Evaluating the Accuracy of Digital Orthophoto Quadrangles (DOQ) in the Context of Parcel-Based GIS

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Abstract

A crucial component in developing an effective GIS based on digital parcel base maps is the acquisition of accurate digital land base data. Accurate land base data make spatial analysis less troublesome and enables better decision making. However, acquisition of accurate spatial data from traditional data compilation techniques could come with a hefty price tag. A popular solution for the accuracy versus cost dilemma is the use of USGS Digital Orthophoto Quadrangles (DOQ). DOQs provide very inexpensive continuous land coverage that could be converted with relatively modest means and expense into a digital parcel map.

Given that DOQs are becoming a common solution for establishing digital parcel coverages, it is prudent to evaluate their accuracy. DOQs are considered to comply with the National Mapping Accuracy Standards (NMAS), but that statement does not render a constructive measure for the accuracy of the data because of the way (or lack of) a dataset is certified as being in compliance with the NMAS. A better approach for evaluating the accuracy of DOQs is to follow the National Standard for Spatial Data Accuracy (NSSDA) guidelines.

In this paper a DOQ was evaluated with the NSSDA standards in order to establish the positional accuracy of the data. The accuracy was found to be within ±25 feet (±7.6 m) at the 95 percent confidence level. The DOQ was also evaluated for its geometric, radiometric, and mosaicking accuracies. This aspect of the DOQ was found to be satisfactory. Finally, the appropriateness of DOQs in the context of a parcel-based GIS was addressed.

Introduction

A parcel-based geographic information system (GIS) is built on a data layer of reference information, such as topography, buildings, road network, streams, etc., to which all other layers are tied geometrically. Traditionally, this type of information was developed by surveyors and/or photogrammetrists. While these methods for acquiring base map data are usually more accurate, in many cases they are prohibitively expensive for many GIS developers. Alternative, and less expensive, data acquisition methods are digitizing existing maps and orthophotos. Digitizing existing maps has numerous drawbacks that include reduced spatial accuracy, incompleteness of information, and geometrical and mathematical (coordinate system) discontinuities. Digitization is also a tedious conversion process, not necessarily inexpensive and is subject to availability of appropriate maps. The other source of data for a parcel-based GIS is a digital orthophoto.

Orthophotos as a data source for compiling parcel data offer several benefits. An orthophoto offers continuous aerial coverage that includes all the existing features in the real world that are larger than the given pixel resolution. Orthophotos can be, and usually are, georeferenced. Orthophotos are also a historical record from which spatial and temporal changes can be derived. Advances in computer technology have made digital orthophotos more readily available. Improvements in computer processing, storage, and software have made them an increasingly practical choice.

Although orthophotos generally offer significant benefits, not all orthophotos are created equal. In general, their accuracy and quality will vary based on the data used to process them, as well as on the particular production procedure. Contributing error factors include the characteristics and calibration of equipment used for image capture such as the camera and/or scanner. Additional elements affecting the rectification process include ground control points (accuracy, amount, and distribution), the aerial triangulation process, digital elevation models (DEM) (including the elevations of features above the DEM surface), and the method/software used for rectification. Therefore, it is essential to note that orthophotos should be evaluated for spatial accuracy and inspected for image quality before acceptance or use.

The spatial accuracy evaluation of the orthophoto and its suitability for a given application can be performed in a number of different ways. One way to do this is to overlay it onto another reference (e.g., a vector-based graphic) information layer known to have higher accuracy. Differences or errors in feature locations between the orthophoto and reference layer are observed and quantified. The results of that error quantification are used to determine the accuracy of the orthophoto. Another way to test the spatial accuracy is by using the Global Positioning System (GPS) to determine accurate positions of features that can be easily identified on the orthophoto. Comparing the GPS coordinate values of these points to those measured on the orthophoto yields the sought after spatial accuracy evaluation. A guideline for such an accuracy assessment is provided by the National Standard for Spatial Data Accuracy (NSSDA) (FGDC, 1998).

In addition to a spatial accuracy examination, orthophotos should undergo an image quality review as well. Image quality can deteriorate during image acquisition, image processing, rectification, and mosaicking. Aspects of image quality include

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brightness and contrast changes between images, recording of scratches and dirt as images, discontinuities at the edges of mosaicked image patches, and so forth. If some of these defects are not addressed, some local anomalies of inaccurate spatial positioning of features or systematic spatial errors may occur. In addition, image defects can result in incorrect interpretation of the real-world landscape. For example, a large blob of dirt could be interpreted as a body of water, etc.

In this paper a Digital Orthophoto Quadrangle (DOQ) is evaluated using the newly endorsed NSSDA standards. The standard provides a guide for establishing the positional accuracy of spatial data. In addition, DOQs are evaluated for their geometric, radiometric, and mosaicking accuracies. The accuracy and the quality of DOQs are evaluated in the context of a parcel-based GIS. In the following section the NSSDA and the DOQ are reviewed. Following this review, an evaluation of a DOQ in accordance with the NSSDA guidelines is presented. Findings of an image quality assessment of the DOQ are presented thereafter. Finally, the appropriateness of DOQs for deriving digital parcel data for a GIS is also discussed.

The National Standard for Spatial Data Accuracy (NSSDA)

The National Map Accuracy Standards (NMAS), which were established in the early 1940s, suffer from many well-documented shortcomings (FGDC, 1998). Besides being incompatible with digital mapping concepts, they have a very vague procedure for determining the accuracy of a map. The National Standard for Spatial Data Accuracy (NSSDA) is a long overdue successor to the NMAS. The NSSDA implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. The NSSDA applies to georeferenced maps and digital geospatial data, in either raster, point, or vector format (FGDC, 1998).

Unlike the NMAS, which sets a compliance accuracy value, the NSSDA does not define threshold accuracy values. Rather, agencies are encouraged to establish accuracy thresholds for their products based on application needs and contracting requirements. It is left to users to identify acceptable accuracies for their applications. Data and map producers should determine what accuracy exists or is achievable for their data and record it on an explicit reporting form.

The NSSDA uses the root-mean-square error (RMSE) to estimate positional accuracy. The RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy. The differenced coordinate values are of well-defined corresponding checkpoints from both data sources. Separate but similar accuracy computations were established for horizontal (X,Y) and vertical (Z) positions. In this paper, only the horizontal RMSE computation is being considered.

The X and Y component horizontal positional RMSE is computed from

$$\mathrm{RMSE}_X = \sqrt{\frac{\sum (X_{data_i} - X_{check_i})^2}{n}} \tag{1}$$

$$\mathrm{RMSE}_Y = \sqrt{\frac{\sum (Y_{data_i} - Y_{check_i})^2}{n}} \tag{2}$$

where $X_{data\,i}$ and $Y_{data\,i}$ are the coordinates of the i^{th} checkpoint in the dataset, $X_{check\,i}$ and $Y_{check\,i}$ are the coordinates of the i^{th} checkpoint in the independent source of higher accuracy, n is the number of check points tested, and i is an integer ranging from 1 to n.

The horizontal error at point i is defined as

$$E_i = \sqrt{(X_{data_i} - X_{check_i})^2 + (Y_{data_i} - Y_{check_i})^2} \tag{3}$$

The above computed accuracy (error) value reflects all uncertainties, including those introduced by (geodetic) control coordinates, compilation, and final computation of ground coordinate values in the evaluated dataset. It is assumed that errors in the spatial data have random behavior and that systematic errors have been eliminated as best as possible. Assuming that errors are normally distributed and independent of each other in the X and Y component, a factor of 2.4477 is used to compute horizontal accuracy at the 95 percent confidence level. When the preceding conditions apply, Accuracy$_r$, the accuracy value according to NSSDA, is computed using the formula

$$Accuracy_r = \frac{2.4477 \cdot \sqrt{\mathrm{RMSE}_X^2 + \mathrm{RMSE}_Y^2}}{2} \tag{4}$$

The NSSDA offers somewhat simplified variations for Equation 4 by considering two cases.

Case I: (yields exactly the same results as Equation 4)
If $\mathrm{RMSE}_x = \mathrm{RMSE}_y$, then

$$\mathrm{RMSE}_r = \sqrt{2} \cdot \mathrm{RMSE}_X = \sqrt{2} \cdot \mathrm{RMSE}_Y \tag{5}$$

$$Accuracy_r = \frac{2.4477 \cdot \mathrm{RMSE}_r}{\sqrt{2}} = 1.7308 \cdot \mathrm{RMSE}_r \tag{6}$$

Case II: (yields results similar to Equation 4)
If $\mathrm{RMSE}_x \neq \mathrm{RMSE}_y$ (the ratio between the largest RMSE and the smallest one is between 0.6 and 1.0), then the circular standard error (at 39.35 percent confidence) may be approximated as $0.5\times(\mathrm{RMSE}_x + \mathrm{RMSE}_y)$ (Greenwalt and Schultz, 1968) and the computed accuracy is

$$Accuracy_r \approx \frac{2.4477 \cdot (\mathrm{RMSE}_X + \mathrm{RMSE}_Y)}{2} = 1.22385 \cdot (\mathrm{RMSE}_X + \mathrm{RMSE}_Y). \tag{7}$$

Accuracy Test Guidelines

According to the Spatial Data Transfer Standard (SDTS), accuracy testing should be performed using an independent source of higher positional accuracy. Consequently, the NSSDA presents guidelines for accuracy testing based on the above principle. The accuracy of the independent test points should fall within one-third of the intended accuracy (95 percent confidence level) of the examined dataset. In addition, a minimum of 20 well-defined test points should be used to evaluate the accuracy of the dataset. Well-defined points are those that can be identified within one-third of the maximum expected uncertainty for the dataset. Recommended features to be used as checkpoints are road/rail intersections, corners of structures, centers of utility access covers, monuments, etc. The appropriateness of a feature to serve as a checkpoint depends on the ground resolution (scale) of the dataset.

The location or the distribution of the checkpoints is also specified in the NSSDA. The NSSDA assumes that the area to be evaluated is a rectangle. The area is to be divided into four quads and a diagonal is to be established across the area. The general guidelines for the location of checkpoints in that rectangular area are as follows:

- Checkpoints should be spaced at intervals of at least 10 percent of the diagonal;
- At least 20 percent of the points are to be located in each quad;
- Checkpoints may be distributed more densely in the vicinity of important features;
- When data exist for only a portion of the dataset, checkpoints should be confined to that area; and

- When the distribution of error is likely to be nonrandom, it may be desirable to locate checkpoints to correspond to the error distribution.

Another important aspect of the NSSDA is that positional accuracy values are to be reported in ground distances in the dataset coordinate units. The number of significant places for the accuracy value shall be equal to the number of significant places for the dataset point coordinates. This means that if, for example, the ground resolution of the dataset is ±1 m, then coordinate values of the dataset should be recorded without decimal places. Accuracy reporting in ground distances allows users to directly compare datasets of differing scales or resolutions. A simple statement of conformance without a testing report (as in the case of the NMAS) is not adequate in itself. Measures based on map characteristics, such as publication scale or contour interval, are no longer adequate when data can be readily manipulated and output to any scale or to different data formats.

Digital Orthophoto Quadrangles (DOQ)

The primary sources of aerial photography used in the production of 1-meter digital orthophotos are black-and-white (B/W) or color-infrared (CIR) imagery from the National Aerial Photography Program (NAPP) and NAPP-like photography. NAPP photography is quarter-quadrangle centered (3.75 minutes of latitude by 3.75 minutes of longitude in geographic extent) at an approximate scale of 1:40,000. Source photography is cloud free and leaf-off in deciduous vegetation regions.

According to the U.S. Geological Survey (USGS) (USGS, 1999), the diapositives used in the production of DOQs are inspected to insure clarity and radiometric uniformity. If necessary, the source photography is enhanced by limited analog dodging and other means to improve image quality. Image brightness values may deviate from brightness values of the original imagery due to image value interpolation during the scanning and rectification processes. Image quality is verified by visual inspection of the digital orthophoto quadrangle with the original unrectified image, to determine if the digital orthophoto has the same as or better image quality than the original unrectified input image. Slight systematic radiometric differences can be detected between adjacent DOQ files due primarily to differences in source photography capture dates and sun angles of aerial photography along flight lines.

All DOQ imagery is also visually inspected for completeness to ensure that no gaps or image misplacement exist in the image. In order to insure complete coverage, DOQ images are commonly derived by mosaicking multiple images. Void areas (appearing as black blobs) for which no photographic source is available may exist. A significant source for lack of imagery can result from projecting or transforming the dataset from other planimetric systems to the Universal Transverse Mercator (UTM) projection. The UTM projection is the official plane coordinate system for DOQs.

The DOQ horizontal positional accuracy depends, in part, on the accuracy of the data inputs, and the rectification and mosaicking processes. The inputs consist of the following:

(1) A user parameter file to control the rectification process. This file includes the camera calibration parameters for the eight fiducial marks.
(2) Measurements of the eight fiducial marks in the digitized image.
(3) A digital elevation model gridded to user specified bounds is used for the rectification. The principal elevation data source are standard DEM datasets from the National Digital Cartographic Data Base (NDCDB). To fulfill DOQ production requirements, DEMs that meet USGS standards are sometimes produced by contractors and are subsequently archived in the NDCDB. The DEM used in the production of DOQs generally has a 30-meter grid post spacing and possesses a vertical RMSE of 7 meters or better. For those areas for which a 7.5-minute DEM is unavailable and relief differences are less than 150 feet (45.7 m), a planar-DEM (slope-plane substitute grid) may be used.

    For each raster image cell subdivision, a brightness or gray-scale value is obtained using the nearest-neighbor, bilinear, or cubic convolution resampling of the scanned image. The pixel processing algorithm is indicated in the header file.
(4) A scanned digital image file covering the same area as the DEM. The source image is an aerial photograph film diapositive created by a precision image scanner with an aperture of approximately 25 to 32 micrometers. Using 1:40,000-scale photographs, a 25-micrometer scan aperture equates to a ground resolution of 1-meter. Scan files with ground resolution less than 1 meter, or greater than 1 meter but less than 1.28 meters, are resampled to 1 meter.
(5) Projection, zone, datum, and X-Y units.
(6) Ground X-Y-Z point values and their corresponding photo coordinates in the camera coordinate system. The accuracy standard of the ground coordinates is Third-Order Class 1 or better (1:10,000). Ground control points are in the Universal Transverse Mercator or the State Plane Coordinate System on NAD83. Horizontal and vertical residuals of aerotriangulated tie-points are equal to or less than 2.5 meters. Standard aerotriangulation passpoints consist of the traditional nine control-points configuration per photograph (six points each for the first and last photograph of the strip).

The majority of DOQ datasets are acquired through government contract. The production procedures, instrumentation, hardware, and software used in the compilation of standard USGS DOQs vary depending on systems used at the contract cooperator or USGS production sites. All data are inspected according to a quality control plan. DOQ contractors must meet DOQ standards for spatial accuracy, attribute accuracy, logical consistency, and data completeness. DOQ availability can be found at http://mcmcweb.er.usgs.gov/status/doq_stat.html.

Quality and Accuracy Assessment of a DOQ

Quality issues fall into two general categories. The first is spatial accuracy and the second is image quality (Smith, 1995). Spatial accuracy refers to the location of pixel elements with respect to their true location on the face of the Earth. Image quality considers pictorial defects and tonal differences, both within and across the DOQ. Some image quality problems may have negative bearing on the spatial accuracy and image interpretation while others are primarily aesthetic in nature.

One of the better ways to sample spatial accuracy is to use the Global Positioning System (GPS). GPS is used to observe and compute accurate checkpoint location coordinate values. Comparing the computed location of the checkpoints with the location of their corresponding image on the DOQ provides the desired spatial accuracy assessment. To obtain a more realistic accuracy assessment, some checkpoints should be selected away from major road intersections because at these points the DEM is usually more accurate than at others. Checking accuracy at points with a more accurate DEM could result in overestimating the accuracy of the orthophoto. Other checkpoints such as clearly visible corners of ground level structures (e.g., swimming pools) will help to assure a realistic accuracy assessment. In addition to checking the absolute difference between these locations, the direction of any discrepancy should also be noted. A common pattern of error direction could indicate the possible presence of systematic errors.

The DOQ for which the evaluation results are presented here is the northwest quadrant of the Roselle, New Jersey quadrangle. The topography of the area of this orthophoto is a mix of flat ground and moderately graded hills. It contains vast built-up areas and road networks, as well as some open wooded areas. It represents a common topography of the large parts of the State of New Jersey and the east coast of the United States.

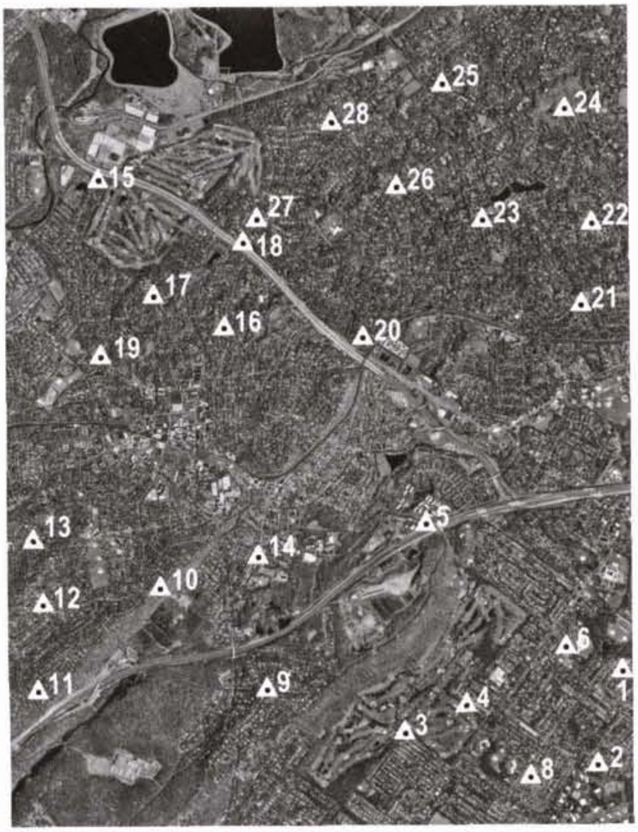

Figure 1. The northwest quadrant of the Roselle, New Jersey quadrangle with the location of the checkpoints.

The DOQ is shown in Figure 1. Assuming that similar procedures and quality control measures are applied to all DOQs, the results of this evaluation could be considered as representative of most other DOQs

In general, the accuracy of a spatial product should be assessed in two phases. The first phase is a general evaluation of the dataset, resulting in a report and a statement about the accuracy of the product. The second phase is to assess the fitness of the dataset for a specific application, given the findings of the first phase. In the following sections the DOQ will be assessed based on this strategy. First, a general evaluation will be made, followed by some observations on the fitness of DOQ for parcel-based GIS.

Spatial Accuracy

As discussed earlier, many factors will affect the spatial accuracy of an orthophoto. Among these factors are those that are related to image acquisition, control point selection and accuracy, and the rectification procedures. The two dominant factors that have the most significant impact on the accuracy of the orthophoto are the ground resolution of the source image and the accuracy (including completeness) of the DEM. The impact of these factors on the orthophoto is discussed in many references, including Slama (1980), Hokle (1996), and Manzer (1996). In this paper, we are interested mainly in the end result or the impact of all the errors on the final accuracy without investigating specific error sources. Therefore, a theoretical discussion on errors and their propagation into the orthophoto will not be presented here. Only the evaluation of the existing errors in the DOQ will be discussed.

A total of 28 checkpoints were selected from the orthophoto and surveyed with GPS equipment. The locations of the checkpoints were selected in accordance with the NSSDA guidelines. Some areas had fewer checkpoints because it was more difficult to identify "well-defined" points at those locations. The checkpoints were located mostly near easily accessible sites representing a wide range of elevation differences. The checkpoints were field surveyed with a Leica MX 8600 Code based GPS receiver in differential mode. The coordinates of the checkpoints were determined from four independent GPS observations. The average accuracy of each checkpoint was ±4 feet (±1.2 m) with an acceptance threshold of ±10 feet (±3 m). Points 5, 9, 13, 20, and 25 had to be re-observed to meet the set threshold. This acceptance threshold is better than one third of the 33.3-foot (10 m) stated accuracy of the DOQ. The checkpoints were digitized off the DOQ using ESRI's ArcView GIS software.

The accuracy evaluation of the checkpoints is presented in Table 1. Examining the differences between the GPS coordinate values and those of the DOQ reveals that they are quite small. Even the largest coordinate difference (at point 17) is less than the 33.3-foot (10 m) stated accuracy of the DOQ. No systematic magnitude and/or orientation pattern of errors was observed. The average difference of a single coordinate was 8 feet (2.4 m) and the median was just 6 feet (1.8 m). The computed root-mean-square errors of the coordinates based on Equations 1 and 2 were

$$\mathrm{RMSE}_{Easting} = \sqrt{\frac{\sum (X_{DOQ_i} - X_{GPS_i})^2}{28}} = 11 \text{ feet } (3.4 \text{ m})$$

$$\mathrm{RMSE}_{Northing} = \sqrt{\frac{\sum (X_{DOQ_i} - Y_{GPS_i})^2}{28}} = 9 \text{ feet } (2.7 \text{ m})$$

At the 95 percent confidence level, the accuracy of the DOQ, as computed from Equations 4, 6, or 7, was

$$Accuracy_r = \frac{2.4477 \cdot \sqrt{11^2 + 9^2}}{2} = 25 \text{ feet } (7.6 \text{ m})$$

Following the approach of the NSSDA, this 25-foot (7.6 m) accuracy value is characterized as neither good, bad, acceptable, or unacceptable. The only conclusion to be drawn from this computation is that the statistically evaluated dataset accuracy is ±25 feet (±7.6 m). Good, bad, acceptable, or unacceptable is a judgement call based on the intended use or application. The appropriateness of this accuracy for a parcel-based GIS will be addressed in a following section.

Image Quality Assessment

Image quality assessment is performed by visually inspecting the DOQ for errors and/or image defects. Some of these defects are merely aesthetic glitches while others result in systematic spatial distortion. An example of the former is a contrast difference between two images of the same object. An example of the latter is misalignment of image patches during the mosaicking process. The misalignment is a pictorial defect but, at the same time, it also presents a spatial error. The main problem with this error is that it is systematic and not random. The NSSDA assumes that only random errors exist in the dataset. It is prudent to point out that these defects are visible mostly along well-defined features such as roads, but many of these image discontinuities could go unnoticed along somewhat fuzzier images. Several such defects were found in the evaluated DOQ, some of which are shown in Figure 2.

As mentioned earlier, aesthetic defects in an image are those that will not result in spatial error but will interrupt the tonal continuity of the image. The most trivial examples for such defects are an abrupt change in the radiometric intensity

Table 1. The RMSE Computations for the DOQ.

	COORDINATES				STATISTICAL ANALYSIS				
	GPS OBSERVATIONS		DIGITAL ORTHOPHOTO		DIFFERENCE		SQUARED DIFFERENCE		
Pt. No.	Northing (m)	Easting (m)	Northing (m)	Easting (m)	in Northing (m)	in Easting (m)	in Northing	in Easting	TOTAL SQUARED DIFFERENCES
1	207181.97	165802.64	207182.59	165804.15	−0.63	−1.50	1.29	7.43	8.71
2	206384.61	165579.43	206385.58	165579.45	−0.98	−0.02	3.12	0.00	3.12
3	206617.37	163939.53	206612.31	163938.53	5.06	1.00	83.97	3.28	87.25
4	206899.02	164446.13	206901.95	164448.96	−2.93	−2.83	28.20	26.28	54.48
5	208428.60	164171.68	208426.89	164175.55	1.71	−3.87	9.60	49.04	58.64
6	207312.38	165362.60	207313.42	165364.80	−1.04	−2.20	3.57	15.93	19.50
7	208189.01	166109.20	208188.01	166108.77	1.00	0.43	3.29	0.60	3.88
8	206247.97	162214.99	206249.73	162215.72	−1.76	−0.74	10.19	1.77	11.97
9	206946.60	162738.33	206939.41	162739.54	7.19	−1.21	169.74	4.80	174.55
10	207813.41	161746.57	207812.40	161743.40	1.01	3.17	3.35	33.06	36.42
11	207012.30	160750.33	207008.15	160742.80	4.15	7.53	56.52	185.88	242.40
12	207669.96	160882.00	207667.52	160872.90	2.44	9.10	19.54	271.80	291.34
13	208341.75	160802.48	208339.25	160801.00	2.50	1.48	20.58	7.22	27.80
14	208158.83	162704.28	208158.99	162705.44	−0.15	−1.17	0.08	4.46	4.54
15	211397.61	161323.41	211396.38	161323.21	1.23	0.19	4.98	0.12	5.11
16	210014.42	162377.98	210009.78	162375.47	4.64	2.51	70.70	20.66	91.36
17	210403.99	161773.68	210406.87	161772.98	−2.89	0.70	27.36	1.60	28.96
18	210839.82	161178.20	210843.90	161175.60	−4.09	2.60	54.78	22.15	76.93
19	209882.80	161348.74	209879.94	161341.94	2.85	6.80	26.71	151.71	178.42
20	210003.80	163640.16	210005.24	163633.70	−1.43	6.46	6.75	137.08	143.83
21	210299.70	165484.49	210297.95	165482.62	1.75	1.86	10.05	11.40	21.45
22	210995.18	165573.93	210995.33	165574.15	−0.15	−0.22	0.07	0.16	0.24
23	211053.94	164650.56	211055.85	164646.96	−1.91	3.60	11.98	42.56	54.54
24	211954.06	165407.56	211950.71	165406.62	3.35	0.94	36.86	2.88	39.75
25	212158.54	164304.47	212160.94	164303.99	−2.40	0.48	18.89	0.74	19.64
26	211301.99	163816.75	211302.46	163816.01	−0.47	0.75	0.72	1.82	2.54
27	211081.14	162707.39	211080.05	162709.37	1.09	−1.97	3.90	12.77	16.66
28	211903.21	163344.37	211900.24	163342.66	2.96	1.72	28.80	9.66	38.46
						Sum	715.61	1026.88	1742.49
						Average	25.56	36.67	62.23
							$RMSE_y$	$RMSE_x$	$RMSE_r$
						RMSE	2.79	3.34	4.36

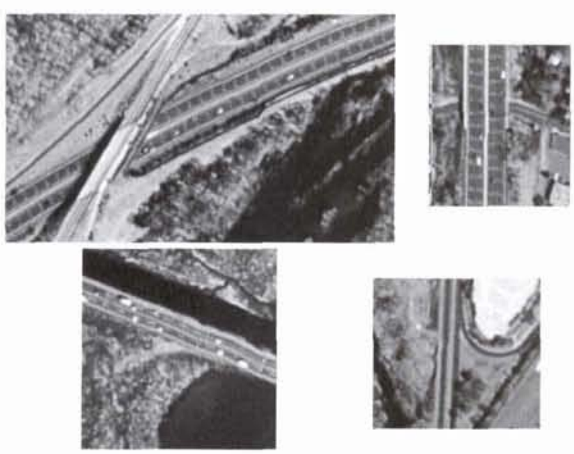

Figure 2. Image displacements at the seams of image patches.

of an image in terms of brightness or contrast. No such defect could be detected in the evaluated DOQ or in some of the adjacent ones.

Other aesthetic defects stem from naturally occurring image anomalies or by human induced errors. Naturally occurring image anomalies are caused mainly by the geometric relationship between the position of the camera and the sun. The impact of this relationship is variation in the visible reflectiveness of the surface. A clear example of this type of defect was observed in an adjacent DOQ (east of the one evaluated here). The top image of Figure 3 shows the reflection of the sun over the water. Obviously, there are no spatial consequences from this error.

Human induced defects may occur during the handling of the image (film development, diapositive printing, and scanning). Examples of such defects are shown in the bottom image of Figure 3. The bright dot (on the left) and the vertical dashed line (in the middle) are not real world features. In some cases, these defects may falsely be interpreted as ground features. Examples of such defects are shown in Figure 4. In the top image of Figure 4, one can see wavy images that could result from improperly dried negative or diapositive films. The bottom image shows a gray line that looks like a linear feature that does not exist in the real world.

Other image quality problems with orthophotos are occluded areas. If the orthophoto was derived correctly, all buildings should have been flattened to the ground. If the side of a building is visible on the orthophoto, it indicates a rectification error. Buildings and other tall features represent two types of errors. The first is that their dimensions are distorted. Thus, digitizing the perimeter of the top of a building not only will position it with a spatial shift but will also yield exaggerated and distorted building dimensions. The second problem above the surface features is that they obscure other features that have

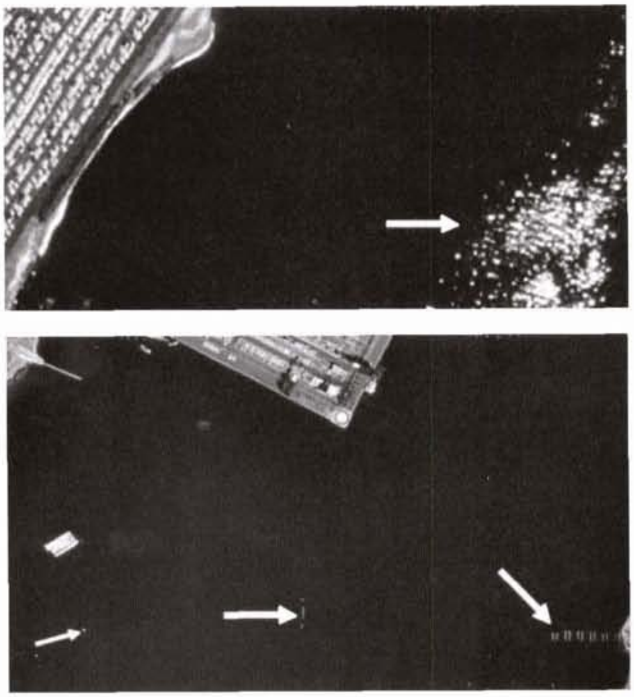

Figure 3. Examples of natural and human-caused image defects.

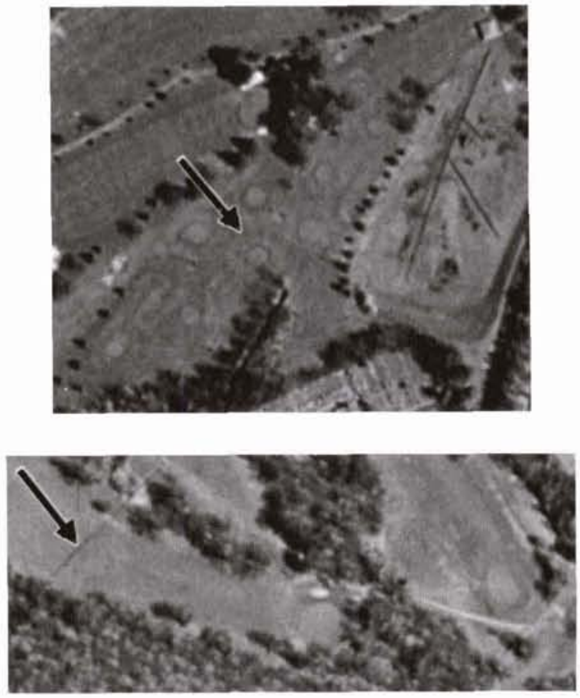

Figure 4. Images of features resulting from imperfect film processing.

to be mapped out. Figure 5 illustrates this problem. On the left image of Figure 5, part of the road is not visible due to rectification error compounded with the presence of the building's shadow. A similar effect can be seen on the right image where a slice of the round building is missing.

To keep these image deficiency examples in perspective, it should be noted that the examined DOQ had only a few image quality errors.

DOQs for a Parcel-Based GIS

Given that DOQs are providing a common solution for establishing digital parcel-based GIS, it is prudent to examine their accuracy in that user context. In other words, given that at a 95 percent confidence level the spatial accuracy of the DOQ was found to be ±25 feet (±7.6 m), we need to establish whether this accuracy is appropriate for supporting a foundation for a parcel-based GIS? Another question to be addressed is; Is the image quality of the DOQ suitable and adequate for digitizing parcel boundaries?

The question of the appropriateness of a ±25-foot (±7.6 m) spatial accuracy has to be answered by examining the specific intended usage of the data. A parcel-based GIS can be used for a wide range of applications. The most general application is for general master plan development. At the other end of the accuracy spectrum is a detailed cadastre that can be (legally) used for property transaction. For a master plan development application, DOQ-based parcel data are certainly accurate enough and appropriate. Master planning requires only a general outline of where the parcels are located with respect to other features. On the other hand, for cadastre boundary location in a built up area, the accuracy requirements could frequently approach ±0.02 feet (±6 mm) to ±0.05 feet (±15 mm). In other applications such as determining which parcels fall inside a flood plain or wetlands, the accuracy requirements are more difficult to establish. In rural areas where parcel sizes are very large, ±25 feet (±7.6 m) may not be very critical and therefore DOQs can be considered as appropriate. However, in densely populated cities where the width of many parcels are 100 feet (30 m) or less, this accuracy may present a considerable problem. Table 2 presents a sample of parcel-based GIS applications for which DOQs are estimated to be appropriate, inappropriate, or problematic.

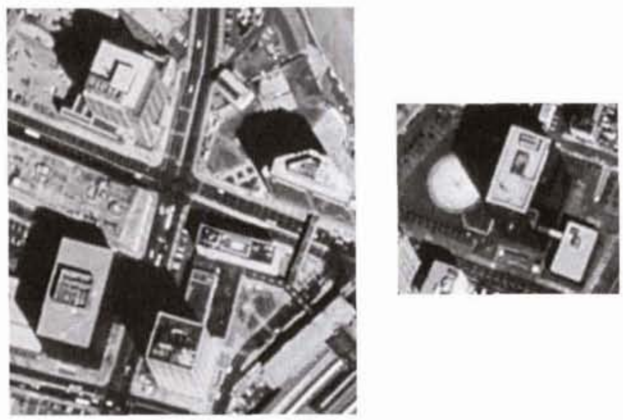

Figure 5. Occlusions due to relief displacement.

Image quality issues have also some bearings on the appropriateness of DOQs for parcel-based GIS applications. The issue to be addressed is whether the image quality of the DOQ is adequate for supporting "heads up" parcel digitization. The ±25-foot (±7.6 m) accuracy was determined at selected well-defined sharp images. Digitizing more fuzzy images, as most of the parcel boundaries are, could result in lower actual accuracy.

Table 2. A Sample of Parcel-Based GIS Applications and the Appropriateness of DOQs.

Appropriate	Problematic	Inappropriate
♦ Master plan development	♦ Land use	♦ Legal property location
♦ General economic development	♦ Environmental permit application review	♦ Utility location, One call system
♦ EMS, 911	♦ Flood plains	♦ Right-of-way
	♦ Wetlands	♦ Drug free zone
	♦ Tax mapping	♦ Engineering
	♦ Automatic notification	

Figure 6. Poor image quality that makes it difficult to delineate individual parcels.

In numerous instances parcel boundaries cannot be identified in the image at all. Figure 6 shows an area of poor image quality that makes it almost impossible to delineate individual parcels. Any attempt at digitizing parcels from images such as that shown in Figure 6 will result in a crude approximation of the parcels with much lower spatial accuracy. Lower spatial accuracy will complicate the dilemma of the appropriateness of a DOQ for some of the parcel-based GIS applications.

Conclusions

The increased popularity of DOQs as base maps for a parcel-based GIS necessitates an accuracy and quality assessment of that product. A sound approach for such an assessment is to perform an NSSDA-based accuracy determination for a DOQ. In addition, image quality issues need to be assessed in the context of specific GIS and DOQ applications.

The evaluated DOQ was found to be accurate to within ±25 feet (7.6 m) at the 95 percent confidence level. Some image quality defects were found but, in general, the consistency and continuity of the image was very good. Details such as parcel boundaries were mostly fuzzy and very difficult to digitize. In built-up areas it was found that buildings and elevated roads were not rectified correctly. The above-ground heights of these structures apparently were not incorporated into the DEM. Therefore, digitizing these features will result in much lower spatial accuracy.

The decision as to whether a DOQ is appropriate for a parcel-based GIS is left to the user. The user should establish a standard independent of the DOQ and then make the determination as to whether the DOQ meets that standard.

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