Interval and Placement Effects on Topographic Data: Using Viewshed Analysis as An Example

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Abstract

This paper explores the sensitivity of analytical results using contours as the topographic data. In visualizing the topography of a landscape using contours, the two parameters under investigation are the size of the contour interval and the base contour chosen. Different contour intervals will generate different descriptions of the landscape. This is labeled as the interval effect. Choosing different base contours to compile the contour database can produce different landscape characteristics. This is called the placement effect. Using viewshed analysis in GIS as an application example, this paper assesses the interval effect and placement effect systematically based upon two study areas in northern Virginia, US. Contour data of 5-foot interval were resampled to derive data of different intervals and of different base contours. In general, larger contour intervals overestimate visible areas but visible locations are not consistently visible with increasing intervals. Results from using different base contours do not exhibit identifiable patterns, but the placement effect can truncate the edge of the landscape by excluding low lying areas. Finally, a probability viewshed approach is suggested to handle the two effects in analyzing contour data. This paper demonstrates that expert and novice users alike using contour data for topographical analysis have to realize that the result is only one of many possible outcomes and this issue is independent of GIS software adopted.

I. INTRODUCTION

The Modifiable Areal Unit Problem (MAUP), which did not attract much attention from geographers until the work by Openshaw and Taylor (1979) appeared, has been regarded by some researchers as one of the most persistent problems in geographical research (Fotheringham, 1989). In brief, the MAUP refers to the inconsistent analytical results based upon data derived from different spatial partitioning schemes, i) at different levels of spatial resolution or scale (scale effect); and ii) at one given level of spatial resolution or scale when different zoning patterns are adopted (zoning effect). The impacts of these two sub-problems of the MAUP on various types of analysis were briefly discussed by Fotheringham and Wong (1991) and the source of the MAUP was partly explored by Arbia (1989). Although some researchers claimed that the MAUP has been solved (King, 1997), unfortunately, most of these claims were either based upon superficial understandings of the problem or, based upon suggested solutions that are not generally operational or practical [interested readers can refer to the edited volume by Wong and Amrhein (1996)].

The nature of the MAUP is relevant as long as spatial data are gathered for partitioned areas, and thus most studies on the MAUP use either vector format data describing areas such as census areal units or raster format data such as that for remote sensing (Bian, 1997). Topographical data in the form of contours, however, are subject to the problems analogous to the two MAUP sub-problems. Any topographic analysis using contours is likely to be sensitive to how the contour data are gathered and recorded. Previous studies have investigated the sensitivity of topographic analysis due to the use of data at different levels of spatial resolution. These studies, however, are limited to the use of raster data such as a Digital Elevation Model (DEM). Other studies, which used contour data, investigated only how the results varied because of using contours at different interval levels.

This paper explores how results from analysis that uses topographic data in the form of contours vary when different contour intervals are used (interval effect) and, when different base contours are chosen (placement effect). To illustrate the effects of using different contour intervals and base contours, viewshed analyses of two regions with different topographic characteristics are performed. Problems related to viewshed analysis in general and algorithm development in specific have been discussed, but they are not the focus of this paper. The objective of this paper is to demonstrate that independent of software and algorithms, result or conclusion drawn from topographical analysis using a set of contours data is one of many possible outcomes due to the interval and placement effects. Users of GIS should be aware of this nature of using contour data. The next section briefly describes the interval and placement effects in topographic analysis based upon contour data. Then the third section describes the study areas and the design of the experiments and results from the viewshed operations are reported. The fourth section assesses the two effects systematically. The final section summarizes the general findings of this study and, other problems related to viewshed analysis.

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II. FROM THE MAUP TO INTERVAL AND PLACEMENT EFFECTS

The MAUP, which concerns different ways of partitioning space, can be explained by its two sub-problems: scale effect and zoning effect. The scale effect refers to the variability in analytical results due to data gathered or tabulated for different levels of scale or resolution. For instance, census blocks are hierarchical subdivisions of census tracts, and analyses using census block data and census tract data are likely to produce different outcomes. Zoning effect, on the other hand, refers to the variability in analytical results due to different spatial partitioning schemes given a particular level of spatial resolution or scale. For instance, in some areas in the U.S., local communities or neighborhoods defined by local authorities and postal zip-code areas defined by the U.S. Postal Service can be of similar sizes in terms of areas, but they do not correspond with each other spatially.

The impacts of the MAUP are evident in numerous studies. As early as the study by Openshaw and Taylor (1979), the MAUP effects on correlation coefficient were demonstrated. Fotheringham and Wong (1991) show that the MAUP effects are found in various types of statistical models. In addition, Wong (1997) demonstrates the MAUP effects on simple indices measuring ethnic segregation or integration. A few studies have explained the source of the MAUP (Arbia, 1989; Cressie, 1996; Wong, 1997), but no studies offer widely acceptable operational, or general solutions to the MAUP. Solutions limited to some specific modeling techniques do exist, such as for migration (Tobler, 1989) and simple correlation analysis (Wong, 2001), and the Geographically Weighted Regression framework (Brunsdon et al., 1996; Fotheringham et al., 1997) seems to be promising in solving the MAUP effects on regression models. Most of these studies use data in a vector format with socioeconomic attributes, such as census data, in the analyses. Other studies on the MAUP used raster format data, and quite often, these data were remotely sensed data (Arbia and Benedetti, 1996; Bian, 1997). But when raster data are used, only the scale effect was investigated. Many studies, however, have investigated how analyses using the DEM disseminated by United States Geological Survey (USGS), and other types of elevation data can yield results that are sensitive to the size of the grid cell, which defines the level of spatial resolution (Gao, 1997, 1998).

The concepts of the MAUP, however, can be extended further to analyze topographic data. Instead of applying the scale effect and zoning effect into the geographical space, the two sub-problems of the MAUP can be translated into the vertical dimension of space, i.e. elevation (or height). Theoretically, elevation data are at interval, or sometimes, ratio scales. Therefore, height, within the limitations of the accuracy of the measuring instruments, can be measured and reported precisely. From the user's perspective, the accuracy of the data, however, is affected by the models adopted to represent the landscape. If the raster structure is chosen, then elevation, theoretically, can be reported with the same level of accuracy as the data are gathered, despite the generalization of the surface elevation due to the surface representation models. Another popular model to represent landscape or topographic data is using contours. The contour model assumes a continuous surface of elevation, and conceptually, there can be an infinite number of contour lines to depict the surface. Unless data users have access to the original elevation data from which users can define the contour interval and select a base contour, otherwise, users have to accept the parameters of the contour data disseminated to them. Therefore, in practice, it is likely that only a set of contours of a given contour interval is used to represent the surface. It is in this case that the interval and placement effects should be considered further. Given today's advancement in geographic information technology, the contour format is still a very popular data format for disseminating topographic data.

Different contour intervals will produce different representations of the landscape. Using a small contour interval or vertical interval is likely to depict the topography more precisely than using larger intervals. In addition to the monetary cost required to obtain more precise data, another cost of using high precision data is the effort required to handle and analyze the massive data. On the other hand, using a large contour interval or a low vertical resolution can only capture the general structure of the landscape and the details of the topography are omitted. Thus, variation in the results due to the use of different contour intervals, which can be labeled as the interval effect, is analogous to the scale effect in the MAUP. Given a chosen contour interval, or the frequency by which contour lines are selected to depict the landscape, another parameter in defining the set of contours is the base contour. It is quite common to choose Mean Sea Level (MSL, 0) as the base contour if the area includes a coastline or waterfront. Sometimes round intervals of elevation (such as 5, 10, 20 regardless of the measurement unit) are used as the base contour. If the set of contours is treated as only one set of sampled contours from the entire contour database, there is no reason to assume that using MSL, or a round number as the base contour will generate a more representative set of contours than using other contours such as 3, 7, or 19 as the base contour. It is likely that using different base contours will generate different landscape surfaces and thus will affect the results of any topographic analysis based upon the generated contours. Choosing the base contour is the same as deciding the placement of the set of contours in the vertical space. Therefore, the variation in the results from choosing different base contours can be regarded as placement effect, which is analogous to the placement of zones, or the zoning effect in the MAUP.

In this paper, viewshed analyses are used to illustrate how these two effects can influence the depiction of landscape and hence results from landscape analysis. Viewshed analysis is a very popular GIS operation used on elevation data. The ideas and concepts are discussed and reviewed frequently in the literature (e.g., Burrough, 1986; Tomlin, 1990), and the viewshed concept can be modified in different algorithms to accommodate specific analyses (Lee, 1991). The interval effect of contour data has previously been mentioned in topographic analysis but not in the context of a viewshed analysis. For example, Gao (1997, 1998) investigated the relationship between the characterization of landscape and the resolution of the contours (i.e. the interval effect), but did not address the placement effect of contours. Fisher (1991, 1992, 1993, 1996) studied the algorithmic and data quality aspects of viewshed analysis, but his studies are limited to using DEMs and the scale effect of the MAUP. This paper attempts to address the interval effect and placement effect on viewshed analysis systematically using contour data.

III. DATA, ANALYSIS AND RESULTS

Loudoun County in northern Virginia, U.S. has spent several years compiling a comprehensive geographical database for the entire county. Included in this database are topographic data in a 5-foot vertical resolution derived from detailed surveys of the county. Within the county, two regions of different topographic characteristics were chosen to illustrate the analysis. One area is southwest of Leesburg, the largest town in the county, with a river cutting through several steep valleys. The other region chosen for this study is in the town of Sterling, which is on the southern bank of the Potomac River with a large portion of low-lying land, but with the relief getting steeper further from the river. Historic and archaeological sites recorded by the county historical database were selected as the viewing positions. These historical sites were used because viewshed analysis is frequently used to reconstruct historical settlement patterns and relationships (Lock and Stancic, 1995). Although this paper is not on archaeological study, we are using these sites as if a formal study is to perform.

There are ten sites in the Leesburg area and eight sites in the Sterling area. The two study regions and their associated sites are shown in Figure 1. Note that several historical sites in the Leesburg area are at the bottom or close to the bottom of the river valley and other sites are clustered along the slope of one side of the river valley. In the Sterling area, several sites are found parallel to the river bank on the low-lying area while the other four sites are somewhat scattered on the steep slope rising up from the bank. The contours and the shaded relief models shown in Figure 1 are in 5-foot intervals for both regions and a summary of the contour data for the areas is also included. In the Leesburg area, the TIN has 196,956 triangles, and in the Sterling area, there are 211,742 triangles. It is clear from the TIN models that the lower elevation areas are at the central to southeast portion in the Leesburg study area, and in Sterling, the low elevation areas are along the river bank on the north.

Treating the original 5-foot contour data as the most accurate description of the landscape based upon the best available data, this sensitivity study is to explore how results from viewshed analysis vary with different contour intervals (interval effect) and the selection of different base contours (placement effect). Therefore, it is necessary to create contour data at different intervals and using different base contours. To create data sets of different contour intervals, the 5-foot contour data were "resampled" to generate contour data of 10-foot, 20-foot and 50-foot intervals. Given each of these contour intervals, different base contours were used to generate separate contour sets. For the 10-foot data, two sets were generated. For the 20-foot data, four sets were generated. Theoretically, the 50-foot data could produce up to ten different sets based on different base contours. But for this exercise, only six sets were generated to illustrate the concepts and problems.

The base contours for all these sets of contours are reported in Table 1. In order to perform viewshed analysis, all contour data sets were converted into TIN using the ArcView 3-D Analyst extension. The original 5-foot contour data, which can be regarded as the most reliable database, followed the same process. Then a viewshed analysis was performed on each of these data sets using the selected historical and archaeological sites to identify areas visible to at least one of these sites. Therefore, the resulting map is a binary map (visible or invisible) in raster format. All of the binary maps output from the viewshed analyses have a spatial resolution of 10 meters. This level of spatial resolution was chosen because even with the steepest terrain in the two areas, no more than two contour lines are within 10 meters apart. In other words, each grid cell should reasonably reflect the results without much smoothing or averaging with 10 meter resolution. Interval and placement effects can be assessed by comparing visibility maps based upon data of different contour intervals or base contour selection.

From Figures 2 and 3, it is clear that the locations of the viewing positions are critical to determine the viewshed. In the Leesburg area, because sites are found either along the river bottom or on the slope of one side of the valley, the viewshed is restricted to the valley area. Locations outside of the valley or beyond the ridges are less likely visible. Similarly, in the Sterling area,

Table 1. Base contours for different sets of contours (in feet)

Contour Intervals (# of sets)	Leesburg	Sterling
10(2)	255, 260	185, 190
20(4)	255, 260, 265, 270	185, 190, 195, 200
50(6)	255, 260, 270, 280, 290, 300	185, 190, 200, 210, 220, 230

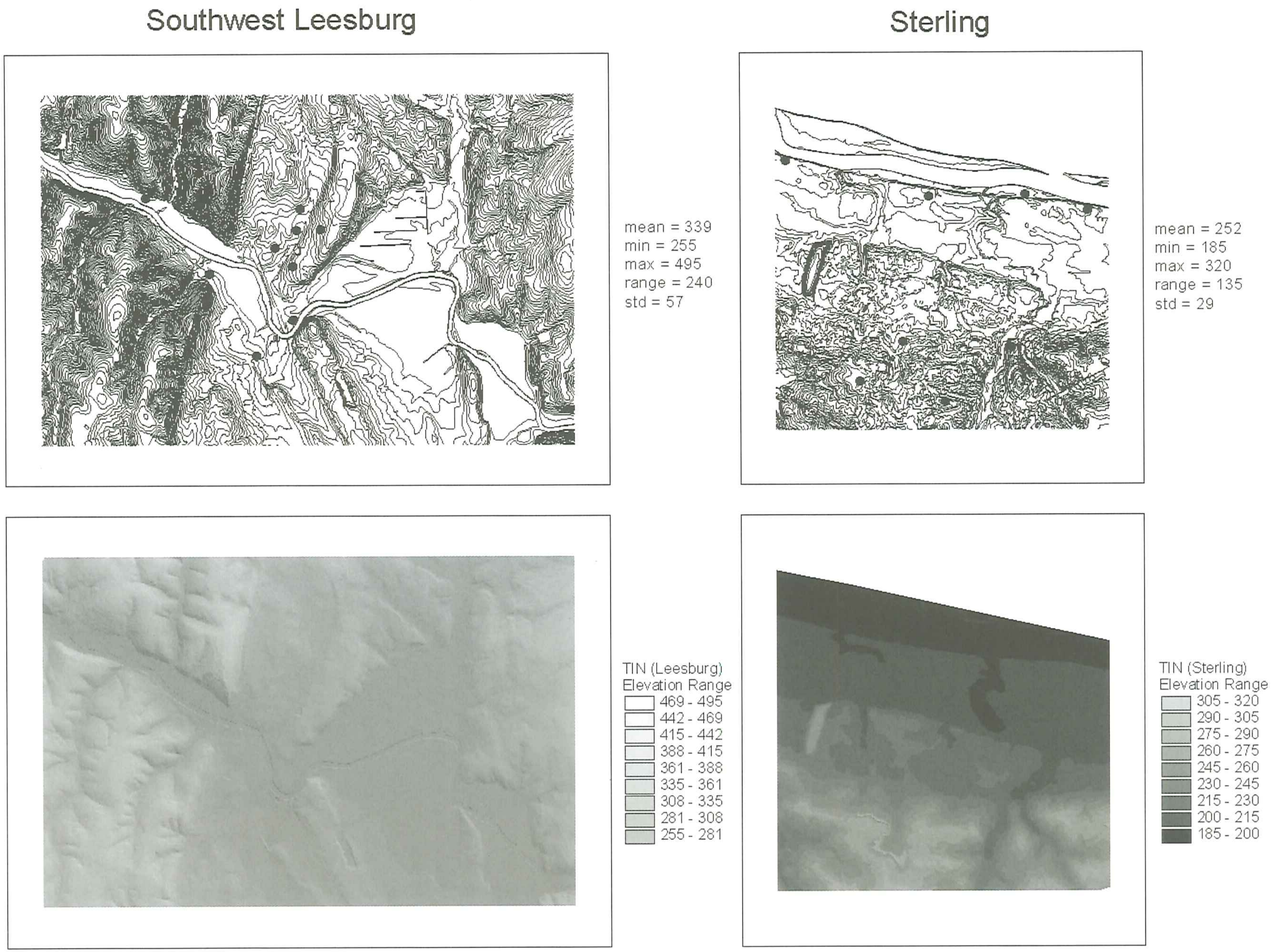


Figure 1. Contours and TIN models for Leesburg and Sterling areas with historical sites (in black dots)

locations south of the highest ridge in the study area are likely not visible because all the sites are on the north side of the ridge. In addition, a stretch of low-lying areas between the bank and the upward slope to the south is obscured from the viewing positions high up on the slope.

Figure 2(a) shows the result of the viewshed analyses which used the original 5-foot contours in the Leesburg region. To illustrate the interval effect, Figure 2 also includes results from using the 20-foot and 50-foot intervals. For a given contour interval, different base contours can be used to create the contour data and thus different results of a given interval can be derived. Differences from comparing results of different contour intervals are scale effect. As the contour interval increases, regardless of the base contours, the visible area tends to increase in the two study areas. In other words, using contour data of coarser vertical resolution is likely to overestimate the size of visible area based on the case studies. Whether overestimation is the norm requires further investigations.

Besides changes in the size of visible area, Figure 2 also shows that results are inconsistent over different intervals. Figures 2(b) and 2(c) were derived from the same base contour, and Figures 2(d) and 2(e) were derived from another base contour. Even though in general, data of larger intervals yield larger visible areas, locations visible at a smaller interval (20-foot) may become invisible at a larger interval (50-foot). Some of these locations are marked by polygons in Figure 2(c). This inconsistent pattern is also identifiable on the set of maps in Figures 2(d) and 2(e).

Figure 3 uses the same format as in Figure 2, but it shows the results of the Sterling contour data, the second study region. Figure 3 depicts similar results: 1) when a larger contour interval is used, the size of visible area tends to increase in general; and 2) locations visible using contours of a smaller interval may become invisible when data of a larger interval are used despite the general finding in #1. Figure 3, however, reflects another major issue. The study area shown by the set of maps in Figures 3(d) and 3(e) is smaller than the study area shown by the set of maps in Figures 3(b) and 3(c). The maps in Figures 3(b) and 3(c) use the lowest contour in the study area (185 feet) as the base contour, but the other set on the right use 200 feet as the base contour. Because the northern part of the study region includes the low lying landscape along the river bank, that portion of the area is not captured by the 200-foot base contour data. In fact, the set of contours (not included in Figure 3) using 220 feet as the base contour shows only half of the entire study area. The truncation of the landscape is very much a placement effect of the contours.

IV. ASSESSING INTERVAL AND PLACEMENT EFFECTS

To develop a better idea of the scale effect, different visibility maps from different contour intervals can be combined to show those areas that are visible or invisible. These maps are compiled using the additive rule of overlay. Assigning the value "1" to grid cells that are invisible and "0" to grid cells that are visible, then adding map layers derived from different contour intervals will generate a map of the combined estimates of visibility. On this map, cells with 0 indicate that the location is visible using any of the different contour intervals. However, at a given contour interval, different maps are produced depending on the base contour. Instead of showing all the possible outcomes, only two composite visibility maps are displaced for each of Leesburg area and Sterling area. These maps are shown in Figure 4 and indicate if a location is visible or invisible in all of the analyses undertaken with different contour intervals. Visually, the pattern of visible areas appears most similar to the viewshed results from using the original 5-foot contours. This outcome is not too surprising; as was mentioned in the last section, contour data of higher vertical resolutions tend to provide smaller visible areas. Thus, the composite maps showing the minimum combined visibility are closest to those derived from data of highest vertical resolution. However, these composite maps are different in detail from the results derived from 5-foot contours because some locations, which are visible using higher resolution contour data, may become invisible when using coarser data. Therefore, the composite maps have smaller visible areas than the results from the 5-foot contour data.

In order to assess the placement effect, different maps derived from different base contours, but using the same contour interval can be combined to show the visible area (Figure 5). These composite maps take into account the placement effect and show visible area regardless of which base contour is used. These composite maps for both study areas are shown in Figure 5. It does not seem to have any particular pattern among these maps when they are compared across different interval levels. Figure 5(f) of the Sterling area, however, exemplifies a problem discussed earlier: a portion of the landscape can be excluded from the analysis because the chosen base contour is higher than areas of lower elevation. This problem will not be apparent if the low-lying areas of the region are away from the edges of the study area, such as the situation in Leesburg where the lowest areas are the river valley in the middle of the entire study region. In the Sterling area, the lowest areas are along the river valley but they are also at the edges of the study area. Thus they were excluded when a base contour of higher elevation was chosen.

To summarize the interval and placement effects, the proportion of the area visible, based upon data derived from each selected contour interval and each selected base contour is reported in Table 2. For each contour interval, an average is derived from the different sets of contours of the proportion area visible. In general, larger contour intervals yield larger proportions of visible area. The coefficients of variation (CV) of these average proportions were derived and these can be regarded as the interval effect as they show how much the overall results of visibility change over different intervals. The

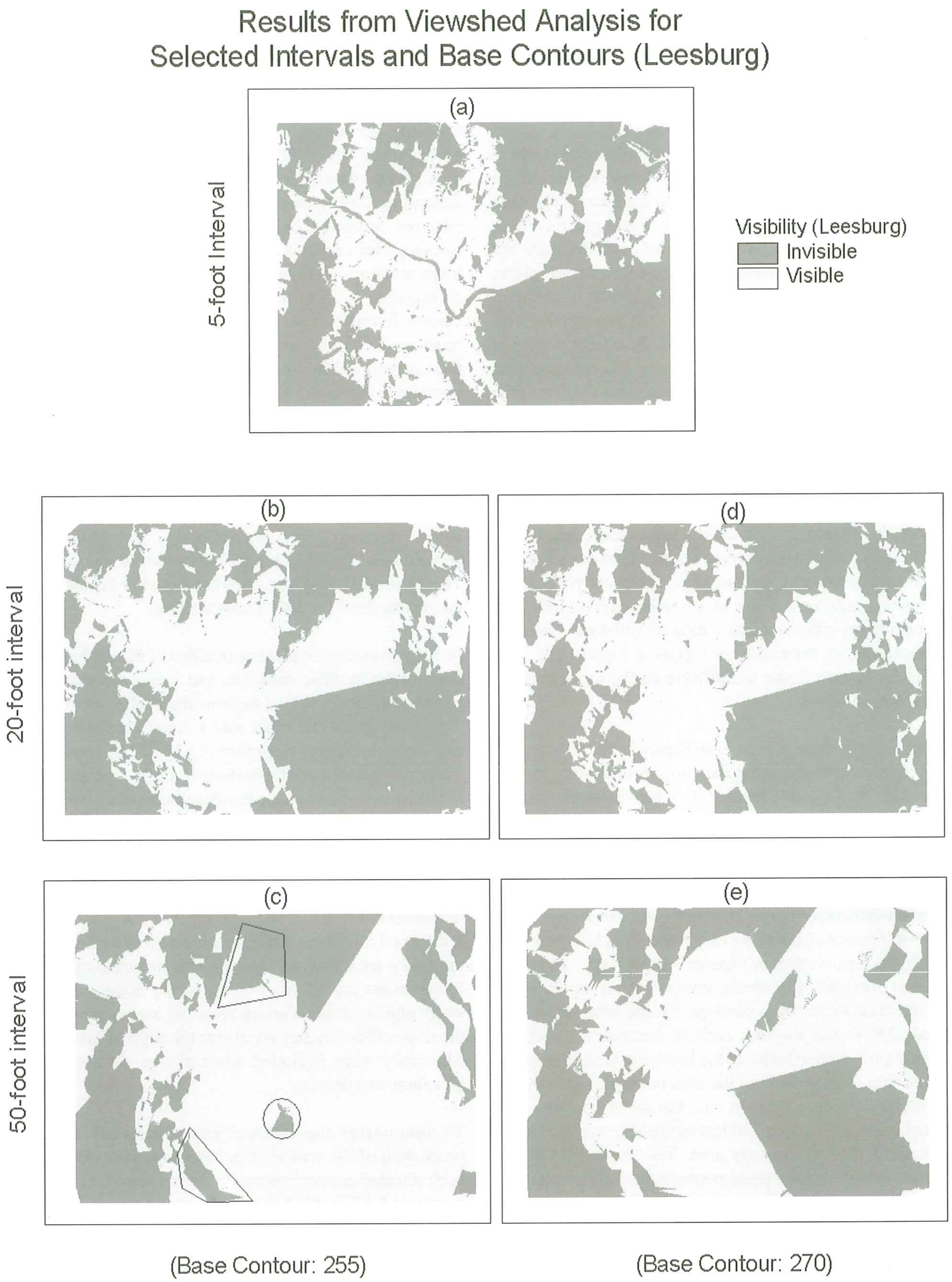


Figure 2. Results of viewshed analyses with selected contour intervals (5-foot, 20-foot and 50-foot) and two different base contours, Leesburg

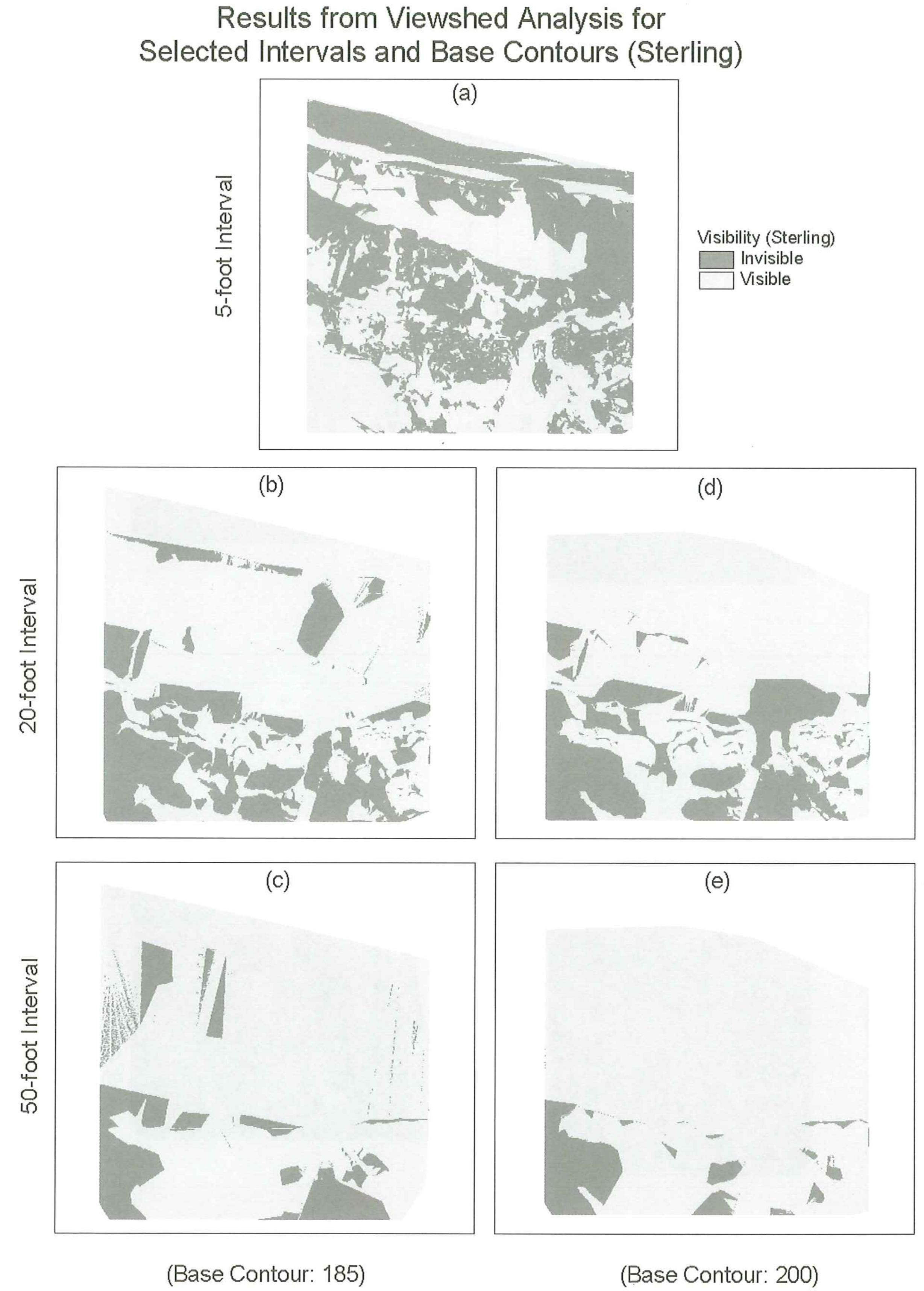


Figure 3. Results of viewshed Analyses with selected contour intervals (5-foot, 20-foot and 50-foot) and two different base contours, Sterling

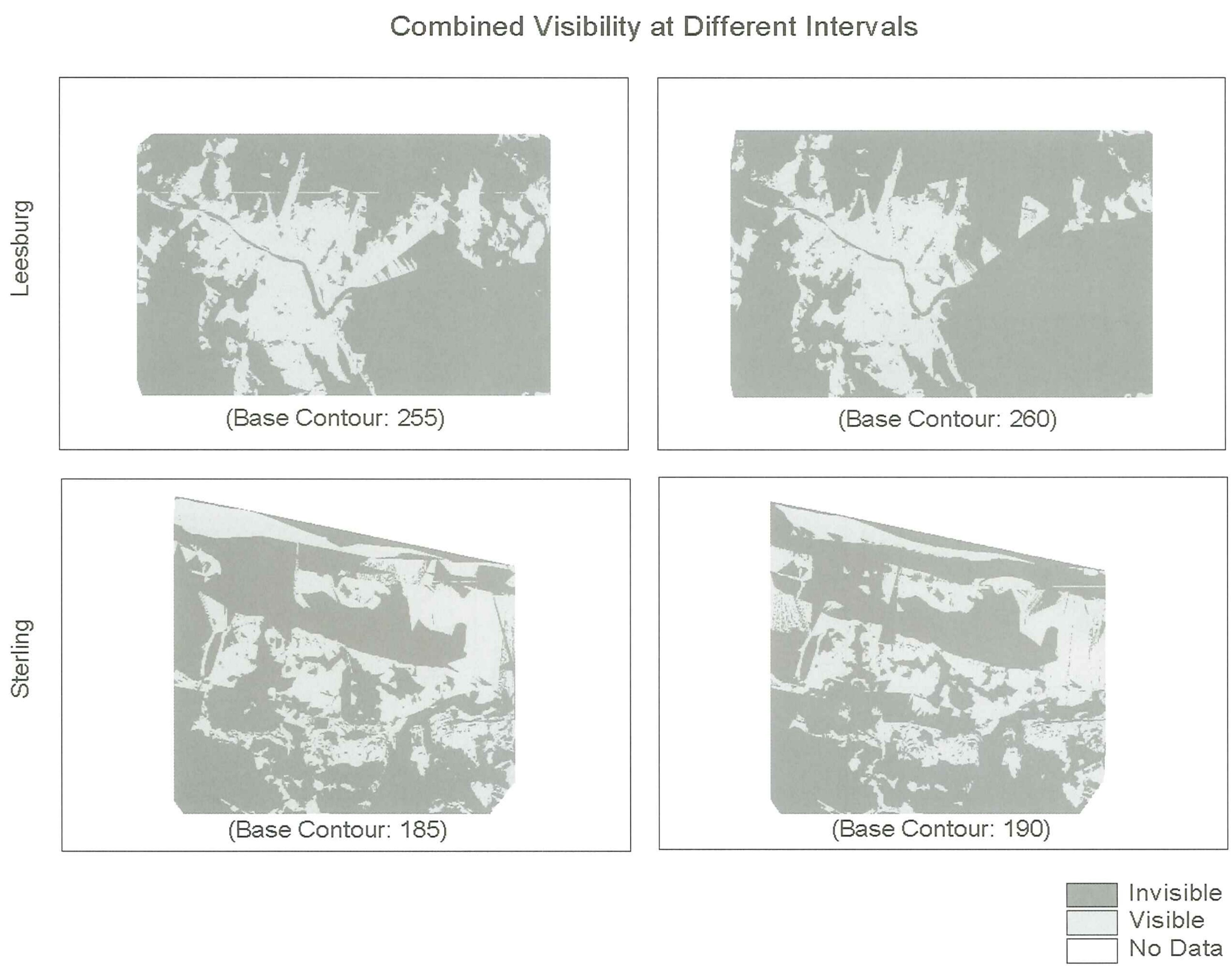


Figure 4. Combined visibility derived from results based upon different contour intervals for two selected base contours, Leesburg and Sterling

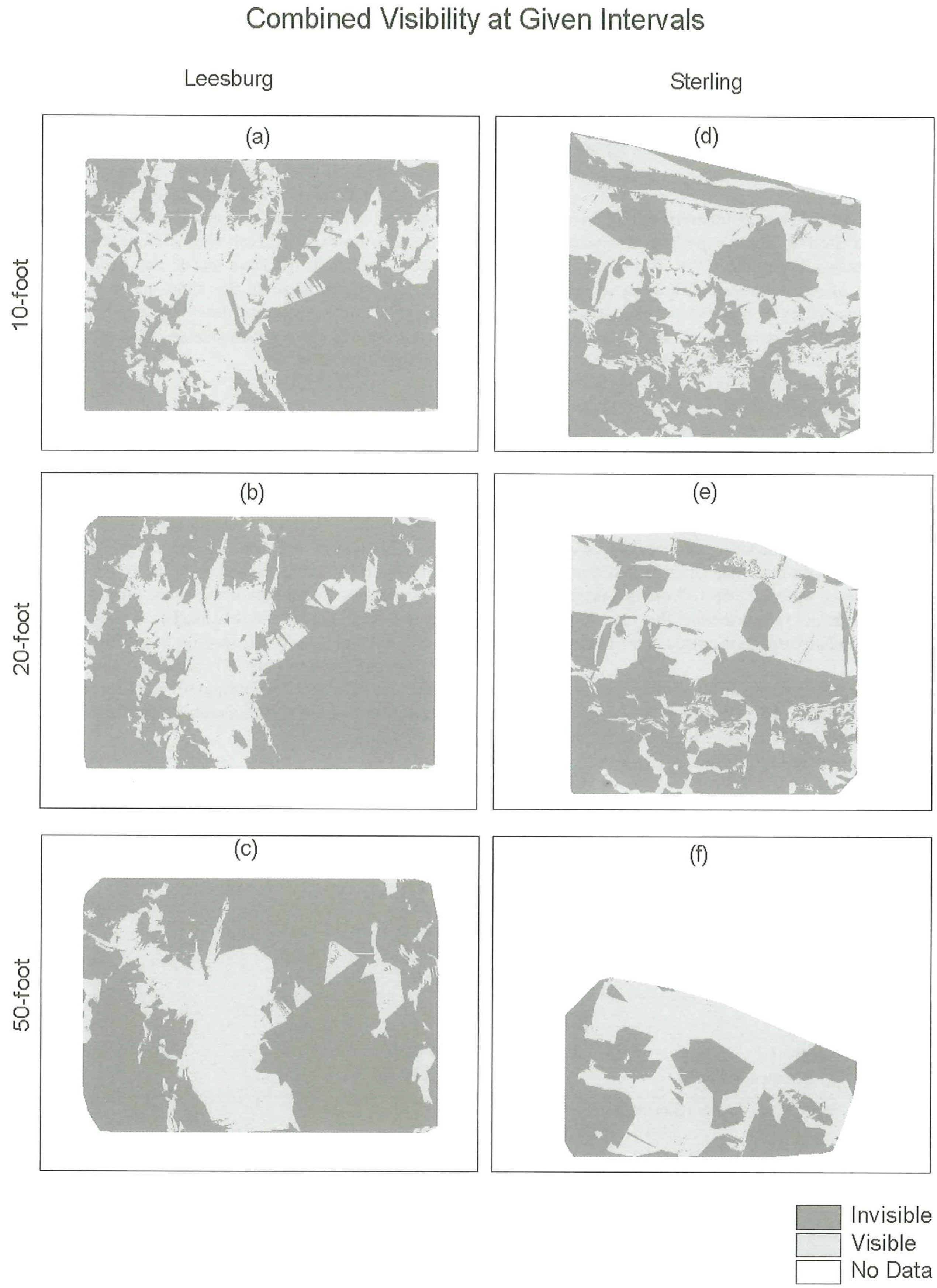


Figure 5. Combined visibility derived from results based upon different base contours for three selected contour intervals (10-foot, 20-foot, and 50-foot)

coefficient of variation is used instead of standard deviation because CV is standardized by the average such that sets of values with different averages are comparable in terms of their variations. For each given contour interval, the CV is derived for the proportions of visible area due to the use of different base contours. These CVs can be regarded as the placement effect because they indicate how the results vary when different base contours are used.

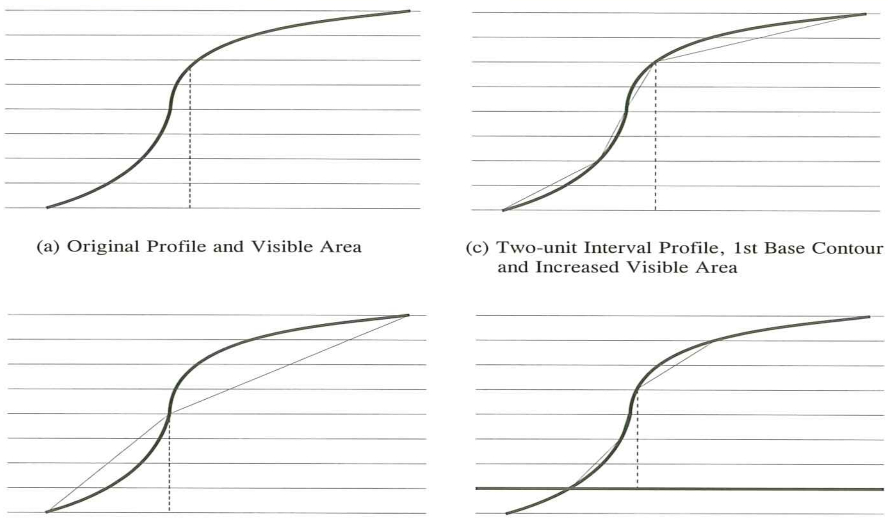
Regardless of the different characteristics of the terrain, both Leesburg and Sterling areas experienced almost identical interval effects based upon their CVs. This result implies that the variations of results in viewshed analysis due to using different contour intervals may not be affected significantly by the topographical characteristics of the landscape. The placement effects as reflected by the CVs, however, show a different pattern. Placement effects for Sterling are rather small (from 0.0683 to 0.0941) and do not vary much over different contour intervals. But in Leesburg, the placement effect is very small (0.0009) at the 10-foot contour level but the placement effect increases quickly when the contour interval increases to 50-foot (0.1525). Thus, for gentle terrain such as that in Sterling, the placement effect does not seem to be affected by the contour interval significantly, while for rugged terrain such as that in Leesburg, the placement effect is sensitive to changes in contour interval (interval effect). Note that the proportions of area visible do not reflect the fact that part of the original study area is excluded due to the placement effect in Sterling.

The tendency of overestimating visible area when larger contour intervals are used is clear from these two study areas. There is, however, evidence showing that increased visibility may not always be the case (Table 2). Two sets of contours at 20-foot interval yielded lower ratios of visibility than the ratio from the 5-foot contours. It is possible that increasing the contour interval may make more locations invisible. Figure 6 uses a hypothetical profile to illustrate both possible outcomes when larger contour intervals are used. Figure 6(a) shows the original profile. Area to the right of the dotted vertical line from the profile is the invisible area and the visible area is shaded. The horizontal lines indicate vertical units. In Figure 6b, a 4-unit interval is used. Assuming that linear interpolation is used, the straight lines cutting the profile is the smoothed profile with the 4-unit interval. The visible area is now slightly reduced. The results from two sets of contour intervals in the Leesburg area demonstrate this situation. In Figure 6c, the contour interval is 2 units and the visible area is slightly larger than the original, which seems to be the predominant situation in the two study areas.

From this simple illustration, whether the visible area will increase or decrease in size due to the interval effect is not a simple issue. The shape of the profile or slope is important, but the placement effect also has its impact. In Figure 6d, the second interval line is used as the base contour instead of the first interval line and a 2-unit interval is used again. In this case, the boundary between the visible and invisible zones has moved to the left as compared to the original profile and the visible area diminishes if the entire profile is used. But when the second interval line is used as the base contour and a 2-unit interval is used, the sections of profile in the bottom and the top no longer exist. Therefore, it is not clear if the visible area in terms of proportion of the entire study area has increased or diminished. In addition, part of the profile or slope may disappear.

Table 2. Summary of interval and placement effects

Percent Area Visible (Leesburg)					
	5 ft	10 ft	20 ft	50 ft	CV(Interval Effect)
	0.4193	0.4232	0.4553	0.6680	
		0.4237	0.4469	0.6684	
Different			0.3860	0.6565	
Base Contours			0.3597	0.7701	
				0.5759	
				0.4840	
Average		0.4235	0.4120	0.6371	0.2316
CV(Placement Effects)		0.0009	0.1130	0.1525	
Percent Area Visible (Sterling)					
	5 ft	10 ft	20 ft	50 ft	CV(Interval Effect)
	0.4981	0.5603	0.7102	0.8527	
		0.6172	0.7252	0.7492	
Different			0.6635	0.8296	
Base Contours			0.7399	0.9699	
				0.9102	
				0.7912	
Average		0.5888	0.7097	0.8505	0.2308
CV(Placement Effects)		0.0683	0.0467	0.0941	



(a) Original Profile and Visible Area

(c) Two-unit Interval Profile, 1st Base Contour and Increased Visible Area

(b) Four-unit Interval Profile and Diminished Visible Area

(d) Two-unit Interval Profile, 2nd Base Contour, and Diminished Visible Area

* Left of the dotted line is the visible area

Figure 6. Changes in visible area for a hypothetical profile with interval and placement effects

From the results of this study it appears that using data of different contour intervals and data derived from different base contours can produce strikingly different viewshed results. From the GIS user's perspective, there is often no control over the contour intervals at which the data are compiled or disseminated. Equally likely, the users often do not have many options but to accept the data regardless of which base contour was chosen to compile the data. Users conducting viewshed analysis usually use only one set of contours, or the only set of contours available to them. This set of contours is only one out of many possible realizations of the terrain surface and thus the result from the analysis is only one of many possible outcomes. Based upon the current study of the two regions, the proportion of visible area is overestimated in all situations (Figures 2 and 3). If we take into account both the interval and placement effects, the visible area should be much reduced. Figure 7 illustrates the outcomes by combining the results of the analyses.

The standard output of a viewshed analysis is a binary visibility map showing locations visible from at least one observing site. An additional output of the analysis is a map indicating the number of observing sites visible to every location. The number of observable sites for each location can be regarded as the score of that location. Higher scores mean that the locations are visible from more observing sites. For each study region, thirteen maps including the original 5-foot contours with the scores for each location were created using different base contours and intervals. In Leesburg, ten sites were selected. Therefore if a location is visible to all observing sites and in all the maps (i.e. regardless of which base contour was used or the contour interval selected), that location should have a score of 130 (thirteen maps and ten sites each) showing the aggregated visibility. The aggregated visibility map of Leesburg is depicted in Figure 7. Using the same idea, an aggregated visibility map of Sterling is also derived in Figure 7. With only eight observing sites, the highest possible aggregated visibility in Sterling is 104. Areas with high aggregated visibility are very limited in both study areas. Even the locations with highest visibility (106 in Leesburg and 58 in Sterling) have scores much lower than the highest possible scores. The highest score in Sterling is just slightly more than half of the highest possible score. These visibility scores can be scaled by the highest possible scores to derive probabilities so that aggregated visibility of different study areas are comparable based upon the standardized visibility scores. These standardized scores can also be treated as the probabilities that the locations will be observable by at least one of the observing sites while taking into account both the interval effect and placement effect of contours. In this study, Sterling has a much lower standardized visibility than Leesburg.

V. CONCLUSIONS AND DISCUSSION

This paper borrows ideas akin to the sub-problems of the modifiable areal unit problem (MAUP) to address issues of sensitivity in topographic analysis using contour data. Similar to the scale effect and the zoning effect of the MAUP, analysis of the landscape using contour data raises the issue of the interval effect and the placement effect of the base contour. Using viewshed analysis as an example application, this paper shows that one set of contours of a given contour interval and derived from a particular base contour can be regarded as one of many realizations of the topography. Using different intervals and/or base contours will generate different realizations of the landscape and thus results from analysis will vary. This conclusion is independent of GIS software adopted and the algorithms applied. Both expert and novice

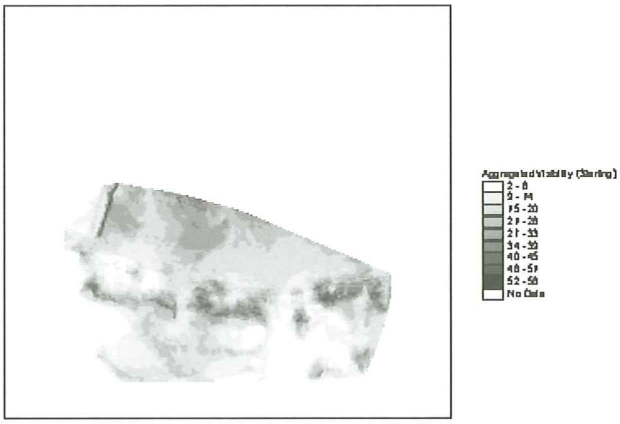


Figure 7. Maps of aggregated visibility for Leesburg and Sterling

users of GIS should be aware of the uncertainty of topographic analysis related to the interval and placement effects when contour data are involved.

This study uses only two areas with different topographic characteristics to perform the viewshed analysis. Such a limited empirical study cannot provide a comprehensive assessment of the impacts of the interval effect in determining the visible area. On the other hand, the placement effect seems to be more significant for relatively rugged landscape (Leesburg) than for more gentle landscape (Sterling). In areas with gentle landscape, however, placement effect could dramatically alter the representation of the landscape. If the chosen base contour is not low enough to include the area with lowest elevation, part of the area, especially along the edge of the study area with low elevation, will be excluded by the contour representation of the landscape. This effect is especially obvious in the Sterling area.

It is clear that the characteristics of landscape have significant impacts on viewshed analysis. On one extreme, if slopes in the study area are perfectly linear to distance, the interval effect will disappear and the placement effect can be solved easily. But unfortunately, most landscapes are much more complicated than landscape with linear slopes. The spatial arrangement of different types of landscape (such as valleys, cliffs, lowland, etc) is an important factor in determining the interval and placement effects. Gao (1998) attempts to link the characteristics of the landscape to various landscape parameters to model the interval effect. This approach has the potential to model the interval effects as long as the landscape parameters are known. Viewshed analysis, however, involves another variable, the locations of observing sites. This additional factor makes it difficult to relate the interval and placement effects with topographic characteristics of the landscape.

On the computational aspect of viewshed analysis, many factors or variables involved may create uncertainty in the analysis results. For instance, the procedure adopted in this study was to convert the contour data into TIN data before the viewshed analysis can be performed. It is widely known that this conversion process may be problematic in certain conditions (Lee 1994), however, this process alone cannot generate the nature and magnitude of the differences in the results depicted in this study. In addition, the truncation of the low-lying areas due to the placement effect is a conceptual problem of using contour data rather than a technical issue related to the data model. On the other hand, there are many problems with existing algorithms for viewshed studies. Even though some improvements were made on viewshed algorithms (Fisher 1996), many more have yet to be tackled. However, factors associated with algorithms were kept constant in this study, and would not affect the general findings of this paper.

This paper explores the sensitivity of landscape analysis with respect to the interval and placement effects of contour data. More systematic studies are required in order to develop "solutions" or approaches to handle these two effects. Fisher (1992) suggests the use of a fuzzy viewshed to indicate the uncertainty of visibility results when various factors of data quality are incorporated into the analysis. The approach of using an aggregated viewshed and the derived probability viewshed, as indicated in Figure 7, is similar to that of the fuzzy viewshed. It is potentially useful to show the overall visibility by taking into account the interval and placement effects. When the aggregated scores are standardized, the standardized scores can be interpreted as probabilities.

To identify the impacts of individual effects and the interactions of factors that affect the sensitivity of viewshed analysis, a promising approach is probably by simulations, which allow for the control of different factors. Future studies should try to identify conditions under which specific outcomes of the interval and placement effects will occur, such as whether the visible area will increase or decrease when larger contour intervals are used.

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