

Producing Cartographic Contours from Elevation Models in ArcGIS

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INTRODUCTION

Contours serve two main purposes on a map: first is to show lines of constant elevation, allowing a map reader to interpret a good estimate of the elevation for a place on the map; second is to show the shape of the landscape in terms of landforms, slope, and aspect.

There are some widely accepted conventions for representing contour lines on maps; here are some key aspects of these conventions:

- For each map a contour interval is selected. This is the vertical distance between two contour lines. The idea is to choose a contour interval that allows contour lines to fulfill their role on the map while not resulting in too many contour lines, particularly in steep areas, that the map reader cannot distinguish one line from its neighbor. The famous Swiss cartographer, Eduard Imhof suggested that the physical distance between contour lines on the map should typically not be closer than one millimeter. Imhof also maintained that there is no perfect contour interval for any given map.
- There are kinds of contour lines:
 - Intermediate contour lines occur at the contour interval and are typically represented with a thin (~0.2 points) brown or tan line on maps. See Figure 1, #1 for example.
 - Index contour lines typically occur at an interval of five times that of the contour interval for the map. Index contours are typically represented with a line that is two to three times thicker than the intermediate contours and possibly a little darker brown, though not obviously so. Index contours are typically labeled with the elevation value they represent. The color of the label is the same as the index contour or just a little darker to facilitate legibility. The label for index contours is placed within the contour line and the line is broken around the label to make the label legible. On the map index contours serve to give the map reader their first clues about the shape of the landscape; map readers are expected to focus more attention on a place to read the intermediate contours and thus gain a fuller understanding of its shape. See Figure 1, #2 for example.
 - Supplementary contour lines represent lines of constant elevation at an interval of half the contour interval and thus, are only shown in very flat areas, typically when the slope is less than three percent. Supplementary contours fill in the gaps between intermediate contours in flat areas, making it possible to see not only the shape of the land, but often some character of the process that shaped the land. For instance supplementary contours in the bottom of a glacial valley or on a large

alluvial fan add much to the map reader's understanding of such places. Supplementary contours must be symbolized in a way that is immediately and obviously different than intermediate contours. Typically, they are the same width or slightly smaller than the intermediate contours, they color should be lighter, and the line should be dashed, typically using a short dash such as a 3:2 or 4:1 ratio of dash to gap.

- Ice/snow and submerged contour lines represent the surface of the land when it is obscured by ice or water. These may be intermediate or index contours, but they should be represented with a different color, typically a blue that cannot be confused with surface water.
- Depression contour lines are hachured on the side of the contour line that faces down hill into the bowl of a depression land form. Some mapping conventions add that the interval between each hachure should be smaller with each progressive contour line inside a depression with the maximum hachure density achieved at the third depression contour. The hachure should be relatively short, ranging from 2.5 to 5.0 points in length and should use the same line symbol as the contour line it is associated with. See Figure 1, #3 and #4 for examples.

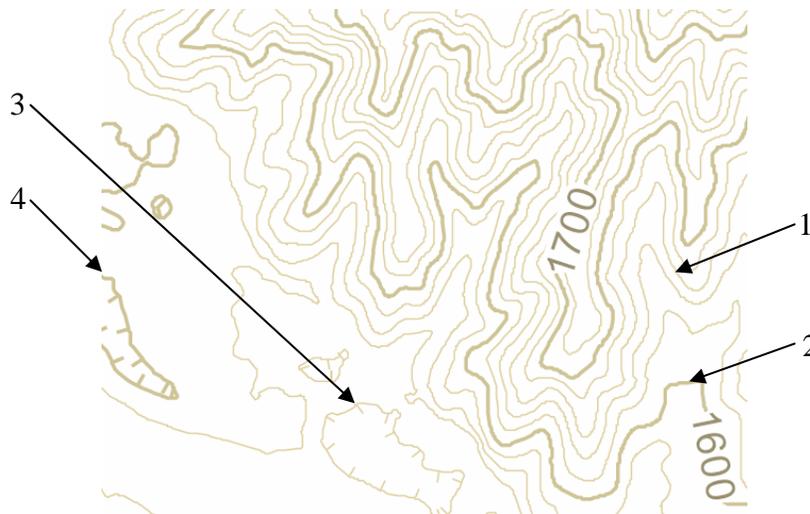


Figure 1. Example of different kinds of Contour Lines

The rest of this paper described how to create each type of contour line and how to ensure the contour lines are of high quality.

GETTING STARTED

Contour lines are produced from a Raster Digital Elevation Model (DEM) using the CONTOUR tool in ArcGIS. Both the Spatial Analyst and 3D Analyst extensions have a contour tool, and either can be used. The values of the DEM dataset are used as the basis for the contour lines' elevation value.

Making new cartographic quality contour line data for a topographic or quasi-topographic map is not as simple as just running the contour tool in ArcGIS. First, depending on the quality

of the DEM, the resulting contour lines may not be fit for use on a given map, so some pre-processing of the DEM may be necessary. The Contour tool produces what is ultimately a very raw version of the contour lines. These must be refined and augmented with information to support cartography, particularly assigning contour line type (intermediate, index, supplementary, or depression).

PREPARING THE DIGITAL ELEVATION MODEL (DEM)

Depending on the specific role contour lines will play on a map, the DEM that will be used to produce the contour lines will need to be pre-processed. Typically this is to smooth surface of the DEM to support creating smooth looking contour lines versus knobby or overly crenulated contour lines, which are commonly perceived as not especially aesthetic and the strange shapes cause map readers to focus on them, and not other more important information on your map. Note that the contour tool is designed as an analytical tool not a cartographic tool.

However, before smoothing the DEM, it is critically important to make sure it is properly projected and that it aligns to your other data, especially any imagery that will be used to capture other features for your map. Another consideration is to check the vertical accuracy of the DEM and the actual values compared to known elevations. There's nothing more frustrating than going through all the steps described in this paper and realizing at the very end that the DEM's coordinate system used a non-standard datum causing all the contour lines to be just a little out of alignment with the features on the map. That said, other data, particularly streams and roads may be captured from other sources and may not align perfectly—in those cases obvious errors should be corrected; consider using the spatial adjustment tools if the DEM is considered better registered, or use the Georeferencing tools to adjust the DEM to other data which may be considered more accurate.

Smoothing the DEM will also mitigate problems with artifacts that frequently occur in DEMs as a result of data collection problems or at the seams where two DEM files have been combined. If more than one DEM file is needed for a your map, use the MOSAIC tool to combine them. The Mosaic tool will ask you to specify a Mosaic Method, and you should use the Blend or Mean method, otherwise you could introduce small cliffs or faults into the resulting DEM.

If you are just learning about producing contours for the first time, go ahead and skip to the next section as this is really something of a refinement that you will come to have a better feel for with experience.

To smooth a DEM follow these steps:

1. Open the FOCAL STATISTICS tool. This tool requires the Spatial Analyst Extension.
2. Your DEM dataset is the input, and typically the name of the output should be the same name plus the string “_Smooth”.
3. Set the Neighborhood parameter to Circle

4. Depending on your DEM, the Radius could be set anywhere between 3 and 10. For now use 5, unless your DEM is very large (more than 6000x6000 pixels) and use 4 in that case. The higher the value, the longer this tool needs to run.
5. Set the Statistics type to Median

The result should be a DEM that has in effect had the little irregularities blended into the surface. The contour tool will produce smoother, more graceful, cartographically appealing contour lines from this DEM.

DETERMINING A GOOD CONTOUR INTERVAL FOR YOUR MAP

As stated above, the best contour interval is functional and does not result in too many contour lines that are too close together on the map. Ideally the perpendicular distance between two contour lines will not be less than 1.0 millimeters. There are two main considerations that affect choosing a contour interval for a map: first is the map's scale, and the second is terrain's ruggedness, i.e., whether the area within the map relatively flat and smooth, hilly, or dramatically mountainous. Use tables 1 and 2 to derive a contour interval.

This interval is a rough estimate and should be tested. Two or three small tests should be done by generating contour lines for small areas of the map you will be making (if the map is small to begin with, like A-size or letter size paper, just try the whole extent of the map). Once you've generated these test contour datasets add them to a map and symbolize them as intermediate contours lines, zoom to each in succession and do the following:

1. set the test map's scale to be the same as the map you will be producing
2. Print the map
3. Visually inspect the map to verify the distance between contour lines the contour lines is more like Figure 2A than Figure 2B.

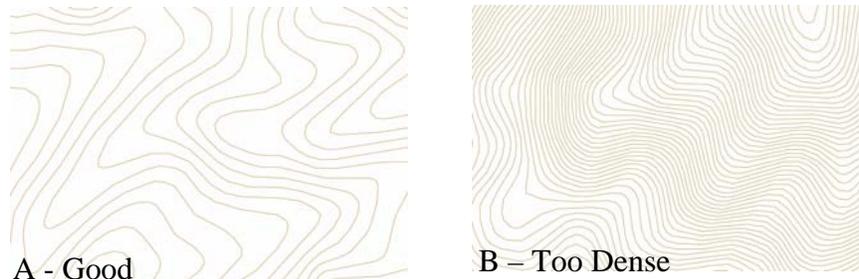


Figure 2. The image of contour lines on the left (A) is a desirable outcome where the closest contour lines are a little over a millimeter apart. The image on the right (B) is too dense with many of the contour lines being less than 0.5 millimeters apart.

To get a good idea of what a good contour interval for a given map might be, use the following Table 1. The information in the table is taken from Eduard Imhof's *Relief Representation* 1982. This guidance expands on Imhof's recommendations to include measurement in feet, and the ranges of contour intervals were also expanded accommodate both

American and European mapping styles. American style contours usually have a smaller contour interval because there was typically no other information shown with contours to depict hypsography, such as terrain shading or rock face depictions.

Map Scales	Predominant Terrain Type ¹					
	High Mountains		Low Mountains		Flat or Undulating	
	Feet	Meters	Feet	Meters	Feet	Meters
1:1,000	5	1	3	0.5	1-2	0.25
1:2,000	5-10	2	5	1	2-3	0.5
1:5,000	10-20	5	5-10	2.5	3-5	1
1:10,000	20	10	10	5	5	2
1:20,000	20-40	10-20	20	10	5-10	2.5
1:25,000	20-50	10-20	20-25	10	5-10	2.5
1: 50,000	50-100	20-40	40-50	10-20	10-20	5
1:100,000	100	40-50	50-80	25	10-25	5-10
1:200,000	200-250	100	100	50	20-40	10
1:250,000	200-400	80-120	100-200	50-80	25-40	10-20
1:500,000	400-500	100-200	200-250	100	40-50	20
1:1,000,000	500-800	200	250-400	100	50-100	20-50

¹Predominant terrain type should be representative of over 50% of the area on a given map. When an even distribution of all three terrain types or between high mountains and flat or undulating (with a relatively low area of low mountains), then consider using supplementary contour lines as well.

Table 1. Suggested contour intervals for different predominant terrain types and scales. The numbers representing contour intervals, do not represent the range of real numbers, but instead just the numbers shown and possibly one or two other nicely rounded numbers between the pair shown.

ASSIGNING INDEX CONTOURS

The simplest way to denote whether a contour line is an index contour is to add a Boolean or short integer field to the contour line dataset and set its value to be true or 1 (one) for index contours and false or 0 (zero) for intermediate contours. Follow these steps to do this:

1. Open the table for your dataset in ArcMap
2. From the Options menu at the bottom select Add Field
3. In the window that opens, name the field "IndexYN" and this example will be for a short integer field, so set the type to be Short Integer.
4. Right-click on the button with your new field's name on it and choose "Field Calculator."
5. Calculate your new field using the following expression: "[Contour] MOD 200". In that expression [Contour] is a reference the field in your dataset that contains the elevation values; MOD is a VBScript operator; and 200 is the contour interval. This will create values that are 0, and other numbers; the zero means that this should be an index contour.

6. From the table window's Options menu choose Select by Attributes and use the following selection clause: "[IndexYN] = 0"
7. Use the field calculator on the IndexYN field and set its value to 1.
8. From the table window's Options menu choose Switch Selection.
9. Use the field calculator on the IndexYN field and set its value to 0.

Optionally you can replace steps 6-9 by using the following advanced calculate statement:

```
k = [Contour] MOD 200
if k = 0 then
  k = 1
else
  k = 0
endif
```

Set the IndexYN field to be equal to "k"

Once you have this field in your dataset and it is populated with the correct values, you can use the Unique Values symbology method in ArcMap to determine which way to symbolize the contour lines.

CLEANING UP CONTOURS

Typically the contours that result from the contour tool are too dense with vertexes and must be simplified or thinned; this will also dramatically improve drawing performance. In thinning out the extra vertexes, the goal is to not change the shape of the contour line when viewed at the scale of the map. Definitely do not over-thin the contour lines such that not only do they change shape, but that they also touch or intersect one-another. The Simplify Line tool has two simplification methods, Bend Simplify and Point Remove. The Point Remove method is more commonly known as the Douglas Peucker method and is the most appropriate for the task of subtly thinning lines.

The simplification tolerance parameter is not an obvious or easy number to logically think of, so the following procedure is described to help find a good starting point:

1. Add the newly produced contour line dataset into ArcMap.
2. Start Editing
3. Zoom to a small area that contains a steep ridgeline (or any place where some of the most closely spaced and undulating contour lines exist).
4. Select one of the contour lines in this area and change the Editor's task to Modify Feature (see Figure 3).

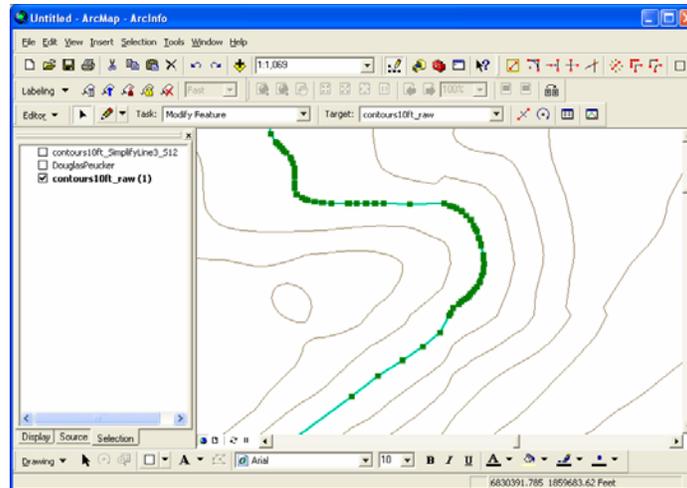


Figure 3. Example of zooming in far enough to see the density of vertexes

5. Zoom into a very small portion of this line, to the point where you can clearly see where the bends in the line occur due to vertexes being present (see Figure 4).
6. Locate three points within the line and use the measure tool to find the perpendicular distance between a line drawn between the first and third points and the second point (see Figure 4).

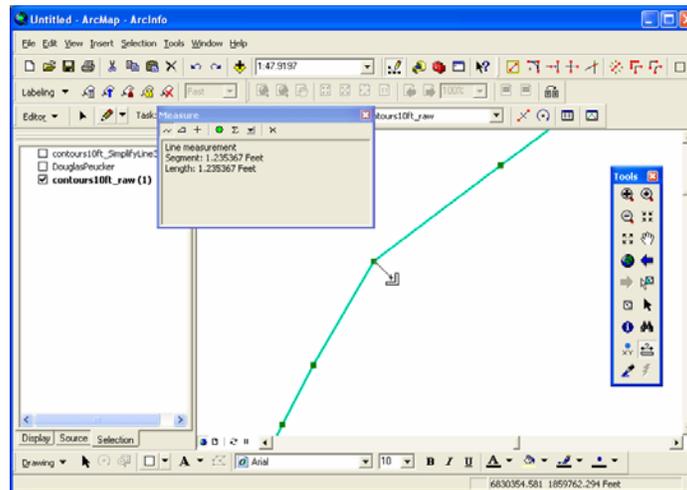


Figure 4. Example of measuring to determine a good simplification tolerance parameter value

7. On the Advanced Editing toolbar (see Figure 5) click the Generalize tool. Enter the distance that was measured in step 6 into the Maximum allowable offset parameter in the Generalize tool's window.



Figure 5. Advanced Editing toolbar with Generalize tool highlighted.

8. Evaluate the result by using the undo and redo tools while the edit task is set to Modify Feature.

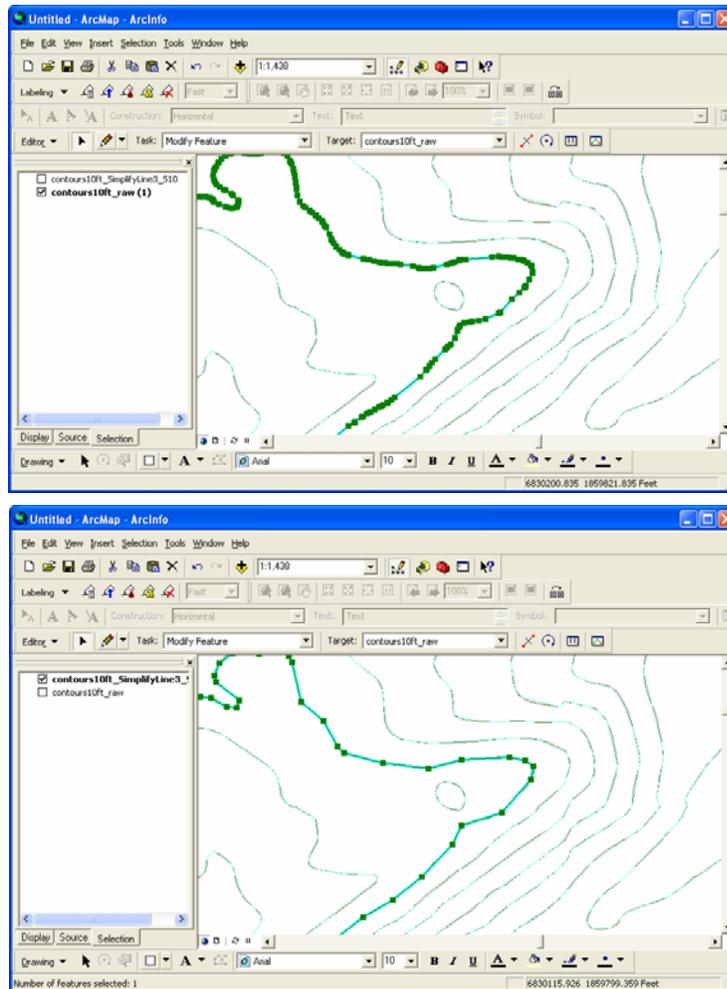


Figure 6. Top shows vertexes for un-simplified contour line, while the bottom shows vertexes after simplifying the line. This example shows what probably be the limits of how far the simplification ought to be pushed. Note the scale of these maps during editing, the contour lines will be used on maps at 1:10,000; a good rule of thumb is to zoom in by a factor 10 when evaluating the quality of the simplification.

The benefits of this reduction of information are faster storage and retrieval times, which are obvious, and less obvious but ultimately a showstopper is greatly improved labeling performance.

HORIZONTAL AND VERTICAL ACCURACY OF CONTOURS

Most topographic maps must adhere to both a horizontal and a vertical standard for accuracy. Contour lines are where these standards literally intersect. Characterizing a contour line's horizontal accuracy describes how well the contour line is located in two-dimensional space. Characterizing a contour line's vertical accuracy describes how close the elevation represented by the contour line conforms to a surveyed elevation control points. Thus, in theory you could perpendicularly intersect a contour line with a rectangular plane and with high probability know that the elevation represented by the contour line is also somewhere on that plane.

Because the accuracy of most DEMs is already characterized and available in the DEM's metadata, that becomes a starting point for measure the accuracy of contours generated from that DEM. Testing the accuracy of contour lines against the DEM that was used to produce the contour lines in the first place means that the sum of the RMSE for the DEM and the RMSE that describes how well the contours match the DEM should be used to express the accuracy of the contour lines for the maps those contour lines are used on. This paper's focus is for creating contour lines from DEMs, however the guidance in this section could also be applied to testing the accuracy of pre-existing contour line datasets to newer DEMs.

Depending on the purpose of the map and the expectations of the map's audience, which differ culturally and nationally, there are expectations of accuracy that may need to be met in producing contour lines. In some countries map accuracy standards exist and are described for maps at varying scales. These standards should be the foremost guide to inform the process of creating contour lines.

Accuracy of contour line location is typically expressed in one of two ways. First is the idea of a fraction of the vertical distance between contours. For example contour lines in a contour line data set with a ten meter contour interval may be accurate to plus or minus five meters ($\pm 5\text{m}$), meaning that a place somewhere up to five meters perpendicular from a point on that contour line is the place where that elevation actually occurs. The second way is by specifying a tolerance for a given map, for example stating that the contour data is accurate to within ± 1.5 meters of the specified value.

Examples of each method include:

1. United States Geological Survey: Vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.
2. SwissTopo: The DHM25 is based on the National Map 1:25,000 and basically corresponds to that accuracy. Comparisons with photogrammetrically determined control points show that the average accuracy reaches 1.5 m for the Swiss Plateau and the Jura Mountains, 2 m for the pre-Alps and Canton Ticino, and 3 m for the Alps. The older height model RIMINI (see separate product information) is suitable for applications with reduced accuracy requirements.

To determine the accuracy of a particular set of contour lines, use the root mean squared error (RMSE), which is a single number, and the closer to zero it is, the better the accuracy. RMSE is computed by sampling some points in the contour lines and testing them against a control dataset. The root of the sum of the differences divided by the number of points will produce a value that should be less than the accuracy tolerance. It is normal to have a higher RMSE value in areas that are steeper or are characterized by high local relief.

There are number of circumstances where contour lines that are generated automatically from a raster DEM may not meet the aesthetic requirements for a given mapping standard. In some maps contours are omitted in certain areas, particularly those areas of the landscape that are temporarily disturbed by human activities. In other cases the resolution of the DEM may not be sufficient to provide enough detail to create contour lines that clearly symbolize human-made or prototypical landforms. There cartographic techniques that can be applied to contour lines that may slightly degrade the above described accuracy measures while enhancing the readability of the map.

Further, in many countries there is an expectation that contour lines should look smooth because ‘noisy’ contour lines distract the map reader and contour lines in such areas are often difficult to read in terms of understanding the shape of the landscape. Such contours are often generalized, particularly in order to simplify them. It is these generalized contour lines that should be tested for accuracy rather than the raw output of an automated algorithm for producing contour lines—though some such algorithms do produce generalized contour lines, so it is important to understand the nature of the algorithm.

ASSIGNING DEPRESSION CONTOURS

There is no automated way in ArcGIS to assign depression contours. There are some tools such as FLOW DIRECTION, SINK and FILL which may look useful for this purpose, but in fact are designed to find small irregularities and fix them, and thus they don’t find larger depressions, which are typically the basis for depression contour lines.

There is a relatively simple manual method that can be used to check for and assign depression contours for a quadrangle sized area in five to fifteen minutes. This method depends on being able to display contour lines with different colors. Thus, depending on the contour interval a field that will contain a string value of the right-most two or three numbers of the elevation will be needed. If the contour interval is 5, 10, or 20, then just two numbers are needed; if the contour interval is 40, 50, 100, or 200, then three numbers will be needed. Follow these steps to set that field up and to identify depression contours:

1. Open the table for the contour lines and add a text field called Right2 or Right3 that is a width of 4.
2. Calculate that field using this statement: `Right(Str([Contour]),2)`. Use a 3 if calculating the right3 field’s values.
3. Add another new field called DeprYN which should be a short integer field. Calculate this field’s values to be 0 (zero).

4. Close the table and open the Layer Properties window for the contour line layer.
5. On the symbology tab choose to show the features with Categories and the unique values many fields.
6. Use two fields, the Right2 or Right3 and the DeprYN. Initially this will not show any depression contours (having a value of 1 or greater); you will need to add them.
7. Click the Add All Values button.
8. Apply the layer properties and close the window
9. Next a color ramp is needed that can be used in the unique values symbology. Open the Style Manager (tools menu, styles sub menu).
 - a. Expand the ESRI.Style and click on the Color Ramps folder to show its contents on the right.
 - b. Scroll down to and right click on the ramp called "Spectrum-Full Bright". Choose copy from the pop-up menu.
 - c. On the left panel of the style manager expand your personal style, and click on the color ramps folder.
 - d. In the right panel, right click and choose Paste.
 - e. Make sure the view in the right panel is for details (right-most button on the lower right of the Style Manager window. This will show the Category column.
 - f. In the category column click on the text for the color ramp you just copied and delete the text. This will allow this ramp to be shown in the unique values symbology color ramp list.
10. Open the layer properties for your contour layer and set the color ramp to be the one you just added.
11. Right-click on one of the rows in the symbol list and choose properties for all symbols. In the Symbol Selector window that opens set the width to 2.0 and click OK; and click OK again to apply and close the Layer Properties.
12. Now you can see each contours in sequence (see Figure 7 for example).

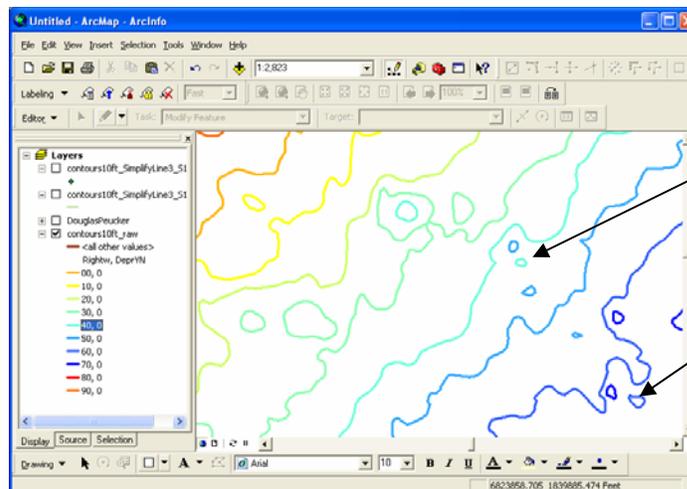


Figure 7. Example of contour lines symbolized to assist in locating depression contours.

13. Start Editing.
14. Zoom into a scale that shows more than what the example in Figure 7 shows, and Identify a few contours in progression to determine which direction uphill is. In Figure 7, uphill is from upper left to lower right.
15. If a color is repeated to the uphill side of the main contour (as indicated by the arrows in Figure 7), then that is a depression contour. Select that contour and open the Attribute Editor and set its DeprYN field's value to 1.
16. The <all other values> symbol will now be used to display that contour line now. Optionally, the layer symbology can be reset to include the depression contour.
17. Optionally, if contours are nested, it may be required that the most deeply nested contours be symbolized with hachures that are more closely spaced. If that is the case, the number entered for the DeprYN field can indicate the level of nesting, so for example a 2 would mean that this contour was the second contour inside a depression.

With a little practice this method can be applied fairly quickly to a large area. Though one warning is to be wary of hills inside of depressions—contour lines inside a large depression contour are not guaranteed to be depression contours. Generally speaking, contours generated from 10 meter pixel SRTM DEMs from the USGS have very few depressions and those can be found with this method in a matter of minutes. On the other hand contours generated from 1-3 meter pixel size LIDAR DEMs will have many depressions and it will take several hours to find and tag all the contours for a city of 250,000 persons.

SYMBOLIZING CONTOUR LINES

The purpose and audience of the map will drive requirements for how contour lines are symbolized on a given map. Figures 8, 9, and 10 illustrate different maps with respect to the purposes and audiences, though the same contour lines were used in each map; just colored slightly differently to work with the background.



Figure 8. Typical topographic map style of representation where the contour lines are fairly dark and prominent as they are the only

way the shape of the terrain is shown on this map. This map was intended for an audience who have been trained to read contour maps.

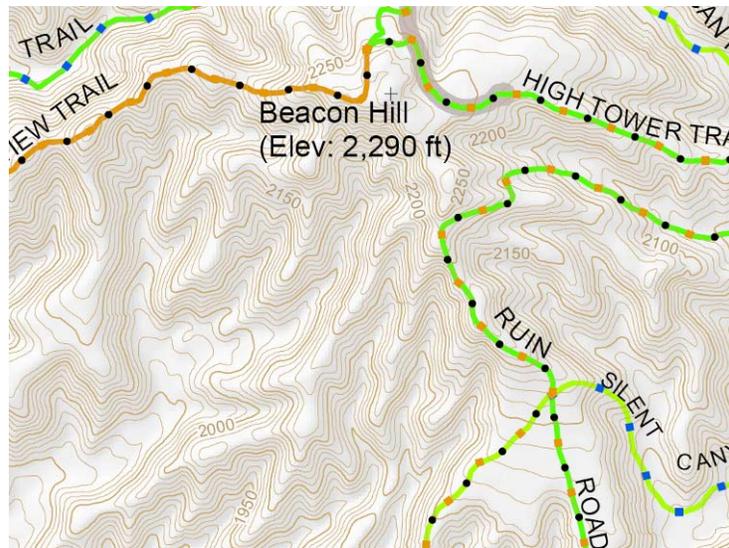


Figure 9. In addition to the contour lines, a subtle relief shading has been added to this map. The audience for this map includes both trained map readers who need to evaluate the contour lines as well as some untrained readers who will be looking to just get a sense of the terrain.

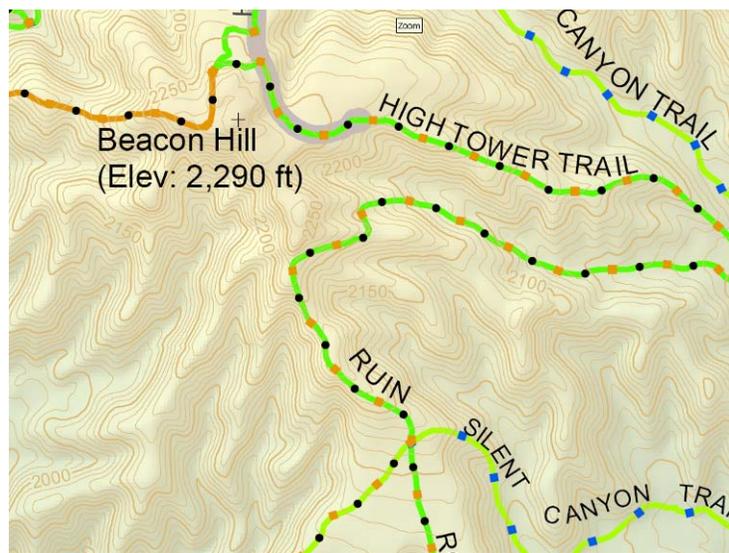


Figure 10. Both relief shading and hypsometric tinting are used on this map which is predominantly intended for an audience that has not been trained to read contour lines; the warm color-rich hypsometric tinting is intended mainly to draw in somebody who is new to the content of the map and give a basic understanding of

the terrain, while also providing map readers who are experts with this terrain the visual cues (contour lines) to effectively guide newer map readers.

In each of the example in Figures 8-10, the color and clarity of representation of the contour lines is set relative to the background of the map by changing the value (on the HSV) scale from fairly dark in Figure 8, which used a value of 72 out of 100; to 80 in Figure 9; and 87 in Figure 10. The idea is that as the more graphically-rich the background became the less prominent the contour lines became.

Symbols for depression contours include hachures that point downward into the center or bowl of the depression. The line for the hachures should be of the same width as the main (uninterrupted) portion of the contour line. The main line should be drawn at the location of the elevation being represented by the depression contour—and should not be offset; thus it is the hachures that are offset. The length of the hachures should be about four times the width of the hachure line for an index contour. For example in Figure 8-10, a the index contours were at a width of 0.44 points, so the length of the hachures was 1.8 points for both index and intermediate contours that represent depressions (See Figure 11 for an example of both types of contour lines using the same length of hachure).

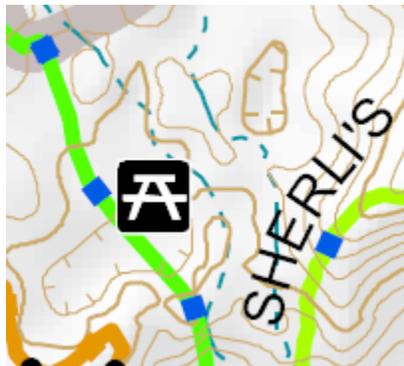


Figure 11. Example of intermediate and index depression contours. Note that both types use the same length of hachure.

LABELING INDEX CONTOURS

Contour lines have been used on maps for nearly 300 years, over the last 150 years contour lines are the predominant vehicle for conveying information about the shape of the land. There is a good deal of information available on how to produce and generalize cartographic contour lines. But when the topic is changed to labeling contour lines, the published guidance and expertise is next to nothing; what does exist is vague and most experts do not entirely agree on how to best label contour lines.

Thus, this section will describe some rules of thumb (convey the vague notions of what is good), describe the most common methods for labeling contour lines that different map makers have upheld as good, and describe how at least one of these methods can be readily achieved in ArcGIS using the Maplex automated label placement extension.

The experts over the past century whose works and maps were consulted were Erwin Raisz, Eduard Imhof, and maps from the United States Geological Survey, Ordnance Survey of Great Britain, and other German and Swiss maps. Desirable traits in contour labels are as follows:

1. Too many labels are a bad characteristic as the information on the map is covered up.
2. Contour labels should either be upright, pointing uphill, or all oriented to the page. If the former method is used, then it is generally considered a kindness to map readers to place more labels on the south facing slopes as these will be right side up for reading.
3. The labels should be on a straight base line—curves cause the numbers to be oriented in a fashion that can be difficult to read.
4. Contour labels should be along fairly straight sections of a contour line. This because the label will blank out a portion of the line and the map reader is left to infer the location of the contour line—a straight line is much easier and more likely to be inferred correctly.
5. Do not add extra ink, which will impede viewing of relevant geographic representations. Extra ink includes such as thousands separators, for example use 1850, not 1,850; and unit of measurement abbreviations, which should be provided as part of the map's legend.
6. If the contour lines and labels are the same color break or mask the contour lines around and behind the label. A 0.5 point (1/144 inch) gap around the contour label is usually sufficient.
7. Index contour labels are most needed near the tops of ridges, bottoms of valleys, and along dramatic changes in slope.
8. Do not place labels near spot heights—the information is redundant.
9. Avoid placing labels on the portions of contour lines that trend north to south.
10. Do not ladder or stagger labels to form any sort of obvious pattern. The key word is *obvious*; as subtle patterns will actually help map readers in finding additional contour labels quickly. Obvious patterns will jump out at map readers, not only distracting them, but also creating false patterns in the landscape.

Thus, a subtly patterned, though nearly random looking scheme for placing contour labels would seem to satisfy the spirit of what is needed without causing unnecessary labor on the part of the map reader. Some have argued that random placement of contour labels is a better option. The problem with random placement is that it requires more labels to be placed in order to make it sufficiently easy to find a label.

Others have argued that contour labels can be placed in patterns that reinforce the shape of the terrain. While this is certainly possible, it also requires a great deal of skill and experience to properly apply such a technique—that skill may no longer exist and the specific methods for labeling contour lines on each given landform apparently were not codified in a comprehensive manner. To even consider this method requires a two-stage process, first identifying the landforms and second having a specific strategy for placing contour labels on each landform—neither stage is currently understood well enough to automate. Further, in good economic times, such work is either deemed beneath human dignity or that the price for the creative energy and tolerance for tedium needed for this task are not worth the result. An interesting irony of the

information age is: information that cannot be automatically produced is often deemed not worth the effort to produce.

From the USGS:

The determination of the best positions and density for contour labels requires good judgment and is influenced by the nature of the terrain, the density of the contour lines, the complexity of the culture and names, and distribution of bench marks and spot elevations. Complex topography generally requires more contour numbers than simple terrain.

Where possible, priority should be placed on positioning contour labels on index contour lines. The second priority should be to place labels on widely spaced intermediate contours. Key positions for index contour labels are near the tops of ridges, bottoms of valleys, and along pronounced changes in slope. Avoid placing contour labels where they will obliterate pertinent hypsographic detail or overprint streams, cultural features, public land lines, or other labels. Although intermediate and supplemental contours should be labeled, the labels should not replace or interfere with the optimum distribution of index contour labels. Some identifying labels should be placed on supplemental contours that have a limited distribution, but not at the expense of index contour labels or the exclusion of labels on adjacent intermediate contours. The ultimate criteria should be whether the map has a balance and is easy to read; this can only be achieved by good editorial judgment.

The following guidelines should be used to achieve the proper density of contour labels:

- *Position index contour labels approximately 1 1.5 miles apart, if possible.*
- *Avoid positioning labels on intermediate contours adjacent to index contours.*
- *Avoid positioning labels closer than 1,000-2,000 feet from spot elevations or control marks.*
- *Avoid positioning labels on contours that trend north to south.*
- *Position the label on the smoothest part of the contour so the least amount of contour detail is obliterated.*
- *Contour label density can normally vary between 3 to 5 labels per square mile, depending on the complexity of the topography and other map detail. However, a density of 1 or 2 labels per square mile is acceptable if there are few contours or a great deal of map detail.*
- *Label supplemental contours adequately enough to enable quick identification of the contour value.*

The zero contour line, when shown, should be labeled "SEA LEVEL" if space permits; otherwise "00" should be used.

Contour crossings on wide, low gradient, double-line streams should be labeled between the shorelines if space permits. Brown leaders can be used on contour crossings on major low-gradient ditches, single-line streams, or narrow double-line streams, but centering the label on the contour is preferable if space permits.

Label the center of depressions ≥ 69.7 square inches (10 square miles at 1:24,000 scale) "DEPRESSION" in black, 10 point descriptive uppercase type with 4-point spacing, if necessary for clarity.

ADVANCED TOPIC: CREATING SUPPLEMENTARY CONTOURS AND THINNING CONTOURS IN STEEP AREAS

Many maps will have a some what polarized mix of terrain types, e.g., maps that intersect where a mountain meets with a flat, usually fluvial valley; the contour interval that is best for the valley results in too many contour lines in the mountains and vice versa. A useful convention, in this case, is to use the contour interval that works better for the high slope areas and augment the areas of low slope with supplementary contours. (Note: the USGS uses the term of supplementary contour lines, while Eduard Imhof uses the term half-interval intermediate contour lines).

There are maps, though, where even this will not work as the mountains are too steep relative to the rest of the terrain. One solution is to remove some of the extra intermediate contours in the steepest areas. The goal is to do so only when necessary so as not to erode the communicative power of the map to convey that the slopes are indeed very steep in that region. This technique requires that the symbology convention for the contour lines uses index and intermediate contours, as the index contour lines will be the primary means for map readers to understand the severity of slope in these steepest regions.

Also, while this section will deal with the procedure for producing supplementary contours and thinning intermediate contours in steep areas, the resulting contour line dataset could also be used in a different manner to resolve this issue. This alternative approach is to reduce the line width of contour lines in steep areas for both index and intermediate contours, which would allow contour lines to be drawn distinctly within areas that would otherwise be too steep to show the lines distinctly. This method also lends itself to printing methods that rasterize the lines at high resolution; as the rasterization algorithms tend to favor maintaining gaps between lines, so as output resolution increases, the more likely distinct lines will be preserved.

The general procedure for producing supplementary contours is to divide the normal contour interval for the map in half, and produce contour lines for the entire map. Then create a slope grid (raster dataset) and reclassify that using slope classes along the lines presented in table 2. for a 1:25,000 scale map. (Generally for smaller scale maps, the need for sub dividing the high slope class will diminish as coarser resolution data is used as the input for contour line production because high slopes tend to be a high localized phenomenon.)

Slope Class	Degrees	± of upper value	Percent	± of upper value
Low	> 1.75°	0.25°	> 3%	0.5%
Normal	1. 75° to 15°	3°	3% to 26%	5%
Ranges for foothills and low mountains				
High ₁	15° to 25°	as needed	26% to 50%	as needed
High ₂	25° to 30°	as needed	50% to 60%	as needed
High ₃	30° to 35°	as needed	60% to 70%	as needed
High ₄	> 35°	as needed	> 70%	as needed
Ranges for high mountains				

High ₁	30° to 35°	as needed	60% to 70%	as needed
High ₂	35° to 41°	as needed	70% to 86%	as needed
High ₃	41° to 45°	as needed	86% to 100%	as needed
High ₄	> 45°	as needed	> 100%	as needed

Table 2. Suggested slope for determining whether to keep supplementary and intermediate contours. The ± values represent the variance that may occur based on how aggressive or conservative the contour interval is to begin with.

The resulting reclassified slope surface will likely be pock-marked with small pockets of slope classes that deviate from the prevailing trend. The idea will be to eliminate the smallest of these because the next still will be to convert these slope classes to polygons which will then be intersected with the contour lines. The object is to not create short contour line segments that do not add additional information with respect to describing the shape of the terrain. To accomplish this, the Spatial Analyst tool called Majority Filter should be used. One problem that may be encountered is that the resolution of the slope grid may be too fine, and while small pockets of non-conforming slope classes may be eliminated, too many slightly larger pockets will remain. If this occurs try using either the Resample tool to reduce the resolution (double the cell size initially) and try again.

Once a classed slope grid is produced that does not contain tiny pockets of variant slopes, convert that to polygons using the polygon tool. Next use the Identity tool with to assign the slope class values from the polygons to your contour lines. Once this is done, select all the contour lines that are of the supplementary interval that are not in extremely flat terrain and delete them.

Depending on the maps you'll be backing the rest of the contour lines should be retained as they may be useful for several different maps. Generally speaking the lines that will not be used on a given map (either between the contour interval for that map or in areas that are too steep should be filtered out of the map using a layer definition query).

MULTI-SCALE, MULTI-PURPOSE CONTOUR LINE DATA MODEL

Simple feature class						Geometry <i>Polyline</i>		Contains M values <i>No</i>		Contains Z values <i>No</i>	
Field name	Data type	Allow nulls	Default value	Domain	Prec- ision	Scale	Length				
OBJECTID	Object ID										
Shape	Geometry	Yes									
ID	Double	Yes			0	0					
CONTOUR	Double	Yes			0	0					
Righ2	String	Yes								4	
Righ3	String	Yes								4	
IsDep	Short integer	Yes			0						
Is20	Short integer	Yes			0						
Is40	Short integer	Yes			0						
Is50	Short integer	Yes			0						
Is100	Short integer	Yes			0						
Is200	Short integer	Yes			0						
Shape_Length	Double	Yes			0	0					

Contains contour lines representing ten foot interval changes in elevation

Elevation in feet

Denotes whether the contour is a depression (values > 1)

Denotes whether the contour is usable for maps needing a twenty-foot contour interval.

Denotes whether the contour is usable for maps needing a forty-foot contour interval.

Denotes whether the contour is usable for maps needing a fifty-foot contour interval.

Denotes whether the contour is usable for maps needing a one hundred-foot contour interval.

Denotes whether the contour is usable for maps needing a two hundred-foot contour interval.

Simple feature class					Geometry Polygon	
LiveOakCan_ContourMasks					Contains M values	No
					Contains Z values	No
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale Length
OBJECTID	Object ID					
SHAPE	Geometry	Yes				
FID_LiveOakCan_Contours	Long integer	Yes			0	
SHAPE_Length	Double	Yes			0	0
SHAPE_Area	Double	Yes			0	0

Masks for contour lines—produced by the Feature Outline Mask tool with the ContourAnno feature class as input and a 0.5 point gap.

FID of contour annotation element that the mask was made for

Annotation feature class					Geometry Polygon	
LiveOakCanyon_ContourAnno					Contains M values	No
					Contains Z values	No
Field name	Data type	Allow nulls	Default value	Domain	Precision	Scale Length
OBJECTID	Object ID					
SHAPE	Geometry	Yes				
FeatureID	Long integer	Yes			0	
ZOrder	Long integer	Yes			0	
AnnotationClassID	Long integer	Yes			0	
Element	Blob	Yes			0	0 0
SymbolID	Long integer	Yes			0	
Status	Short integer	Yes	0	AnnotationStatus	0	
TextString	String	Yes				255
FontName	String	Yes				255
FontSize	Double	Yes			0	0
Bold	Short integer	Yes		BooleanSymbolValue	0	
Italic	Short integer	Yes		BooleanSymbolValue	0	
Underline	Short integer	Yes		BooleanSymbolValue	0	
VerticalAlignment	Short integer	Yes		VerticalAlignment	0	
HorizontalAlignment	Short integer	Yes		HorizontalAlignment	0	
XOffset	Double	Yes			0	0
YOffset	Double	Yes			0	0
Angle	Double	Yes			0	0
FontLeading	Double	Yes			0	0
WordSpacing	Double	Yes			0	0
CharacterWidth	Double	Yes			0	0
CharacterSpacing	Double	Yes			0	0
FlipAngle	Double	Yes			0	0
Override	Long integer	Yes			0	
SHAPE_Length	Double	Yes			0	0
SHAPE_Area	Double	Yes			0	0

Contour annotation. Initially created with Maplex labeling and then hand edited to finish properly