, water table etc.

Digital Elevation Models are made via the following techniques:

– Photogrammetrical techniques. These methods use stereoscopic aerial photographs or satellite images to sample a large number of points, with X, Y and Z values, by means of advanced photogrammetrical equipment. After that, the points are interpolated into a regular grid (raster). The method is rather time consuming (each sampling point has to be measured by an expert through the lowering of a floating mark on the stereo model) and requires photogrammetrical experts, and a set of very detailed control points. Furthermore, the hardware and software for generation DEMs is still rather expensive, although lately software packages that run on a PC have become available.

– Point interpolation techniques. When point data is available for an area, obtained via ground surveys using theodolites and/or Global Positioning Systems (GPS), point interpolation can be used to generate a DEM. For complex terrain, the interpolation techniques are also rather complex, taking into account breaklines of slope. Point interpolation techniques will be treated in the next chapter.

– Interpolation of contour lines. When neither existing DEMs derived from photogrammetric techniques nor detailed point data is available, the contour information on existing topographic maps is the only source from which you can generate a DEM. In that case the contour lines are digitized and interpolated. The interpolation of contour lines is a standard procedure in ILWIS to generate a DEM. This is what we will discuss in the next section.

Digital Elevation Models can either be stored in vector or in raster format. DEMs in vector format are often in the form of *Triangulated Irregular Networks* (TIN), which can be seen as a series of polygons in the form of a triangle, in between three points. Each triangle has a uniform slope steepness and slope direction. When the terrain is more complex, the number of triangles needed to represent the terrain increases.

In ILWIS, the TIN structure is not used. DEMs are always in the form of raster maps, with a value domain. Each pixel in the raster map contains the altitude of the center of the pixel. Increasing the pixel size will therefore result in more general

DEMs. The accuracy of a DEM depends very much on the detail of the contour lines, that were used for the interpolation, and the scale of the original topographic map from which the contour lines were digitized. The larger the scale of the map, and the smaller the contour interval, the more accurate the DEM will be.

Digital Elevation Models have a very wide application. They form one of the input maps in many GIS projects. They are also the basis for a large number of derivative information. The most important applications of DEMs are:

– Slope steepness maps, showing the steepness of the slope in degrees, percentages, or radians for each pixel.
– Slope direction maps (also called slope aspect maps), showing the compass direction of the slope (between 0 - 360 degrees).
– Slope convexity maps, showing the change of slope angles within a short distance. From these maps you can see if the slope is straight, concave or convex in form.
– Hill shading map (or shadow maps), showing the terrain under an artificial illumination, with bright sides and shadows.
– Three dimensional views showing a bird’s eye view of the terrain from a user defined position above the terrain.
– Cross-sections indicating the altitude of the terrain along a digitized line.
– Volume maps (or cut-and-fill maps), generated by overlaying two DEMs from different periods, which allow you to quantify the changes in elevation that took place as a result of slope flattening, road construction, landslides etc.

In this chapter, firstly the method for generating a DEM will be explained, followed by a series of exercises dealing with the derivative maps.

Before you can start with the exercises, you should start up ILWIS and change to the subdirectory c:\ilwis21\data\usrguide\chap10, where the data files for this chapter are stored.

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- Double-click the ILWIS program icon in the ILWIS program group.
- Change the working drive and the working directory until you are in the directory c:\ilwis21\data\usrguide\chap10.

10.1 Creating a Digital Elevation Model: contour interpolation

In this section you will create a DEM for the Cochabamba study area, from the digitized contour lines. The contour lines were digitized manually. See chapter 3 for an explanation on how to digitize contour lines.

When you digitize contour lines of an area, you should make sure to extend the digitized contour lines a little bit out of the study area in which interpolation takes place, since artifacts may occur at the borders of the area in which interpolation takes place.

The creation of a Digital Elevation Model from a segment map is done with the Contour interpolation operation. This operation works in two steps:

- Segment to raster conversion. First the segment map is converted to raster, using a georeference in which the pixel size, the number of lines and columns, and the minimum and maximum X and Y coordinates of the map are defined. It is important to make sure that the pixel size is not too large, in relation to the maximum spacing of the contour lines. Otherwise it may happen that two contour lines may have to be located in the same pixel, which is of course not possible. In this case the program will select one of the two values of the contour lines and will omit the other, which may lead to problems in the interpolation. The input segment map should be a value map. The raster map resulting from the segment to raster conversion will contain values for those pixels covered by a contour line. All other pixels in the map remain undefined.
- Contour interpolation. A linear interpolation is made between the pixels with altitude values, to obtain the elevations of the undefined values in between the rasterized contour lines. The output of the contour interpolation is a raster map in which each pixel in the map has a value. The interpolation method is based on the Borgefors distance method. The operation calculates, for each undefined pixel between the segments, the shortest distance towards the two nearest isolines. Figure 10.1 shows an example in which the height value (h) for each pixel, between two contour lines, is calculated using the following formula:

$$h = H_2 + (d_2 /(d_1 + d_2) * (H_1 - H_2))$$

in which:

H_1 and H_2 are the height values of the higher and lower contour lines. d_1 and d_2 are the distances from the pixel to the higher and lower contour lines (see figure 10.1).

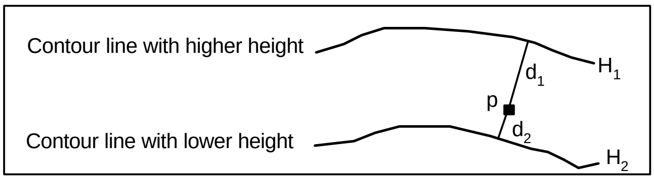

Figure 10.1 Two contour lines (H1 and H2) and the shortest distances from a pixel (p)

Most of the time needed in the interpolation is used for the calculation of the shortest distance to two known values, which has to be done for every undefined pixel. This calculation is done iteratively; the program calculates forwards and backwards (from top line to bottom and vice versa) until no more changes occur. Then a linear interpolation is performed using the two distance values. This returns the values for the undefined pixels. During the calculation several Megabytes of hard-disk are used for storing temporary maps.

In this exercise segment map `Contour`, with a value domain, is used to generate the DEM.

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- Double-click the InterpolSeg operation in the Operations-list. The Interpolate Contour Map dialog box is opened.
- Select the segment map `Contour` from the list box Contour Map.
- Type `Dem` in the list box Output Map.
- Click the check box Show. Select Georeference `Cochabam`.
- Change the precision to `0.1`.
- Select the check box Show.
- Type for the Description: `DEM created from the segment map Contour`.
- Click OK.

The calculation will take some time, depending on the computer configuration and other programs that are working simultaneously. It is advised to close other programs while performing contour interpolation, since this will slow down the process considerably. The Display Options - Raster Map dialog box will be opened after the operation is finished.

The default representation which is indicated in the Display Options dialog box is the same one as was used for the segment map contour: the user defined value representation height.

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- Accept the defaults by clicking the OK button. The map is displayed.
- Click several places in the map and read the altitude values.
- Select from the Layers menu the command Display Options, and select the map `Dem`. The Display Options dialog box is reopened.
- Select the representation `Clrstp12` and click OK. The map is displayed again with another representation.

- Display the map Dem again with other representations. Close the map when you have finished.

A DEM can be classified or sliced through the operation Slicing . Ranges of values of the input map are grouped together into one or more output classes. The output map resulting from the Slicing operation is a map with the domain type group. A domain group should be created beforehand or during the operation using Map Slice dialog box; it lists the upper boundaries of the groups and the group names. A detailed description of the Slicing procedure was given in chapter 7.

Use of Spot heights

The interpolation of contour lines will give wrong results for hilltops, which are enclosed on all sides by a contour line. They will appear as flat areas with the same altitude as the contour line surrounding it. To improve this, it is possible to combine the segment map, containing the contour lines, with a point map, containing the altitudes of the hilltops. Both maps should be converted to raster, then combined into one raster map. This raster map is then used as the basis for the interpolation.

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- Open segment map Contour.
- From the Layers menu select Add Data Layer, and Point map.

  The Add Point Map dialog box appears. Select Point map Spothght and click OK.

  The Display Options dialog box is opened.
- Press the Symbol button.

  The Symbol dialog box appears. Select Symbol: Plus. don't change the default (1) for Line Width. Clear the check box Stretch. Click OK. You are back in the Display Options dialog box.
- Click OK. The point map is displayed on top of the contour lines.

When you zoom in on one of the crosses you will see that it is located within a closed contour line: on a hilltop. Of course the same could be done for closed depressions.

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- Close the map window.

Now we have to rasterize the point map and combine it with the rasterized segment map into a single map, which will be the input map for the interpolation. The rasterized segment map contour was created already during the contour interpolation operation.

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- Double-click the PntRas operation in the operation-list.

  The Rasterize Point Map dialog box is opened.
- Select the Point map: `Spothght`. Select the check box Show. Select the Georeference `Cochabam`. Click OK.

  The segment map is rasterized.
- After that the Display Options dialog box is opened. Click OK.

  The rasterized point map is displayed.
- Close the map.

Now both the point map and the segment map have been rasterized, and you can combine them.

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- Type the following formula on the command line of the main window:

  ```
  Combine:=iff(isundef(Spothght),Contour,
  Spothght)
  ```
- Press Enter. The Raster Map Definition dialog box appears. Click OK. The map is calculated, and the Display Options dialog box appears. Click OK. The map is now displayed.

In the Map calculation formula, it was tested whether a pixel in the map `Spothght` is undefined. If that is so, this map `Contour` is used in the output map. If not, then the values from the raster map `Spothght` are taken. Now you can do the actual interpolation, using the map `Combine` as input map. The interpolation expression on the command line is used, instead of the interpolation dialog box, since that box requires a segment map as input.

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- Type the following formula on the command line of the main window:

```
Dem1:=MapInterpolContour(Combine.mpr)↵
```

- The Raster Map Definition dialog box appears. Change the Precision to `0.1`. Click OK.
- The map is calculated, which will take some time.
- Double-click the raster map `Dem1`, and click OK in the Display Options dialog box appears. The map is now displayed.
- From the Layers menu, select Add Data Layer, and Point map. The Add Point Map dialog box appears. Select point map `Spothght` and click OK. The Display Options dialog box is opened.
- Press the Symbol button. The Symbol dialog box appears. Select Symbol: `Plus`. Accept the default (1) for the Line Width. Clear the check box stretch. Click OK. You are back in the Display Options dialog box. Select the check box Text. Click OK. The point map is displayed on top of the `Dem`.
- Open the pixel information window and add the maps `Dem` and `Dem1`. Check the altitude value of the hilltops with the mouse.
- Close the map window and the pixel information window.

The combination of contour lines with spot heights is very important for hilly areas, where a lot of isolated hills can occur. Normally the altitude of isolated hilltops is indicated on topographical maps. If they are not available you will have to make an “educated guess”, taking into account the value of the enclosing contour line, the contour interval and the overall steepness of the terrain.

If you only have elevation data stored as points, the contour interpolation cannot be used for generating a Digital Elevation Model. In that case you will have to use a point interpolation operation, such as Moving Surface. This will be demonstrated in the next chapter.

Summary: Contour interpolation

The creation of a Digital Elevation Model from a segment map is done with the Contour interpolation operation. This operation works in two steps:

– Segment to raster conversion. First the segment map is converted to raster, using a georeference.

– Contour interpolation. A linear interpolation is made between the pixels with altitude values, to obtain the elevations of the undefined values in between the rasterized contour lines. The output of the contour interpolation is a raster map in which each pixel in the map has a value.

10.2 Filters applied on Digital Elevation Models

Filtering is the calculation of pixel values in an image or a raster map based on the pixel values of the central pixel and its neighbors. In other words, filtering is a process in which, usually a window of 3 X 3 or 5 X 5 pixels, is moved over the map, to calculate an output value for the central pixel in the window according to its neighbors.

Filters are commonly used in image processing (see chapter 6) but can also be applied to raster maps (see chapter 9). A special group of filters is used for calculating slope steepness, the slope shape (concave, convex) and shadow from a Digital Elevation Model. The existing standard filters in ILWIS that can be applied on DEMs are given in table 10.1.

Table 10.1 List of standard filters in ILWIS

Filters	**Symbol**	**Application**
Filters that can be applied on DEMs	DFDX	detects slope differences in x-direction.
	DFDY	detects slope differences in y-direction.
	D2FDX2	detects slope shape differences in x-direction.
	D2FDY2	detects slope shape differences in y-direction.
	LAPLACE	calculates gradients both in x- and y-direction.
	SHADOW	applies artificial illumination (from the Northwest) to the DEM.

Creating a hillshading map

In this exercise, the ILWIS standard filter `Shadow` is applied on the digital elevation model (`Dem`) to create a shaded relief image. The shadow filter simulates sun illumination on the surface, with the sun in the North-West. The shaded relief image is merely used for display.

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- Double-click the Filter operation in the Operations - list. The Filtering dialog box is opened.
- Select Raster map `Dem`.
- Select `Shadow` in the list box Filter Name.
- Type `Hillshad` in the text box Output Map.
- Click the check box Show.
- Type the description: `Hillshading map generated from the map Dem`.
- Click OK.
  The map is calculated, after which the Display Options dialog box is opened.
- Click OK in the Display Options dialog box. The map is now displayed.

The map shows the representation of the mountains under an artificial illumination, as if the sun is shining from the NW. Steep slopes directed to the SE are dark, and slopes directed to the NW are very bright.

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- Close the map window.

You can generate hillshading maps with illumination from other directions by changing the `Shadow` filter.

Using gradient filters

The most important type of filters that can be used on a DEM are called gradient filters. With the help of the gradient filters `Dfdx` and `Dfdy`, horizontal and vertical gradients are calculated for each pixel. The gradient maps are used to produce slope steepness maps as well as slope direction maps.

The gradient filters can be seen as a window which is moved over the map, starting from the upper left pixel in the map. Each value of the filter is multiplied by the corresponding pixel value in the map. The results, for all the pixels in a filter are added up, and the resulting value is multiplied by the gain and stored in the central pixel of the output map. Then the window moves one pixel to the right, and the procedure is repeated. After finishing with the last pixel of the first line, the window moves to the first pixel of the second line. In this way, a new value is calculated for every pixel in the map. In figure 10.2 a schematic example is given of the principle of the horizontal gradient filter.

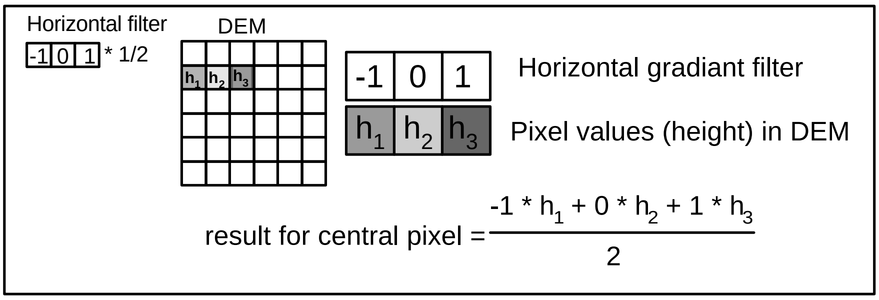

Figure 10.2: The filtering procedure, applying a horizontal gradient filter on a DEM. The direction of the horizontal and vertical filters is not important. Filters -1 0 1 and 1 0 -1 will give the same value but opposite sign, e.g. in the calculation of slope angles

The simple horizontal gradient filter showed in figure 10.2 is not the one which is actually used in ILWIS. It is only used here to make the example understandable. The actual gradient filters (`Dfdx` and `Dfdy`) used by ILWIS are a little more complicated and give a better estimation of the first derivative. They are presented in figure 10.3.

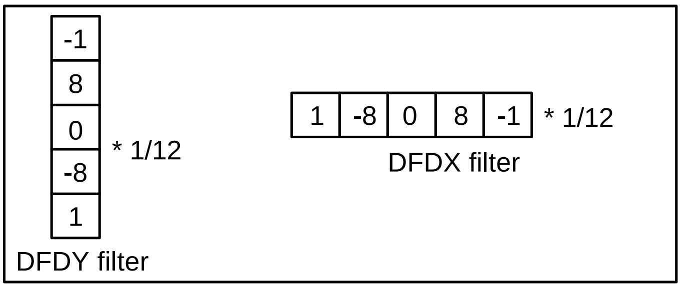

Figure 10.3 The vertical (Dfdy) and horizontal (Dfdx) gradient filters used in ILWIS

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- Double click the Filter operation in the Operations - list. The Filtering dialog box is opened.
- Select Raster map: `Dem`.
- Select Filter Name: `Dfdx`.
- Type for Output Map: `Dx`.
- Click the check box Show.
- Accept the defaults for the Domain, Value Range and Precision.
- Click OK.

The map is calculated, after which the Display Options dialog box is opened.

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- Click OK in the Display Options dialog box. The map is now displayed.
- Open the pixel information window and add the maps `Dem` and `Dx`. Zoom in on the map until you can see individual pixels. Compare the values of the map `Dx` for a certain pixel, with the difference of the altitude of its left and right neighbors in the map `Dem`.
- Repeat the procedure to create a gradient map in the y-direction, but select the filter `Dfdy` and type `Dy` for the output map name.
- Close the map window and the pixel information window when you have finished the exercise.

Calculating slope shape

Before continuing with the creation of a slope steepness map, you will have a look to another set of filters that are useful for DEMs. A number of filters can be used to investigate which parts of the terrain are convex (showing negative values in the output map) or concave (positive values in output map). Flat areas and uniform slopes obtain the output value 0. The following filters can be used:

– D2fdx2. This 1 by 5 filter detects slope shape differences in x-direction.
– D2fdy2. This 5 by 1 filter detects slope shape differences in y-direction.
– Laplace. This 3 by 3 filter can be used to detect slope shape differences in both x and y directions.
– D2fdxdy. This 5 by 5 filter detects slope differences in both x and y direction (second derivative).

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- Double-click the Filter operation in the Operations - list.
  The Filter map dialog box is opened.
- Select Raster map: `Dem`.
- Select Filter Name: `D2fdxdy`.
- Type for the Output Map: `shape`.
- Click the check box Show.
- Accept the defaults for the Domain, Value Range and Precision.
- Click OK.

The map is calculated, after which the Display Options dialog box is opened.

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- Click OK in the Display Options dialog box.
  The map is now displayed.
- Check some of the pixel values.

The map shows many different values, showing the degree of concavity of the slope. The negative ones indicate convex slopes, and the positive values concave slopes. The value close to zero represents straight slope or flat areas.

It would be better to classify this map into three classes: `convex`, `straight`, and `concave`. We can do this by reclassifying the map. We can use the Slicing operation for classifying this value map `Shape` (as was explained in chapter 7), but since there are only three units, we can also use a Map calculation formula, resulting in three classes. The resulting map will be a class map. The domain will be created semi-automatically after writing the formula.

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- Type the following formula on the command line of the main window:
```
Shapecl=iff(Shape<-0.5,“Convex
slope”,iff(Shape>0.5,“Concave slope”,“Straight slope”))
```
- Press Enter.

  The Raster Map Definition dialog box is opened.
- Click the Create button next to the list box of the Domain.

  The Create Domain dialog box is opened.
- Enter the Domain name: `Shapecl`.
- Click OK in the Create Domain dialog box.

  The Domain Editor is now opened.
- Close the domain editor.

  You are now back in the Raster Map Definition dialog box. Click OK.
- Answer Yes to the question: `Add string ‘Convex slope’ to domain ‘shapecl’`.
- Answer Yes to the question: `Add string ‘Straight slope’ to domain ‘shapecl’`
- Answer Yes to the question: `Add string ‘Concave slope’ to domain ‘shapecl’`
- Open the map `Shapecl` and check the contents. Close it when you are finished.

The map `Shapecl` shows for each pixel whether the slope is convex, straight or concave. However, since nearly every pixel is having a different class, the result is difficult to read. To improve this we could use a majority filter, which will take the majority class in every 5 by 5 pixel.

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- Filter the map `Shapecl` using the `Majority` filter and generate the result map `Shapeclf`.
- Display this map and compare it with the map `Shapecl`. After that, close all map windows.

Filters used to calculate internal relief

With the help of filters, it is also possible to calculate internal relief in a digital elevation model, expressed as the maximum elevation change within 1 hectare, or within 1 square kilometer. The filter type that can be used for this is the rank order filter. A rank order filter will place all the pixel values that occur within the filter (in a 3 by 3 filter that would be 9 values) in an increasing order. The user can then select which value from that rank should be taken. So, in the case of a 3 by 3 filter, the first value in the rank would be the minimum of the 9 pixels, the fifth value would be the median and the ninth value would be the maximum.

For calculating the internal relief we would need the minimum and the maximum value within a sufficiently large area (for example within a hectare) and then calculate the difference.

The georeference `Cochabam` contains the information of the pixel size of the raster maps (including the DEM) of the data set we are using: 20 meters. So in order to calculate the internal relief per hectare we need to use a filter of 5 rows by 5 columns.

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- Double-click the Filter operation in the Operations - list.
  The Filter map dialog box is opened
- Select Raster map: `Dem`.
- Select Filter Type: `Rank order`.
- Clear the check box Predefined.
  We want to use a user-defined filter.
- Enter the value 5 for rows and columns.
  We want to use a 5 by 5 filter.
- Enter the value `1` for the rank. This will give us the minimum value.
- Type the Output Raster Map: `Demmin`.
- Click the check box Show.
- Accept the defaults for the Domain, Value Range and Precision.
- Click OK.

The map `Demmin`, giving the minimum altitude within each hectare is given. Now we also need to calculate the maximum.

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- Repeat the same procedure as described above, with the following exceptions:

  - The rank should now be 25 (the maximum value 5 by 5 pixels).

  - The output map name is : Demmax.
- After the map Demmax is calculated, type the following formula on the command line of the main window:
  Intrel=Demmax-Demmin
- Press Enter. The Raster Map Definition dialog box is opened.
- Select the domain Value, and change the Value Range from 0 to 1000, and the Precision to 1.0.
- Type the description: Internal relief in meters per hectare. Click OK.
- Double-click the map Intrel. First it is calculated, then the Display Options dialog box is opened. Select the representation pseudo.
- Click OK. The map is displayed. Check some values by clicking.
- Close the map when you are finished.

Summary: filters used on Digital Elevation Models.

The following filters are useful to apply on Digital Elevation Models:

– Shadow filter. The shadow filter simulates sun illumination on the surface, with the sun in the North-West. The shaded relief image is merely used for display.

– Gradient filters. With the help of the gradient filters DFDX and DFDY, horizontal and vertical gradients are calculated for each pixel.

– Slope shape filters. With the help of second derivative filters, such as D2FDXDY, you can detect slope differences in both x and y direction, and calculate if the slope is convex, concave or straight.

– Rank order filters. With the help of rank order filters it is also possible to calculate internal relief in a digital elevation model, expressed as the maximum elevation change within 1 hectare, or within 1 square kilometer.

10.3 Creating a slope map

In principal, a slope angle or slope percentage can be calculated for each pixel in a raster map, as shown in figure 10.4.

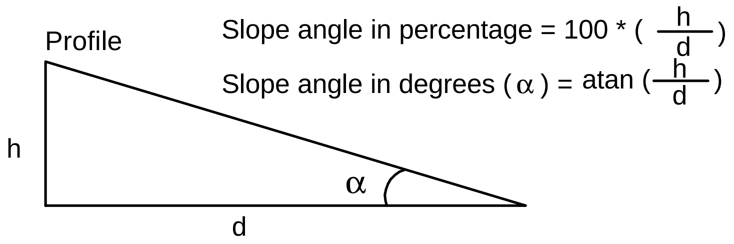

Figure 10.4: Slope steepness calculation. *h* is the height difference between two points and *d* is the distance between them on the map.

In ILWIS, the slope angle or slope percentage can be calculated in X and Y direction using a digital elevation model (DEM), gradient filters (Dfdx and Dfdy) and a map calculation formula. The following steps have to be done to calculate a slope map:

- Constructing a DEM (see exercise 10.1).
- Calculating gradient maps in X and Y direction (see exercise 10.2).
- Calculating the slope angle or slope percentage using map calculation formulas.

In this exercise the gradient maps `Dx` and `Dy` (created in the previous exercise), are used to generate a slope map. The pixel size in these gradient maps is 20 meters and the domain type is value.

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- Type the following formula on the Command line in the main window:
  `Slopeper=((HYP(Dx,Dy))/pixsize(Dem))*100`

In this formula HYP (*hypotenuse*) is an internal MapCalc/TabCalc function to calculate the positive root of the sum of a square `Dx` plus square `Dy` (Pythagoras rule), `Dx` is the horizontal gradient map, and `Dy` the vertical gradient map. In this formula, the numerator is divided by the pixel size, using the internal function pixsize(map), since the gradient is expressed in meters difference per pixel and the result should be in meters difference per meter. The value 100 in the formula gives the slope in percentage.

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- Press Enter. The Raster Map Definition dialog box is opened.

- Type for the Description: Slope map in percentages.
- Click OK.

The expression and the input maps names are stored in the output map. An icon for the output map is also created and displayed in the Catalog. In order to perform the calculation the output map has to be displayed.

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- Double-click the map Slopeper. The map is now calculated. After that the Display Options dialog box is opened. Select the representation Pseudo. Click OK. The map is now displayed.

As you will see, slope values in this map may well rise above 100%. Note: the following slope values are the same: 30° = 58 %, 45° = 100 %, 60° = 173 %, 80° = 567 %. Now you will calculate a slope map in degrees.

- Close the map Slopeper.
- Type the following formula on the command line:

```
Slopedeg = RADDEG(ATAN((HYP(Dx,Dy))/pixsize(Dem)))
```

ATAN and RADDEG are internal MapCalc/TabCalc functions. The ATAN function calculates the arctan ($\tan^{-1}$), and returns real values in radians in the range $-\pi/2$ to $\pi/2$. The function RADDEG is used to convert from radians to degrees.

- Press Enter. The Raster Map Definition dialog box is opened.
- Select the Value Range from 0 to 90 and the Precision of 1.0. Click OK.
- Double-click the map Slopedeg. The map is now calculated. After that the Display Options dialog box is opened.
- Select the representation Pseudo. Click OK. The map is now displayed.
- Open the pixel information window and add the maps Slopeper and Slopedeg to it. Compare the values and calculate if they are correct in respect to each other.
- Close the maps when finished.

10.4 Slope direction (aspect)

The slope direction (or slope aspect) can also be calculated by combining the gradient maps, resulting from the application of horizontal and vertical filters on a digital elevation model (DEM).

In this exercise a slope direction map is calculated for the Cochabamba area. The two maps with the horizontal and vertical gradients (Dx and Dy) were created in exercise 10.3. You have to create the maps Dx and Dy using the steps in the mentioned exercise if you have not yet done it so.

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- Type the following formula at the command line in the ILWIS main window:
  `Aspect = RADDEG( ATAN2(Dx,Dy)+pi)`

in which:

RADDEG and ATAN2 are internal MapCalc/TabCalc functions. ATAN2(*y*,*x*) returns the angle in radians of two input values; *y* is vertical, *x* is horizontal. The function RADDEG is used to convert from radials to degrees. The value for pi (π) is 3.141592653589.... The map dx is horizontal gradient map, and dy the vertical gradient map. The formula results in values between 0 and 360, according to the degrees of the geological compass. For flat areas no slope direction can be calculated; they will obtain an undefined value.

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- Press Enter. The Raster Map Definition dialog box is opened.

The values that result from the formula are between 0 and 360 (degrees of the compass). In order to be able to display them correctly we need to make a domain Compass, for which we will create a special representation later.

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- Click the Create button next to the list box Domain. The Create Domain dialog box is opened.
- Type the Domain Name: Compass. Select the option Value. Click OK. The Edit Domain dialog box is opened.
- Type for the Description: Compass direction
- Enter the Min and Max: 0 and 360. Enter the Precision: 1.0.
- Click OK. You are now back in the Raster Map Definition dialog box. Click OK.

The expression is stored in the output map and an icon for the output map is also created and shown in the Catalog. Before we will calculate and display the map we need to make a good representation first.

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- Open the File menu, and select Create, and Create Representation. The Create Representation dialog box is opened.
- Type the Representation name: `Compass.`
- Type the Description: `Compass directions.`
- Select the Domain: `Compass`. Click OK.
- The value representation is now opened, showing the limits `0` in black and `360` in white.

Since the compass direction 0 is equal to 360 (it is a circular scale) we should make the color for these the same: black. We also need to add another limit: 180, which will get a white color.

☞

- Open the Edit menu and select the Insert limit command . The Insert limit dialog box is opened.
- Enter the value `180` and select the color `White`. Click OK.
- Double-click the limit 360. The Edit limit dialog box is opened. Select the color : `black`. Click OK.
- Select from the Edit menu the command Stretch steps. Enter the stretch steps: `25`. Click OK.
- Now the representation is ready. It goes from black for northern directions, via white colors in the south, and back to black colors .
- Close the Representation Editor.
- Double-click on the map `Aspect`. First it will be calculated, and then the Display Options dialog box is opened.
- Select the Representation `Compass`. Click OK. The map is displayed.
- Add the segment map contour to the map window. Display the segments in a single color (black).
- Check the slope directions by clicking on the pixels.
- Close the map window.

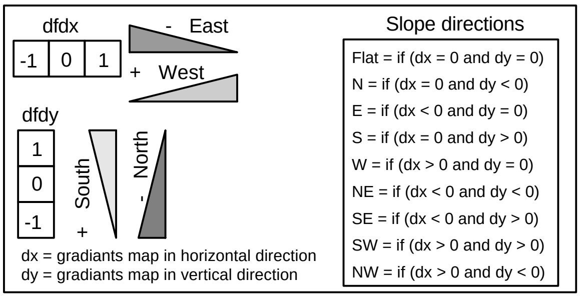
❗ In previous DOS versions of ILWIS, an aspect map was calculated in a different way, using much more complex formulas. First an intermediate map `asp` is calculated as the arc tangent of `Dx` / `Dy` (`Dx` = horizontal gradient map, `Dy` = vertical gradient map), using the formula:

```
asp = 57.29578*( ATAN (Dx / Dy))
```

in which:
The `ATAN` function calculates the arctan ($\tan^{-1}$), and returns real values in radians in the range $-\pi/2$ to $\pi/2$. The map asp will contain values between -90 and +90.
It is important to evaluate, in which quadrant of the geological compass, the slope is directed. The following formula can be used for the calculation of slope aspects and determination of the quadrants in which the slope is directed:

```
Aspect=iff((dx=0)and(dy=0),?,iff((dx<0)and(dy=0),90,
iff((dx>0)and(dy=0),270,iff(dy>0,180+asp,iff( dx>0,
360+asp,asp)))))
```

`Asp` is the map created with the previous formula.
(It may be necessary to split the formula into two parts, since it may contain too many IFF statements).



10.5 Display 3D

A digital elevation model can be visualized in 3 dimensions using a georeference 3D. The program produces as output a line grid. It is possible to superimpose any map (satellite images, thematic maps) with the same coordinate system, on the perspective view. The user can specify the view parameters (altitude, rotation, distance, vertical exaggeration, etc.) to define the perspective of the observer in relation to the 3D model.

In the following exercise the digital elevation model (Dem) created in exercise 10.1 is displayed in a 3 dimensional view. In order to help you to create the best view, the program constructs a line grid in X and Y directions.

☞

- Double-click the Display3D operation in the Operations-list.

The Display 3D dialog box is opened.

☞

- Click the Create button in the GeoReference list box.

The Create Georeference dialog box is opened.

☞

- Type Dem3d in the text box GeoReference.
- Type 3D view, Cochabamba in the text box Description.
- Select the raster map Dem in the list box DTM.
- Click OK. Now you are back in the Display 3D dialog box.
- Click OK. The Display Options- 3D grid dialog box is opened.
- Click OK.

The 3-D view is now displayed with default values. The view can be edited by editing the georeference 3-D.

☞

- Select from the Edit menu the command Georeference.

The GeoRef 3D Editor is opened. By changing the values in this editor you can change the view direction, altitude etc. This is explained in Figures 10.5 and 10.6.

You can imagine a 3-D view as the view that you would have from an area when you are in a helicopter which is at a fixed position. This position is called the *location point*. The location point is at a certain height (*location height*, in meters) and at a certain X and Y coordinate in the map. From the location point you are looking at the study area. The point in the center of your view is called the *view point*, which also has a certain X and Y coordinate. You can draw an imaginary line between the location point and the view point, which is called the *view axis* (see figure 10.5).

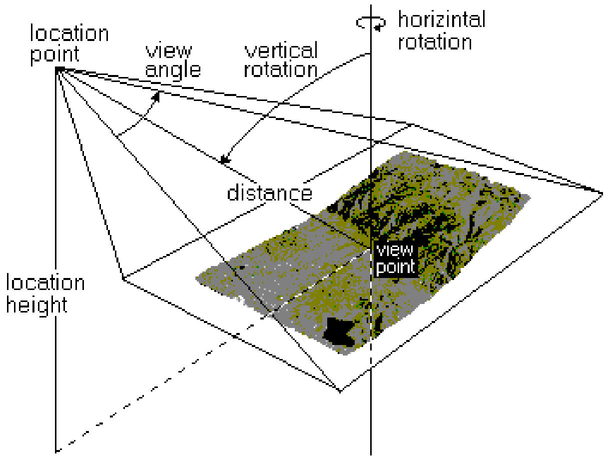


Figure 10.5: The parameters used to define a 3-D view. The *location point* is the point from which you look, and the *view point* is the center of the area to which you look. The location point is at a certain height (*location height*), and at a certain *horizontal rotation* with respect to the N-S line. The line between the view point and the location point has a certain *distance*, and a certain angle with respect to a vertical line through the view point (*vertical rotation*)

The view point is at a certain *distance* from the location point. This distance is the real distance and not the projection of this line on the map. The viewing axis also has a certain horizontal rotation with respect to a line in N-S direction. This is called the *horizontal rotation (angle)*. The horizontal rotation angle is taken as a negative value when the viewing axis is rotated in Western direction, and positive when rotated in Eastern direction. For example: When you are looking from the SW the horizontal angle is -45 degrees, and when you are looking from the NE the horizontal angle is +135 degrees.

The viewing axis also makes an angle with respect to a vertical line. This is called the *vertical rotation (angle)*. The vertical rotation angle is 0 degrees when you are exactly above the viewpoint, and it is 90 degrees when your helicopter is at the same altitude as the view point. If the view point is at the surface, this means that you have a view as if you were standing on the ground at a certain distance.

The last parameter to explain is the *viewing angle*. This is defining the field of view at which you are looking at the view point. You can imagine it as a cone, with the viewing line as the center, starting at the location point. When the viewing angle is 180 degrees, it is as if you are looking at the terrain with a fish eye lens.

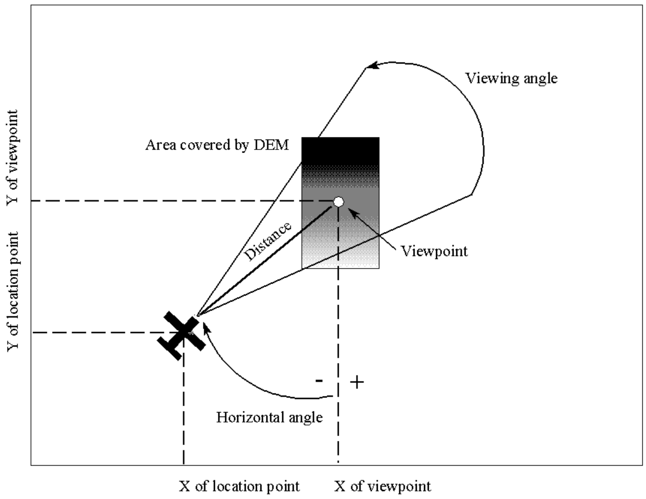


Figure 10.6: Parameters used to define the 3-D view. The *coordinates* of the location point and the view point can be entered, as well as the *distance* between the two (actual distance, not the distance in the map). The horizontal rotation angle is the angle between the line connecting the view point and the location point with respect to a N-S oriented line. The viewing angle is the angle at which you look to the view point (it is the sum of the two angles at both sides of the line connecting the view point and the location point)

In the following exercise you will learn how to work with the different parameters, in order to get an optimal 3-D view. The first impression is that it is quite complicated to enter so many parameters manually. However, many of these are interrelated, and there are a few which are crucial: Horizontal rotation, vertical rotation, distance, viewing angle and scale height.

You will first generate a 3-D view, from which you are looking from the South at a distance of 21 km and a high vertical angle.

☞

- Change the Scale height to `2`.
- Change the Viewpoint to approximately : `801130` and `8026630`.
- Change the Horizontal Rotation to : `0`.
- Change the Vertical Rotation to `82`.
- Change the Distance to approximately `21000`.

- Change the Location Height to approximately 6144.
  The numbers above are just an indication. You will probably not get exactly the same numbers yourself.
- Press the Redraw button in the map window.

The view should now be similar to the one shown in figure 10.7.

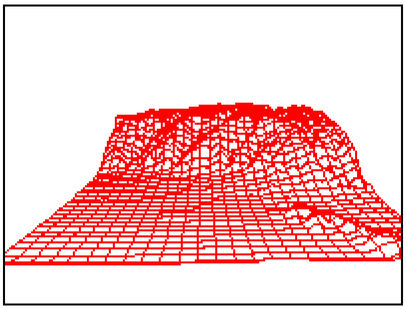


Figure 10.7: A 3-D view from the South with a high vertical rotation.

To evaluate the effect of a smaller vertical angle, you will now change the view again.

☞

- Change the Vertical Rotation to 40. Note that the location point and the height change automatically.
- Press the Redraw button in the map window.

The view should now be similar to the one shown in figure 10.8. Note that you now see a larger part of the area.

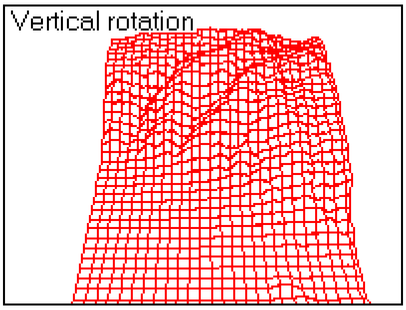


Figure 10.8: A 3-D view showing the effect of a smaller vertical rotation.

Now you will see the effect of changing the horizontal rotation. You need to change the vertical rotation back to the original value.

☞

- Change the Vertical Rotation to 82.
- Change the Horizontal Rotation to 30. This means you are now looking from the south-southeast towards the north-northwest.
- Press the Redraw button in the map window.

The view should now be similar to the one shown in figure 10.9. Note that the 3-D view is now rotated.

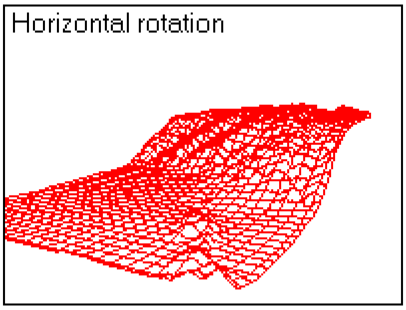


Figure 10.9: A 3-D view from the south-southeast (30 degrees rotation from the South)

The next parameter that we will change is the view angle. Increasing the view angle is similar to zooming in with a camera. You will see a smaller area, but in more detail.

☞

- Change the Viewing angle to 60.
- Change the Horizontal Rotation to 0.
- Press the Redraw button in the map window.

The view should now be similar to the one shown in figure 10.10. Note that you will see a smaller area.

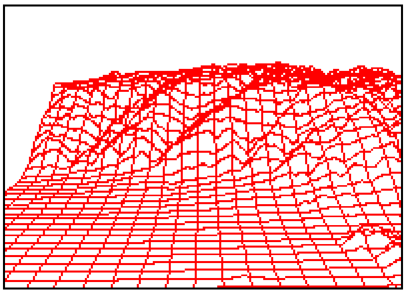


Figure 10.10: A 3-D view showing the effect of a larger viewing angle

Finally, you will look how you can change the position of the viewpoint. The viewpoint is always in the exact center of the 3-D view: It is the point to which you are looking. Changing the viewpoint location by typing the coordinates is possible, but rather tedious. There is a much faster method for changing the viewpoint location. When you click on a point within the 3-D view in the map window, the coordinates of this point will be taken in the Georef 3-D Editor as the new viewpoint.

☞

- Select a point in the 3-D view which is away from the center. Note that the parameters change in the Georef 3-D Editor.
- Press the Redraw button in the map window.
- Practice some more with changing the view parameters.

Selecting the best parameters for defining a 3-D view seems quite difficult when you are doing it for the first time. However, if you practice some more with the editor you will see that a number of parameters are interrelated. The horizontal and vertical angles determine, together with the distance, the position and height of the location point.

When you have finished with editing the parameters of the Georef 3-D Editor, you can leave the editor by pressing the Exit Editor button on the button bar in the map window.

☞

- Click the Exit Editor button on the button bar of the map window.
- Close the 3-D view.

3-D view with raster draping

In the previous exercise you have created and edited a 3-D view using a grid for 3-D display. It is also possible to drape a raster map on top of the 3-D view. In this exercise you will create a 3-D view using a hillshading map.

☞

- Double-click the georeference `Dem3d1` in the Catalog. The Display Options - 3D Grid dialog box appears.
- Clear the check box Grid. Select the check box Raster Drape, and select raster map `Shadows` from the drop-down list box.
- Click OK. The hillshading map is now draped over the 3-D view.

As you can see the display is still rather course. This is because you selected a pixel step of 3. With the pixel steps, you can define the number of rows and columns from the raster map, that are used at the same time to drape over the 3-D model. The best result is obtained by selecting a pixel step of 1. This will, however, lead to a much slower display. Therefore, larger pixel steps are used to evaluate the 3-D view, and then the final view is made with a pixel step of 1.

☞

- Click with the right mouse button on the 3-D image, and select `1 3-d grid` from the context-sensitive menu.

  The Display Options - 3D Grid dialog box appears.
- Change the Pixel steps to `1`, and click OK.

  The 3-D view is redisplayed slowly, but more accurately.
- Close the map window.

The creation of the best 3-D view is done interactively using the Display3D operation. Once you are satisfied with your 3-D view, you can generate it as a file with the Apply3D operation.

☞

- Double-click the operation Apply3D in the Operations-list.

  The Apply3D dialog box is opened.
- Select the input map name: `Shadows`, the georeference `Dem3d1` and the output map name `Shadow3d`.
- Select Show and click OK.

The 3-D view is now created. This will take a while.

- After that the Display Options dialog box is opened. Click OK in the Display Options dialog box.

  The 3-D view is displayed.

Adding vector layers to a 3-D view

One of the major advantages of the 3-D views in ILWIS is that they remain georeferenced, so that you can display other data layers on top. You can also use the pixel information window to retrieve information of raster and vector maps, combined with attribute tables, while moving the mouse pointer through the 3-D view.

☞

- Drag-and-drop the polygon map `Citybl` to the map window in which the 3-D view `Shad3d` is displayed. The Display Options-Polygon Map dialog box is opened.
- Change the Boundary Width to `0`. This way only the polygons are shown in color, without boundary lines. Click OK. After a while the polygon map is drawn in the perspective view.
- Add also the segment map `Drainage` to the map window.

It is also possible to use the pixel information window in combination with a 3-D view, although it will be slower than normal.

☞

- Open the pixel information window and add the maps `Citybl` and `Dem` to it.
- Move with the mouse pointer to one of the city blocks displayed in the 3-D view, and read the information from the pixel information window. Do not move too fast, because it takes longer for the program to find the coordinates from a 3-d view then it does in a normal map.
- Close the map window and the pixel information window.

Summary: 3-D display

A digital elevation model can be visualized in three dimensions using a georeference 3D. To generate a 3D view you have to use Display3d operation.

- The operation produces as output a line grid. It is possible to superimpose any map (satellite images, thematic maps) with the same coordinate system, on the perspective view. The user can specify the view parameters (altitude, rotation, distance, vertical exaggeration, etc.) to define the perspective of the observer in relation to the 3D model.
- The creation of the best 3-D view is done interactively using the Display3d operation. Once you are satisfied with your 3-D view, you can generate it as a file with the Apply3D operation.
- One of the major advantages of the 3-D views in ILWIS is that they remain georeferenced, so that you can display other data layers on top. You can also use the pixel information window to retrieve information of raster and vector maps, combined with attribute tables, while moving the mouse pointer through the 3-D view.

10.6 Creating cross-sections from a DEM

In this last exercise, dealing with the use of Digital Elevation Models, a simple method is presented to generate altitude information from a DEM along profiles. The profiles are segments, which can be digitized with the mouse or the digitizer. The objective is to display in a graph the distance from the starting point of the profile along the X-axis and the altitude along the Y-axis.

In order to do so we have to make the following steps:

- Digitize a line along which you want to create a cross-section.
- Use the operation Segment to Points, to convert the digitized line to regularly spaced points.
- Open the point map as a table, and calculate the column `Distance`, which is the distance from the starting point of the profile.
- Read the values of the altitude from the DEM for the X and Y coordinates specified in the table.
- Plot the distance against the altitude in a graph.

For this exercise you will use a predefined segment (map `Profile`). If you want digitize profiles yourself, you should make sure that each profile consists of one single segment, with a unique code. It is possible to have several profiles in the same file, but then they should be coded differently (e.g. profile1, profile2, etc.). For the conversion from segments to points, only one segment should be present in the file. If you have more profiles, the process should be done for each profile individually and the conversion from segment to point should be preceded by the Mask Segments operation, which you use to copy one single profile segment into another file.

☞

- Click the right mouse on the segment map `Profile`, and select Vectorize, Segment to Point from the context-sensitive menu. The Segment to Point dialog box is opened.
- Enter the value for Distance: `50`. This means that along the segment, points will be stored at every 50 meters.
- Type for the Output Point Map: `Profile`.
- Select Show and click OK. Now a point map is made containing points at every 50 meters along the profile line. The Display Options dialog box is opened.
- Click OK. Now the point map is displayed. Zoom in on a section to verify that they are individual points. Close the point map.

Now that the point map is generated, we can open it as a table, and read the altitude values from the DEM for each point.

☞

- Click with the right mouse on the point map `Profile`, and select the command Open as Table from the context-sensitive menu. The point map is now shown as a table with three columns: X , Y, and Name.
- Type the following formula on the command line of the table window: `Distance = (%R-1) * 50`
- Press Enter, and click OK in the Column Properties dialog box.

The objective of this formula is to use the record indexes (the values shown in the left gray column). The predefined variable %R refers to these record indexes of a table without a domain. The formula results in distances in meters, from the start of the profile.

Now we will read for all the points, the values of the digital elevation model (DEM), from the pixels with the same X and Y coordinates as shown in the table. This can be done with the MapValue function.

☞

- Type the following formula on the command line of the table window: `Altitude=MapValue(Dem.MPR,coord(X,Y))`
- Press Enter, and click OK in the Column Properties dialog box.

Now we have both the distance as well as the altitude, and the profile can be drawn.

☞

- Select from the Options menu the command Show Graph.
- Select the column `Distance` for the X-axis and the column `Altitude` for the Y-axis. Click OK. The Edit Graph dialog box is opened.
- Accept the default settings, and click OK. The profile is now shown.
- Close the graph and the table window.