Exploring and Evaluating the Consequences of Vector-to-Raster and Raster-to-Vector Conversion

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Abstract
Spatial data can be represented in two formats, raster (grid cell) or vector (polygon). It is inevitable that conversion of the data between these two formats be essential to the best use of the data. Most geographic information systems (GIS) now provide software for such a conversion. The objective of this study was to explore and evaluate the consequences of data conversion on the accuracy of the resulting data layer. Simple shapes were chosen to document the results of the raster-to-vector and vector-to-raster conversion processes. These shapes included a square, a triangle (not aligned with the grid), a circle, a hole within the circle, and a non-convex shape. Error matrices were employed to represent the changes in area through the conversion process. A second set of data including a circle, a thin rectangle, and a wide rectangle were used to examine the effect of grid cell size on both presence/absence of a feature as well as to maintain the feature's shape. Finally, recommendations for continuing this work and its application to information derived from remotely sensed data were presented.

Introduction
Assessment of accuracy has long been a critical issue in the world of map making — How well does the position of the line on the map match its actual location on the ground? and/or, How well does the mapped category match what is actually found on the ground? National Map Accuracy Standards were established in the 1940s to be used with United States Geological Survey (USGS) maps. These standards were based upon the publication scale of the maps (1:62,500, 1:24,000, and 1:12,000), and specified the maximum allowable horizontal and vertical positional error (Maling, 1989). More recently, the use of remotely sensed data, especially satellite imagery, has dictated the need for assessing map category accuracy (Congalton, 1991). The advent of geographic information systems (GIS) presents a new set of accuracy problems because these computer maps can be plotted at any scale with relative ease. The map may meet accuracy standards at the input scale, but not necessarily at a larger scale that may be used for output, neither of which is always identified by digital map makers.

Spatial data are currently available and used in two digital formats. Raster data such as satellite images and scanned maps are comprised of numerically coded grid cells. Vector data are comprised of coded points, lines, and polygons. The growing use of GIS has brought about a need to convert data between these two formats. For example, satellite data are obtained in raster format (i.e., pixels) and yet it is common to want to use these data (e.g., vegetation or land cover) as a layer in a vector GIS. The user would have to translate the raster data into a vector format before it can be of use. The objective of this study was to explore and evaluate the effects on the data of this conversion process and the accuracy of the resulting digital map layer. Some simple polygons were taken through the conversion process to look for changes in shape, shifting of the position (edges), and changes in size of the polygons.

Literature Review
There are two data formats available for digital maps: raster and vector (Burrough, 1986). A map in raster format is composed of numerically coded grid cells, each code representing a specified classification, and each grid cell containing one of these classification values. The classification system may be, in the simplest case, binary (0/1) where 1's identify the location of an entity such as a road and 0's indicate locations where these entities are not found. The classification system may also be rather complex as in satellite images where values for each grid cell fall within a range (0 to 255) of digital numbers (corresponding to 8-bit data), each representing the amount of light within a given bandwidth reaching the satellite from a specific area on the ground (grid cell or pixel). Vector maps, on the other hand, are stored in the computer as a series of points, lines, and polygons (Congalton and Green, 1992). Each entity is coded appropriately, and represented much as we would expect. A point has an identification number and a location marked by a pair of (x,y) coordinates. A line is composed of a series of points, and a polygon is composed of a group of lines. Digital maps of a given area can be produced in either of these two formats; the choice is up to the users and is usually based upon their needs and the software available to them.

The format of the map influences the accuracy of the map as does the method of input. Vector maps are usually digitized (traced with an electronic device that records x,y coordinates of each entity on the map) manually, introducing a new source of error. If this is the case, then the input map will have a specified scale, and, possibly, a specified level of accuracy. The party responsible for creating the original digital map can apply digitizing standards. For example, the University of Rhode Island requires that 80 percent of all lines within a digital map layer lie within 0.2 inches and 90 percent of all lines lie within 0.1 inches of the lines on the source document when drawn or plotted at the same scale (RIGIS, 1988).

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Burrough (1986) noted that there are two sources of error associated with digital maps, those associated with the source document, and those associated with the digital representation. He presented an assessment of errors associated with digitizing a map. For example, the width of the line and the scale of the source map that is to be digitized have an influence on the position of the cursor (therefore, on the x,y coordinates collected) during digitization. Also, the number of vertices collected while digitizing curves has an influence on their shape. If digitizing standards exist, and if we know the accuracy associated with the original source map, then it will be possible to produce overall accuracy information for the digital map layer which can then accompany the digital map through future operations.

With the increased use of geographic information systems (GIS) comes increased use of alternative methods of data input and output, and a need for combining data stored in various formats. Scanning of paper maps and incorporating satellite data into GIS layers is on the increase. A major problem arises here in that these maps are not always stored digitally in the same format, but rather they exist in a combination of formats, and have a combination of accuracy levels. If we have a raster GIS and all of our data are in raster format or if we have a vector GIS and all of our data are in vector format, our problem becomes one of accuracy level between input maps. However, if we wish to combine raster and vector data layers within one GIS system, and output the data to another GIS system or to an output device that converts the data to another format (electrostatic plotters, for example, will convert vector data to raster format before plotting and pen plotters necessarily plot vector lines), then we need to be able to quantify the level of accuracy of the product. Obviously, there is a need to assimilate existing data regardless of its format. We are also faced with the problem of how to go about converting maps between the two formats, and how to assess the accuracy of the maps that result from the conversion process, especially if the conversion occurs more than once in the lifetime of a digital map layer.

Conversion between raster and vector formats has long been considered. The first applications developed were vector images displayed on raster devices such as television screens (Franklin, 1979). More recently, with the increase in use of computers and graphics plotters and display devices, it has been necessary to evaluate methods of rasterizing lines for the purpose of displaying them on raster display devices (Franklin, 1979). Parker (1988) investigated raster-to-vector translations for the purpose of speeding manipulation of raster images. Vectors are more easily scaled, rotated, and plotted; they also require less storage space on a computer disk. If raster images could be reliably transformed into vector data, many operations could be performed with more efficiency. Much of the focus for the raster/vector translation seems to be based on which algorithms to choose to minimize computer processing costs (available or required memory, I/O cost, amount of data contained in memory at one time, etc.).

This paper will not address computer programming or hardware issues in detail as pre-existing software and hardware will be used. Instead, the objective of this paper is to explore and evaluate the accuracy of the translations and the differences between files presented in these two different formats. This project examined, on an individual polygon basis, the effects of rasterization of vector data and of vectorization of raster data. A second item of interest here involves multiple translations from vector to raster and back, in an effort to model reality. A single map, for example, may in its lifetime be converted back and forth several times through raster/vector translators for various types of analysis. The question here is what effect does the conversion process have on the accuracy of a digital map.

Background

Two processes, rasterization of vector data and vectorization of raster data, were investigated in this study. A basic understanding of these conversion processes and the error attributable to them will give rise to an understanding of the limitations of the resultant data. The first process, rasterization of vector data, occurs any time data are created in raster format. If existing vector data files are sent to a raster display device (plotter or terminal) or to a raster geographic information system, they must be rasterized first. Satellite imagery is purchased in raster format, yet it too is the result of a rasterization process. Features on the ground are composed of lines (roads, streams) or polygons (trees, bare ground, lakes, soil types), but the satellite captures images of these features as 10-, 20-, or 30-metre grid cells; hence, it rasterizes images as it captures them. The second process, vectorization of raster data, occurs every time raster data (satellite images or scanned data, for example) are incorporated into vector-based output devices or geographic information systems. Combinations of these two processes occur when data are moved back and forth between raster and vector systems.

Vector-to-Raster Conversion

Several issues involved with the actual conversion of vector data into raster format have been identified. Piwowar (1987) noted three: (1) polygon fill — filling the interior regions of a newly rasterized polygon with the correct classification value; (2) cut cells — choosing one classification for a cell that actually contains more than one class; and (3) cell size — choosing cell sizes that balance the size of the raster file with the quality of the conversion.

Polygon Fill

Polygon fill is transparent to the user of the Arc/Info geographic information system (ESRI, 1990), the software selected for this project. The POLYGRID routine assigns a single value to each cell in the interior region of a polygon based on a user-assigned item value found in the polygon attribute table of the coverage. Because there is no user input to drive or alter this particular process, the reader is deferred to Franklin (1979), Lee (1981), Pavlidis (1981), and Piwowar (1987) for a more detailed discussion of the polygon fill issue.

Cell Classification

Arc/Info assigns the value of a raster cell to the classification that makes up the majority of the area of the cell. It does have an option, however, to weight classes so that the class with the highest weight, rather than the class with the largest area, becomes the value of the grid cell. Walsh *et al.* (1987) cited Nichols (1975) who used areal extent within a cell and the soil type occurring at the midpoint within each cell to create detailed soil maps for analysis. His results showed the areal method to be the more accurate. Other methods of cell assignment have been studied. For example, Kishimoto *et al.* (1986) evaluated three digitization schemes. In the first scheme, called grid intersect quantization, a pixel is included in the raster file if and only if the vector to be rasterized intersects the square whose four vertices are the centers of the four grid cells sharing the grid point. Second, the square box quantization rotates that square, using centers of the four adjacent pixels rather than midpoints of their edges. Finally, the last scheme is called Danielson's quantization and includes a grid point in the raster version of a file if it lies within a specified distance of the vector (Figure 1).

Cell Size

Grid cell size is also an important consideration in the vector-to-raster translation. Choice of grid cell size determines what information is carried to the raster format, and with

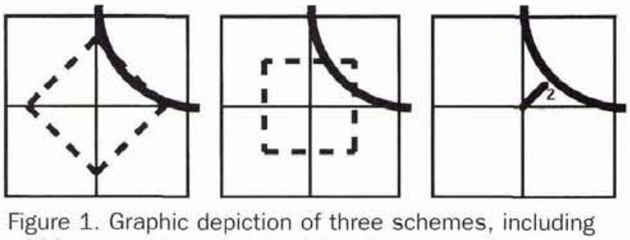

Figure 1. Graphic depiction of three schemes, including grid intersect, box, and Danielson's quantizations, used for cell assignment.

what level of accuracy it is maintained. Eveleigh *et al.* (1989) found, while extracting contour lines from scanned imagery, that problems arise when the pixel size is large enough to contain more than one contour line. Their solution was to reduce the size of the grid cells in relation to the raster image. Walsh *et al.* (1987) found that accuracy of his land-cover classification map decreased as the resolution of the grid cells became more coarse. Piwowar (1987) suggests that the optimum grid cell size should be one-fourth the size of a minimum polygon to be sure to maintain integrity of the data. Kishimoto *et al.* (1986) found up to 30 percent error in areas and expected squared distances between vector circles and their raster counterparts for trials where the grid cell sizes were large with respect to the circles (grid cell size of 1 square unit, circle with radius of 20 units).

Whede (1982) studied the cell size issue as well, concurring with Piwowar (1987) that, as the size of the grid cell increased, accuracy of the resultant raster data decreased. He found that for a given polygon, once the grid cell reached a certain size (resolution exceeding twice the area of the minimum mapping unit), the mapping error would reach 100 percent. Large cell sizes in relation to the minimum polygon size would present a situation where the polygon would never dominate a cell, and would therefore never be included in the rasterized version of the file. Grid position becomes a factor as well. A small polygon may not dominate any cells if the grid is in one position, and thereby be lost. Yet, if the grid is shifted, it may be included in the translation (Figure 2). When considering a complete map, consisting of several polygons at the minimum mapping unit size, some will be included and some lost no matter where the grid is positioned. Whede (1982) concludes that, "Grid positioning is not an important map accuracy consideration for maps but is a significant source of mapping error variation for individual map polygons."

For the purpose of this study, the grid cell size was predetermined — 25 metres for geocoded TM data or 30 metres if not geocoded and either 10 or 20 metres for SPOT data. The issue at hand, then, was what size should be chosen for the minimum mapping unit (MMU)? Whede (1982) found that one should expect 100 percent error for these smallest polygons if the grid cell size chosen was more than twice the area of our minimum mapping unit. Piwowar (1987) suggested that the grid cell size should be one-fourth of the area of the MMU in order to maintain the integrity of our data. The issue then is whether or not it is important to know what the shape of this minimum polygon is or simply to know that it exists. If only the presence of the minimum polygon is required, then a larger cell size can be chosen than if the knowledge of the exact shape of the minimum polygon is needed.

Raster-to-Vector Conversion

Several issues involved with the actual conversion of raster data into vector format have also been identified in this project: (1) pre-processing raster files to reduce the sheer volume of information that is to be processed, (2) enhancement of the raster image, (3) post-processing of data once it has reached the vector format, and (4) addressing differences in appearance of polygons represented in raster and vector format.

Pre-Processing of Data

Pre-processing of raster data may be employed to reduce the large amount of data that may exist in a single raster file. The result of digital satellite image classification is a pixel-by-pixel labeling of the entire image. These data are easily stored in raster format but difficult to convert to vector format. In the worst case scenario, each pixel in the image would become a polygon. Such a large amount of data would quickly defeat even the largest computer. Additionally, in many instances the desired result of image classification is not a pixel map, but rather a polygon map of areas of similar characteristics (i.e., forest stands). These polygons would approximate the result achieved by on-the-ground field visitation or more commonly by photo interpretation. It is, therefore, desirable to reduce the pixel-by-pixel classification to some smaller number of polygons, i.e., simplify the image before the conversion to vector format.

Enhancement of Data

Besides reducing the number of individual classified pixels in a satellite image, we may wish to enhance areas of interest on the raster image before the translation to vector format. Parker (1988) identified the regions (or lines in the case of a line file) of interest, and then enhanced them. Enhancement was performed using a thresholding program that creates a binary raster image. Vectors were then extracted from this binary image by use of a simplified chord test. In this test, a pixel was selected to become the end point of a vector, the vector was then grown in one direction, and calculated from the equation $Y = mX + b$, until the vector ends. A pixel was considered to be part of the vector if the distance from its center to the vector being created was less than one pixel width. Parker (1988) created sets of pixels that belong to lines, then extracted lines to create vector images. He did not perform an accuracy test on the final vector image; however, all vectors created necessarily lie within one pixel length of the original raster data.

Post-Processing of Data

Another consideration in the raster-to-vector translation process is the appearance of the newly created vector data. For the purpose of presentation or analysis, a user may wish to modify the blocky appearance of the data. Modifications may include smoothing the initial vectors to remove or reduce the amount of aliasing (i.e., stair-stepping) so that they will have a more "real" appearance, or reducing the number of vectors (or vertices within vectors) produced during the initial translation. Bury (1989) described a methodology for the raster-to-

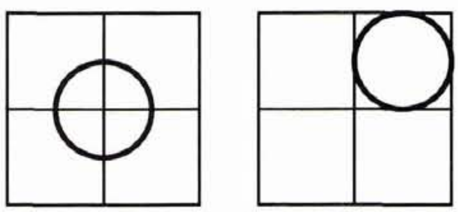

Figure 2. Diagram showing the effect of grid position on detection of small polygons.

vector conversion that included simplifying and smoothing the vectorized raster file to reduce the jagged appearance of the polygons, thereby producing a more realistic map layer. The sheer number of single cell polygons that may exist in a satellite image, for instance, may become a problem during a raster-to-vector translation. If the user has not employed any pre-processing techniques, he may wish to reduce the number of these individual polygons that have been produced by eliminating those that are too tiny to have meaning or by combining them with other polygons. The problem that arises is that the user is changing the data, and therefore its level of accuracy. Eliminating small polygons or smoothing lines enhances the graphic appeal of the map product but has an effect on the accuracy of the map that needs to be addressed and understood.

The raster-to-vector translation may present yet another problem — each vector created from a raster file contains the vertices of each and every corner of each and every grid cell that it bounds. Each line is composed of a series of *x,y* coordinates (vertices) that when combined form a series of short segments; when these short segments are combined, they form a line. Where the newly formed line passes between several grid cells in a straight line, extraneous vertices are created at corners of each and every grid cell. This artifact complicates the data and requires more disk space than necessary because only the two end points are needed to define a straight line. Douglas and Peuker (1973) and Roberge (1985) investigated algorithms to generalize lines and to reduce the number of coordinates required to form the lines. This reduction in the number of *x,y* coordinates required to define the line saves both memory during the plotting or display process and disk space. By reducing the number of coordinates in a line, the quality of the display is also improved. According to Roberge (1985), if the resolution of the data is smaller than that of the display device, displaying it actually means trying to draw sub-pixel sized lines.

ESRI's Arc/Info software contains routines to post-process the newly vectorized data. ELIMINATE removes tiny polygons based on user specific criteria (for example, if the area is less than a given value or if the perimeter-to-area ratio is abnormally high, a polygon will be removed). The GENERALIZE routine uses the Douglas and Peuker (1973) algorithm to remove extraneous vertices and to smooth the sharp stairsteps from the vectorized data. Other software products often have similar capablities.

Apparent Differences between Raster and Vector Files

It is important to address the differences between the appearance of polygons represented in raster and vector formats. Diagonal lines and circles, for example, are not represented in raster format by straight lines or smooth curves. Instead, they are stairstepped because their source was a grid of classified raster cells and it is impossible to draw straight lines using grid cells in any non-ordinal direction. These "island" polygons present a problem in that not only the outer edge but also the inner edge of a polygon must be taken into account for display or area/perimeter calculation. Single pixel width protrusions, especially if they exist on a diagonal where grid cells come together as points rather than areas, present a problem during the initial vector calculation because a single polygon may be broken up into small square pieces lying along a diagonal, or they may be lost completely. Therefore, shapes of the objects can be dramatically changed during the translation process.

Accuracy

To measure the accuracy of these conversions, the attributes of the objects in question can be measured. In the case of a raster-to-vector conversion, the area and perimeter are common parameters to measure (Kishimoto *et al.*, 1986; Walsh *et al.*, 1987; Piwowar, 1987; Keefer *et al.*, 1988; Prisley *et al.*, 1989). Measuring these parameters, however, does not tell the entire story. Displacement (mentioned by Piwowar (1987) but not quantified) is the difference between the original shape and the raster shape. It shows a change in shape and the amount of shifting that may have occurred. A measure of the displacement, the area between where the vector was and where the raster is, will provide more information about the accuracy of the translations. This project quantified the amount of area committed to each polygon in error, the amount of area omitted from each polygon, and the amount of area correctly assigned to each polygon within a map. This analysis was represented as an area error matrix. Other measures of change have been investigated and may merit further investigation. Prisley *et al.* (1989) found that the variance of the area may be used as a parameter to compare raw versus smoothed lines in raster/vector format and Kishimoto *et al.* (1986) studied the squared distance between the vector and raster images of a circle.

Methods

The Process

In this study, Arc/Info (ESRI, 1990) was used as the primary software for the raster-to-vector and vector-to-raster conversion. The two steps in the process were as follows:

(1) Vector → Raster (→ Vector for comparison)
(2) Vector → Raster → Vector then GENERALIZED

The vector-to-raster conversion was performed within Arc/Info using the POLYGRID routine (PC Arc/Info, Overlay Module). The process began with five simple shapes (Data Set 1), input as vectors, and rasterized using five grid cell sizes (0.5, 0.2, 0.1, 0.05, and 0.025 inches on each side or 0.25, 0.04, 0.01, 0.0025, and 0.0006 square inches). The raster-to-vector translation was then computed within Arc/Info using the GRIDPOLY routine (PC Arc/Info, Overlay Module) with grid cell sizes identical to those used for the initial rasterization. ESRI's raster-to-vector conversion produces a vector copy of the raster file. Vertices exist at the corner of every raster cell that borders a polygon, and the areas of each new vector polygon correspond to those calculated by summing the number of cells per polygon in raster format then multiplying that sum by the size of the grid cell. Table 1 presents the areas of the original vector shapes, the areas after the shapes were rasterized at the various grid cell sizes and then converted back to vectors, and the fraction of each grid cell size per shape. Because the raster shapes and the vectorized raster shapes are the same in area, the vectorized version of the raster file can be treated as if it were the actual raster file. The advantage here is that overlay functions from a vector GIS can be used to calculate areas of displacement between vector and raster files. In addition to the conversion routines, this project utilized the Arc/Info GENERALIZE (PC Arc/Info Starter Kit) and SPLINE (PC Arc/Info Arcedit Module) commands with an emphasis on changes in shape and area of the original polygons.

The Data

Two sample data sets were generated for use in this study. Data Set 1 consists of five simple shapes including a square, a triangle (not aligned with the grid), a circle, a hole within the circle, and a non-convex shape. Data Set 2 consists of three simple shapes of equal area (one square inch) including a circle, a wide rectangle, and a narrow rectangle.

Results

The results of the analysis of Data Set 1 are presented in Figures 3 and 4 and Tables 2 through 6. The smallest polygon

Table 1. A listing of the areas (square inches) of the original vector shapes, the raster and vectorized raster shapes compared to the original (square inches and percent), and the fraction of each grid cell size per shape.

ORIGINAL VECTOR AREAS (SQUARE INCHES)

BACKGROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE
56.6065	2.604	1.8668	5.8588	.5086	2.5554

RASTER and VECTORIZED RASTER DATA AREAS (SQUARE INCHES and % DIFFERENCE FROM ORIGINAL)

GRID CELL SIZE (in ^{2})	BACKGROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE
.25	57.25 (101.1%)	2.25 (86.4%)	1.50 (80.4%)	6.00 (102.4%)	0.50 (98.3%)	2.50 (97.8%)
.04	56.6 (100.0%)	2.56 (98.3%)	1.84 (98.6%)	5.88 (100.3%)	0.52 (102.2%)	2.60 (101.7%)
.01	56.45 (99.7%)	2.72 (104.5%)	1.90 (101.8%)	5.81 (99.2%)	0.51 (100.2%)	2.61 (102.1%)
.0025	56.645 (100.0%)	2.56 (98.3%)	1.865 (99.9%)	5.86 (100.0%)	0.5075 (99.8%)	2.563 (100.3%)
.0006	56.613 (100.0%)	2.60 (99.8%)	1.866 (100.0%)	5.854 (99.9%)	0.51 (100.2%)	2.557 (100.0%)

FRACTION OF GRID CELL SIZE PER SHAPE

GRID CELL SIZE (in ^{2})	BACKGROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE
.25	1/226	1/10	1/7	1/22	1/2	1/10
.04	1/1415	1/65	1/47	1/146	1/13	1/64
.01	1/5660	1/260	1/187	1/586	1/51	1/256
.0025	1/22,643	1/1042	1/747	1/2344	1/203	1/1022
.0006	1/93,344	1/4340	1/3111	1/9765	1/848	1/4259

was the hole with an area of 0.5086 square inches (Table 1). Using a grid cell size of 0.25 square inches or 0.5 by 0.5 inches (Figure 3), the hole is present in rasterized format but information about its shape is lost. The larger circle becomes an orthoconvex polygon, a polygon whose intersection with any horizontal or vertical line is a point, a line segment, or the empty set. Using smaller grid cell sizes, the hole also appears as a nonrectangular ortho-convex polygon (Figure 4). Error matrices (Tables 2 through 6) are used to show the correctly classified area (values on the main diagonal), the area of commission error (i.e., areas mistakenly put into other shapes), and the area of omission error (i.e., areas mistakenly left out of the correct shape) for each of the five shapes plus the background.

Total area assigned to the polygon (Table 1) is misleading because it contains two types of error. Some areas were committed to each rasterized polygon in error, and some areas were omitted from each rasterized polygon in error. A look at an example quickly demonstrates the power of the error matrix for comparing total area at a given grid cell size versus correct area (i.e., area that falls within the original vector shape). At a grid cell size of 0.5 by 0.5 inches (0.25 square inches), Table 2 shows a total area for the rasterized square shape as 2.25 square inches or 86.4 percent of the true vector area. However, the actual area correct is the value in the major diagonal of the error matrix which is 2.07 square inches or 79.5 percent of the true vector area. This result demonstrates that, although in the rasterization process the shapes may not change that much, shifting of the shapes can be a big problem.

As the grid cell size decreases, the number of these error polygons increases dramatically (Figures 3 and 4) but the area of each polygon decreases even more dramatically. The

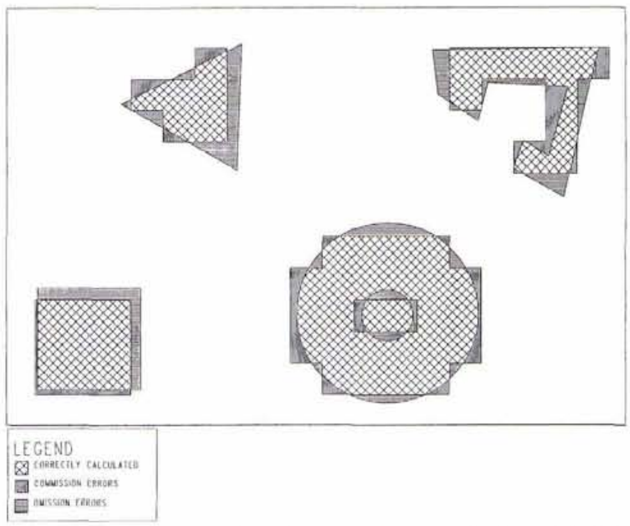

Figure 3. Plot of the five shapes using a cell size of 0.25 square inches (0.5 by 0.5 inches).

overall effect was a reduction in the total area found in these error polygons (refer back to Tables 2 through 6). A measure of the change of shape and a method of determining the amount of area committed to each polygon and omitted from each polygon in error was needed. Using the overlay functions of Arc/Info, the original vector data were combined with a vector representation of the raster data. This overlay capability produced a map (Figures 3 and 4) that illustrated classification errors by showing where shifting of initial polygons occurred (as with the square shape) and by highlighting areas that were either omitted from or committed to each of the polygons in error. The previous error matrices (Tables 2 through 6) quantify these results.

Observing the transformations of the shapes through the rasterization process, we see that the square shape remains square in some of the procedures and loses the sharpness of its corners in others. The triangle loses its sharp corners and becomes smaller, and its diagonals have become stairstep-

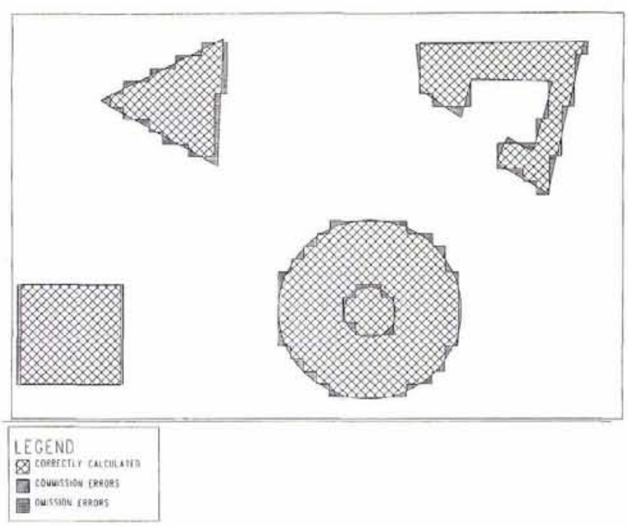

Figure 4. Plot of the five shapes using a cell size of 0.04 square inches (0.2 by 0.2 inches).

Table 2. The error matrix presents the omission and commission errors (in square inches) and the area correct (in square inches and percent) when the five shapes were gridded using a 0.25-square-inch grid cell size.

Raster Data \ Vector Data	BACK GROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE	
BACKGROUND	55.12 (97.4%)	0.54	0.60	0.45	0.00	0.55	57.26
SQUARE	0.18	2.07 (79.5%)	0.00	0.00	0.00	0.00	2.25
TRIANGLE	0.23	0.00	1.27 (68.0%)	0.00	0.00	0.00	1.50
CIRCLE	0.58	0.00	0.00	5.29 (90.3%)	0.13	0.00	6.00
HOLE	0.00	0.00	0.00	0.13	0.37 (72.7%)	0.00	0.50
SHAPE	0.49	0.00	0.00	0.00	0.00	2.01 (78.7%)	2.50
	56.60	2.61	1.87	5.87	0.50	2.56	

Table 3. The error matrix presents the omission and commission errors (in square inches) and the area correct (in square inches and percent) when the five shapes were gridded using a 0.04-square-inch grid cell size.

Raster Data \ Vector Data	BACK GROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE	
BACKGROUND	55.94 (98.8%)	0.12	0.18	0.17	0.00	0.18	56.59
SQUARE	0.08	2.48 (95.2%)	0.00	0.00	0.00	0.00	2.56
TRIANGLE	0.16	0.00	1.68 (90.0%)	0.00	0.00	0.00	1.84
CIRCLE	0.20	0.00	0.00	5.63 (96.1%)	0.05	0.00	5.88
HOLE	0.00	0.00	0.00	0.06	0.46 (90.4%)	0.00	0.52
SHAPE	0.23	0.00	0.00	0.00	0.00	2.37 (92.7%)	2.60
	56.61	2.60	1.86	5.86	0.51	2.55	

ped. The circles, as previously stated, became ortho-convex polygons. The convex shape retained convexity on this first trial, but lost its sharpest angles. All of the shapes show some amount of shift, based on grid cell size and position and the number of transformations performed.

Comparing the size of the various shapes after rasterization was also very interesting. In general, the total areas remained quite consistent (Table 1), especially after the fraction of grid cell size to shape was greater that 1/10. An examination of the circle and the hole at the 0.25-square-inch grid cell size reveals 90.3 percent correct area for the circle and 72.7 percent correct for the hole. It should be noted that the fraction of grid cell size to shape was 1/22 for the circle and only 1/2 for the hole. Using the 0.04-square-inch grid cell size, the results improve considerable to 96.1 percent and 90.4 percent, respectively, and a fraction of 1/146 and 1/13, respectively.

Generalization of the 0.04 grid cell data (Figure 5) had a smoothing effect on some of the shapes. It converted the triangle back into a shape very close to a triangle (four sides rather than three). The circle became an octagon, and the hole lost its stairstepped shape. The generalized shape gained some area (note the reduction in area of omission and the increase in the area of commission). Once again, all areas were quantified in an error matrix (Table 7).

Initial analysis of five simple shapes (Data Set 1) led to the conclusion that the amount of error associated with a vector-to-raster-to-vector conversion depended not only on the grid cell size in relation to the polygon area, but also on the shape of the polygon. Polygons with small perimeter-to-area ratios (circles, squares), for example, did not have the same errors as polygons with large perimeter-to-area ratios.

Understanding this phenomenon is important to anyone planning to analyze remotely sensed data for natural resource applications. Congalton (1988) explored spatial complexity and patterns of error for three sets of remotely sensed data: agriculture, rangeland, and forest land. A comparison of patterns of error observed in three difference images illustrated the varying spatial complexity of the landscape. Polygons from agricultural land, for example have small perimeter-to-area ratios because agricultural crops are typically grown in large homogeneous areas. Polygons from rangeland are mixed, composed of both large homogeneous grassy areas, and small woody areas. Forest land polygons, on the other hand, are the most spatially complex.

Possible reasons for the complexity of forest land classification data are the presence of linear features such as rivers and mountain ridges. Polygons resulting from classification of a forest data set will be less blocky than those from either rangeland or agriculture datasets. Riparian vegetation, for example, may run for miles along both sides of a river, but

Table 4. The error matrix presents the omission and commission errors (in square inches) and the area correct (in square inches and percent) when the five shapes were gridded using a 0.01-square-inch grid cell size.

Raster Data \ Vector Data	BACK GROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE	
BACKGROUND	56.15 (99.2%)	0.03	0.05	0.13	0.00	0.10	56.46
SQUARE	0.14	2.58 (99.1%)	0.00	0.00	0.00	0.00	2.72
TRIANGLE	0.09	0.00	1.81 (97.0%)	0.00	0.00	0.00	1.90
CIRCLE	0.08	0.00	0.00	5.70 (97.3%)	0.03	0.00	5.81
HOLE	0.00	0.00	0.00	0.03	0.48 (94.4%)	0.00	0.51
SHAPE	0.15	0.00	0.00	0.00	0.00	2.46 (96.3%)	2.61
	56.61	2.61	1.86	5.86	0.51	2.56	

Table 5. The error matrix presents the omission and commission errors (in square inches) and the area correct (in square inches and percent) when the five shapes were gridded using a 0.0025-square-inch grid cell size.

Raster Data \ Vector Data	BACK GROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE	
BACKGROUND	56.43 (99.7%)	0.06	0.04	0.05	0.00	0.07	56.65
SQUARE	0.01	2.55 (97.9%)	0.00	0.00	0.00	0.00	2.56
TRIANGLE	0.04	0.00	1.83 (98.0%)	0.00	0.00	0.00	1.87
CIRCLE	0.05	0.00	0.00	5.79 (98.8%)	0.02	0.00	5.81
HOLE	0.00	0.00	0.00	0.02	0.49 (96.3%)	0.00	0.51
SHAPE	0.07	0.00	0.00	0.00	0.00	2.49 (97.4%)	2.56
	56.60	2.61	1.87	5.87	0.51	2.56	

TABLE 6. THE ERROR MATRIX PRESENTS THE OMISSION AND COMMISSION ERRORS (IN SQUARE INCHES) AND THE AREA CORRECT (IN SQUARE INCHES AND PERCENT) WHEN THE FIVE SHAPES WERE GRIDDED USING A 0.0006-SQUARE-INCH GRID CELL SIZE.

		Vector Data						
		BACK GROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE	
Raster Data	BACKGROUND	56.50 (99.8%)	0.03	0.02	0.03	0.00	0.03	56.61
	SQUARE	0.02	2.58 (99.1%)	0.00	0.00	0.00	0.00	2.60
	TRIANGLE	0.02	0.00	1.85 (99.1%)	0.00	0.00	0.00	1.87
	CIRCLE	0.03	0.00	0.00	5.82 (99.3%)	0.01	0.00	5.86
	HOLE	0.00	0.00	0.00	0.01	0.50 (98.3%)	0.00	0.51
	SHAPE	0.04	0.00	0.00	0.00	0.00	2.52 (98.6%)	2.56
		56.61	2.61	1.87	5.86	0.51	2.55	

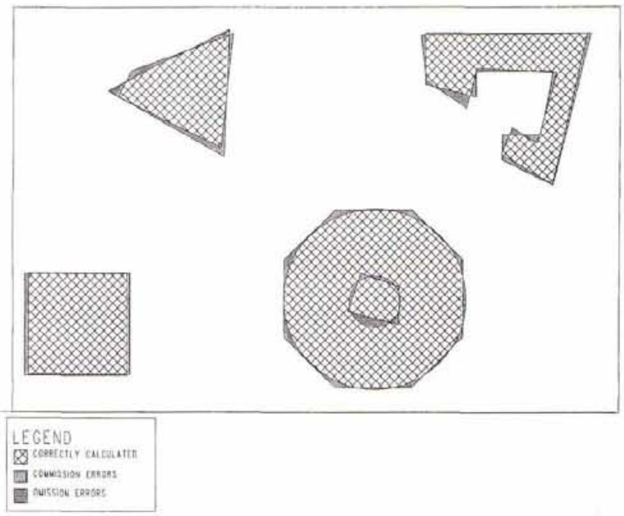

Figure 5. Plot of the five shapes after generalization and using a cell size of0.04 square inches (0.2 by 0.2 inches).

may never extend beyond 40 or 50 feet from the water's edge. Such a polygon may exceed a minimum area requirement for mapping yet, because its perimeter-to-area ratio is large, it may be lost or radically distorted in a vector (actual ground truth) to raster (satellite image representation) to vector (GIS map layer) conversion process.

In an effort to investigate the effects of shape and area in relation to grid cell size, three polygon shapes of equal area (one square inch) were rasterized and then vectorized using 14 square grid cell sizes (1.00, 0.75, 0.70, 0.65, 0.60, 0.55, 0.50, 0.45, 0.40, 0.35, 0.30, 0.20, 0.10, and 0.05 inches). These three shapes, called Data Set 2, include a circle, a wide rectangle to represent low perimeter-to-area ratio shapes, and a narrow rectangle to represent high perimeter-to-area ratio shapes. The objective of this exercise was two-fold. First, for each shape, to determine the maximum grid cell size required to maintain the presence of the polygon through the vector-to-raster-to-vector process. And second, for each shape, to determine the maximum grid cell size required to maintain the shape of the polygons.

It is important to find the maximum grid cell size requirement in relation to the polygon size and shapes for two reasons. First, this was a computerized process and our data requires disk space, CPU, and memory for processing. To use more than the minimum number of grid cells (maximum grid cell size) would increase costs of storage and processing time unnecessarily. Second, considering the problem from an opposite approach, if using satellite imagery for the initial raster representation of the real world, then the grid cell dimensions are precisely known (10 or 20m for SPOT data, 30m for Landsat TM data). Now, knowing the relationship between grid cell size and both shape and areal extent of our landscape polygons, a minimum polygon size and shape can be applied and used with specified confidence.

Results of this minimum polygon exercise illustrate the concepts described above. Please see Appendix A at this point for a selected graphical representation of the following results. Presence of all polygons occurred at a grid cell size of 56 percent of the polygon area for circles (perimeter/area ratio: 3.5), 42 percent of the polygon area for the wide rectangles with perimeter/area ratio 5 (0.5 by 2 inches), and 12 percent for narrow rectangles with perimeter/area ratio 8.5 (0.25 by 4 inches). Whole polygons were observed for circles at all grid cell sizes, for 5:1 rectangles at 12 percent and for 8.5:1 rectangles at 1 percent. Shape is most closely approximated when the smallest grid cell size is used, regardless of the shape of the entity. The errors were quantified in Figures 6, 7, and 8. Each figure shows the calculated total area, the actual correct area, the omission error, and the commission error for the various grid cell sizes.

Circles were never split into multiple polygons. Large grid cell sizes with respect to polygon area (42 to 56 percent) captured the circles in one or two grid cells, producing square or rectangular polygons. Presence of the polygons was maintained, but shape characteristics were lost. At cell sizes between 42 percent and 1 percent of the polygon area, the polygon shape progressively approximates a circle. Finally, at cell sizes of 0.05 and 0.01 inches, the smallest two cell sizes, the shapes begin to appear circular.

Wide rectangles with 5:1 perimeter/area ratios were always present at grid cell sizes less than 42 percent of the polygon area. Orientation of the rectangles with respect to the underlying grid is an important factor in their rasterization. If a rectangle is angled slightly (for example, angle less than 35 degrees) with respect to the underlying grid, it is captured as a rectangle but rotated into alignment with the grid. If the same rectangle is now rotated more than 35 de-

TABLE 7. THE ERROR MATRIX PRESENTS THE OMISSION AND COMMISSION ERRORS (IN SQUARE INCHES) AND THE AREA CORRECT (IN SQUARE INCHES AND PERCENT) WHEN THE FIVE SHAPES WERE GRIDDED AND THEN GENERALIZED USING A 0.04-SQUARE-INCH GRID CELL SIZE.

		Vector Data						
		BACK GROUND	SQUARE	TRIANGLE	CIRCLE	HOLE	SHAPE	
Raster Data	BACKGROUND	55.91 (98.8%)	0.12	0.17	0.06	0.00	0.10	56.36
	SQUARE	0.08	2.48 (95.2%)	0.00	0.00	0.00	0.00	2.56
	TRIANGLE	0.09	0.00	1.69 (91.0%)	0.00	0.00	0.00	1.78
	CIRCLE	0.25	0.00	0.00	5.77 (98.5%)	0.10	0.00	6.12
	HOLE	0.00	0.00	0.00	0.03	0.41 (80.6%)	0.00	0.44
	SHAPE	0.28	0.00	0.00	0.00	0.00	2.46 (96.3%)	2.74
		56.61	2.60	1.86	5.86	0.51	2.56	

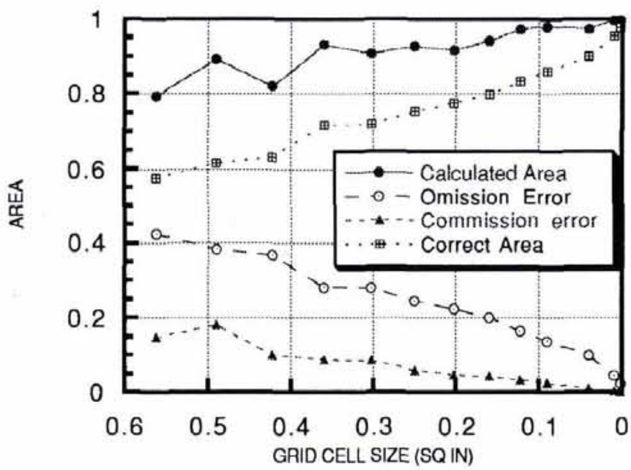

Figure 6. Graph showing the error associated with various grid cell sizes for the circle.

grees with respect to the underlying grid, it is split into multiple polygons (two or more diagonally adjacent grid cells). Not until we reach a grid cell size less than 20 percent of the original rectangular area do we observe individual, unique polygons in one-to-one correspondence with the original vector polygons. As observed with circles, the smallest two grid cell sizes most closely approximate the original shapes. Diagonal lines are always stair-stepped, and shifting occurs unless the original raster happens to be perfectly aligned with the underlying grid.

Narrow rectangles with 8.5 perimeter/area ratios were chosen to represent the long thin shapes we may observe in a spatially complex satellite image. Presence was not observed until the grid cell size reaches 36 percent of the polygon area. One-hundred percent of both circles (3.5:1) and 5:1 rectangles were present by the time the grid cell reaches this small size. Not until the grid cell size reached 12 percent of the area of these rectangles was 100 percent presence attained. Rotation and shifting occurred with these rectangles as was the case with the 5:1 rectangles. A new effect was observed with these 8.5:1 polygons; multiple polygons were not only present, but they were not always adjacent to one another. Gaps of one or two grid cells lie between the polygons created from this vector-to-raster-to-vector process when the cell size lies between 25 and 9 percent of the original polygon area, and the original rectangles are not aligned with the underlying grid. At a cell size of 4 percent of the polygon area, all multiple polygons were diagonally adjacent; at a cell size of 1 percent of the polygon area, the multiple polygon phenomena was lost.

Conclusions

This paper has demonstrated many of the problems associated with raster-to-vector and vector-to-raster conversion. It has dealt with the polygon shape and size and also with grid cell size. It has addressed presence/absence as well as shape retention of the data during the conversion process. Two very simplistic data sets were employed and yet the problems have been clearly demonstrated. Surely more questions have been raised by this work than have been answered. It is clear that work in this field must continue. More complex data sets must be evaluated and the effects of data conversion on accuracy must be clearly documented. Therefore, the last section of this paper will discuss some future directions for this work.

Future Directions

There is a great need to continue the work begun in this project on real data, especially that generated from digital remote sensing. As previously discussed, satellite data are already in raster format. The usual procedure would be to classify the data, post-process it, and vectorize the data for input into a vector GIS. A number of factors besides the data conversion must be considered in evaluating the accuracy of this procedure. Walsh (1987) and Skidmore and Turner (1989) examined geometric errors in raster and vector images. Geometric errors are those resulting from registration of satellite image data to map projections. Both authors found errors less than 0.5 pixels acceptable.

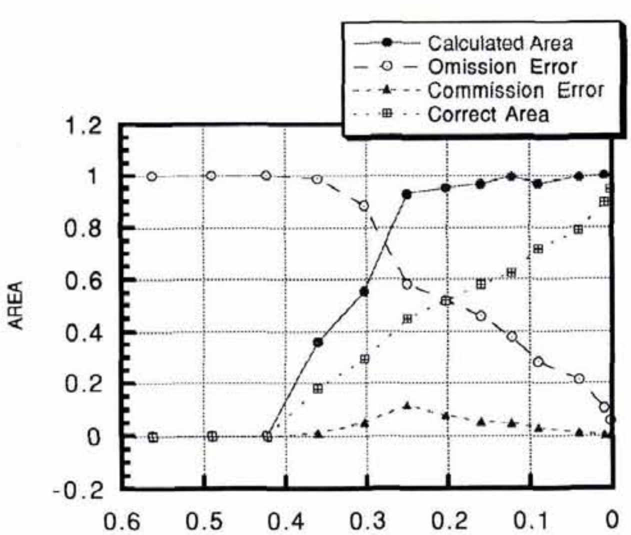

Figure 7. Graph showing the error associated with various grid cell sizes for the thin rectangle (8.5:1 perimeter/area ratio).

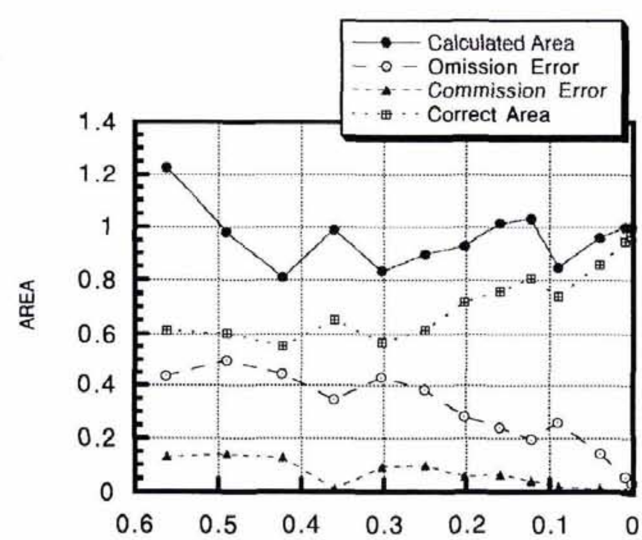

Figure 8. Graph showing the error associated with various grid cell sizes for the wide rectangle (5:1 perimeter/area ratio).

Therefore, the first source of error in any accuracy assessment of satellite data is an acceptable error of 0.5 pixels due to geometric correction. Secondly, error is introduced in the classification process. As a result of the classification process, some percentage of the image is represented as single-pixel polygons. These single-pixel polygons fall into one of two categories. Either they are small patches of vegetation scattered throughout an area, for example, grassland with scattered groups of trees, or they are linear features with large perimeter-to-area ratios that were split into a series of diagonally adjacent, single-pixel polygons, for example, riparian vegetation along a river bank, or the river itself.

The first case, individual scattered pixels, presents a different, more easily addressed set of problems. If these scattered pixels are smaller than mapping minimums, they can be eliminated by recoding them before vectorization.

A more serious and realistic set of complications arises when these scattered single pixels appear as linear single pixels. Single pixels representing linear features are likely to exceed mapping minimums; therefore, they are important to the classification and cannot be eliminated. A majority filter should be applied to an image in this case to remove the scattered individual "salt and pepper" pixels while retaining single pixels that may be part of an important linear feature. Errors due to this post-processing can be quantified by vectorizing two raster image files, one that has been postprocessed, and one that has not. These two vector files can then be UNIONed in Arc/Info (PC Arc/Info, Overlay Module) and the areas (correctly classified areas as well as those omitted or committed in error) summarized and reported.

Once the image has been post-processed, it can be brought into Arc/Info using the GRIDPOLY command (PC Arc/Info, Data Conversion Module). Stairstepping can be removed by GENERALIZEing the data with a grain distance between 1.25 and 1.5 times the grid cell size. Then, using the SPLINE command with tolerances set smaller than the grid cell size, the resultant vectors can be smoothed to give the map a more realistic appearance.

Errors could then be quantified for this smoothing process much more easily than they can be quantified for the postprocessing. Both the vectorized version of the pre-processed raster data and the smoothed vector data are present on the computer disk in Arc/Info format. UNIONing these two files will produce a third file containing three types of polygons, those correctly classified, those omitted from their correct polygons, and those incorrectly committed to polygons. The areas summarized here will show the error in the smoothing and overlay processes alone; there will be no direct comparison to ground truth.

A final procedure to test the accuracy of the data would be to digitize a map or portions of a map representing "GROUND TRUTH" and then overlay it with the post-processed, smoothed vector file to perform a comparison.

Obviously, there are a number of factors that contribute to the accuracy of a map derived from remotely sensed data besides just the conversion between raster-to-vector and vector-to-raster. It is important that not only the overall accuracy be evaluated but also that the component parts contributing to that accuracy be adequately studied. The procedure for such a study has been outlined here. Future work to answer questions about real data examples from a variety of applications must be undertaken.

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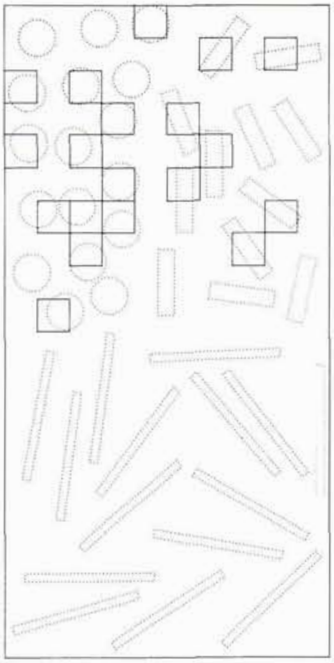
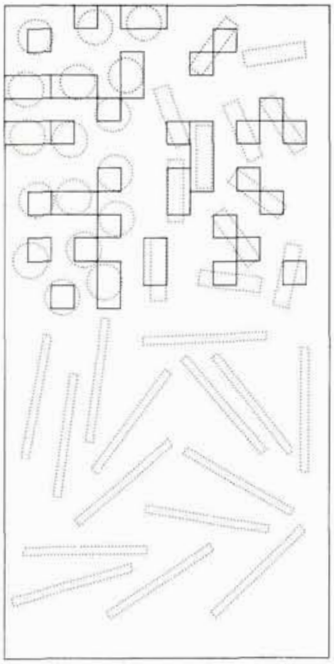
Appendix A

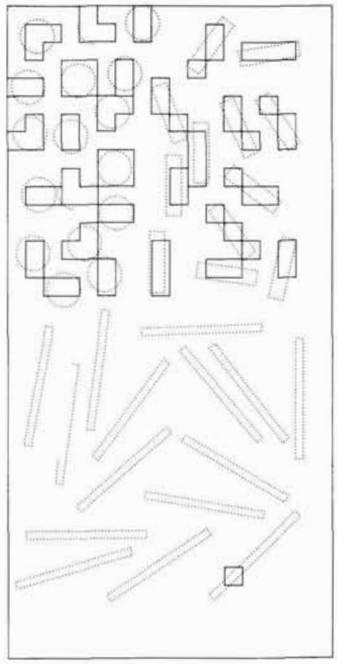
Grid cell size of 1 inch or 100 percent of the original polygon (vector) area.



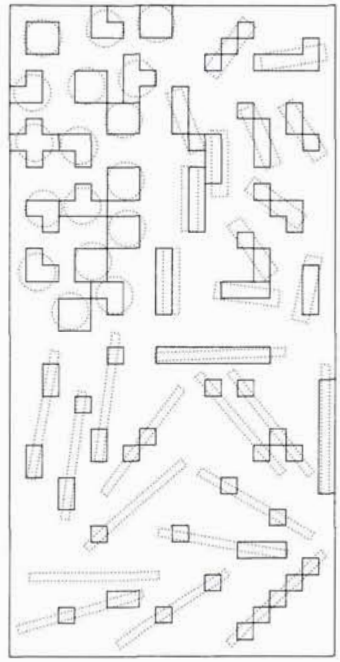
Grid cell size of 0.75 inches or 75 percent of the original polygon (vector) area.



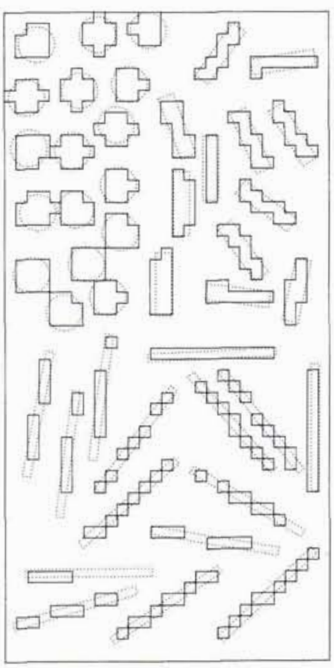
Grid cell size of 0.60 inches or 60 percent of the original polygon (vector) area.



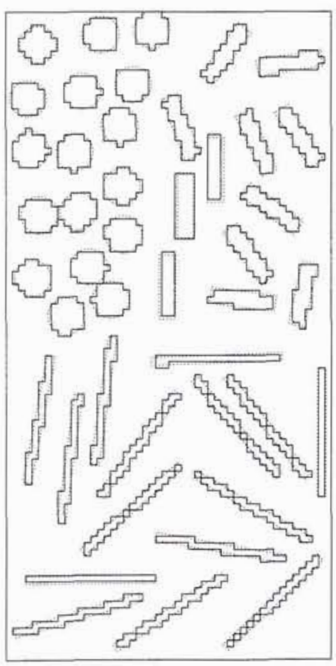
Grid cell size of 0.50 inches or 50 percent of the original polygon (vector) area.



Grid cell size of 0.35 inches or 35 perecent of the original polygon (vector) area.



Grid cell size of 0.20 inches or 20 percent of the original polygon (vector) area.



Grid cell size of 0.05 inches or 5 percent of the original polygon (vector) area.