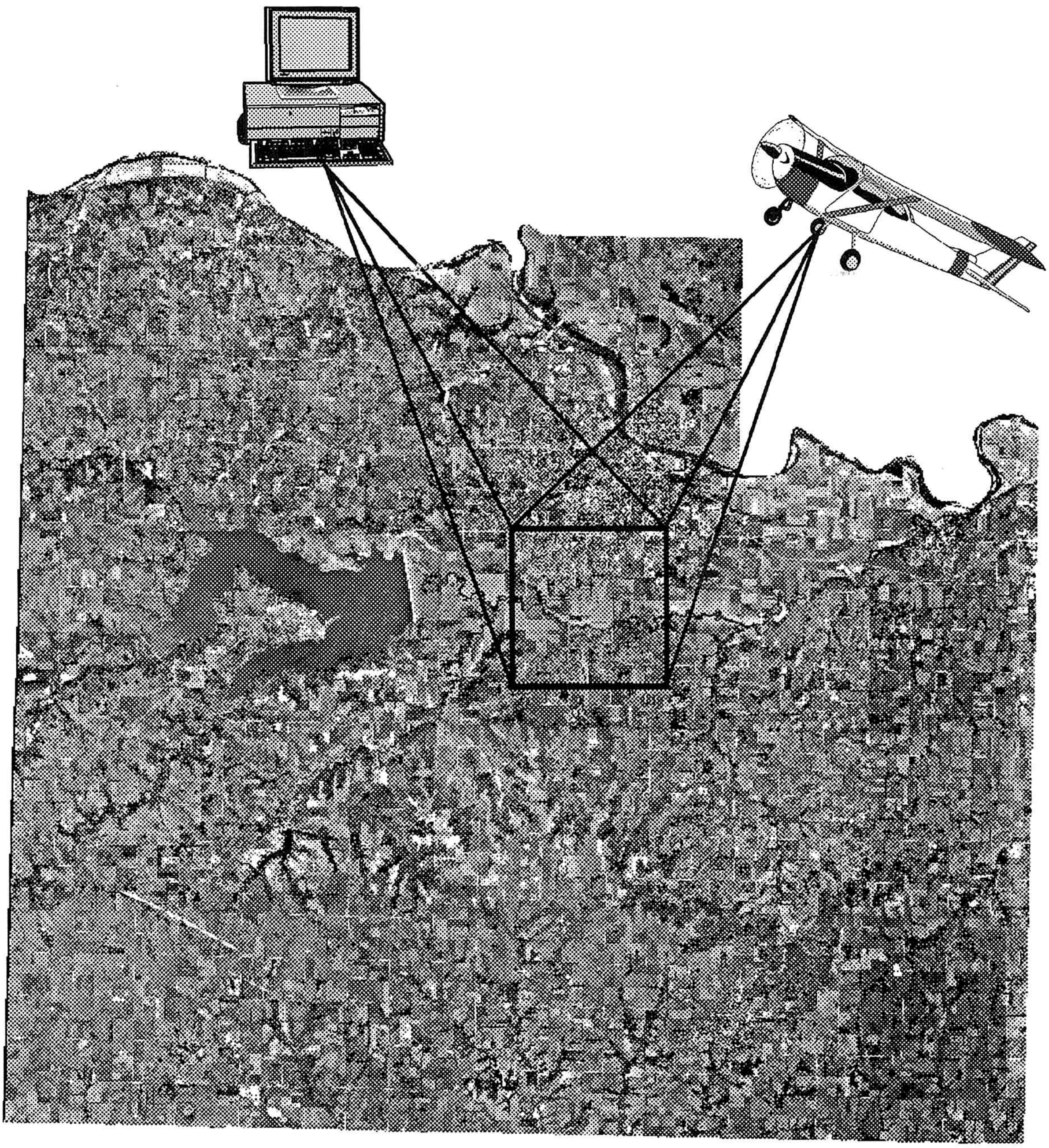
State of Kansas
Geographic Information Systems (GIS)
Policy Board



Digital Orthophotography
Pilot Project
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Kansas Geological Survey
Open-file Report 95-31

Kansas Geological Survey
Open-file Report

Disclaimer

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Digital Orthophotography Report Index

EXECUTIVE SUMMARY

The following report addresses issues related to Digital Orthophotography Quarter Quadrangle (DOQQ) product comparisons, testing applications, and secondary issues related to DOQQ use. In addition, this report contains basic information about DOQQs and their potential use.

All DOQQ products tested met National Mapping Accuracy Standards for their scale. Four DOQQ products with differing levels of horizontal control and altitude were compared with one another. It was discovered that improved horizontal control in conjunction with increased spatial resolution results in a more accurate DOQQ product. However, this improvement comes with some drawbacks: 1) a greater expense to create an enhanced DOQQ product and 2) increasing spatial resolution resulting in extremely large image files. For the applications tested, the 1-meter standard DOQQ product was adequate in both spatial resolution and accuracy.

Digital orthophotography is an excellent base for rectifying existing databases and for capturing new data. Users will find the visual impact of seeing what they are mapping (heads-up digitizing) an improvement over blind mapping on a digitizing tablet. Applications that proved to be successful with DOQQs are:

- Conflating existing data such as transportation network center lines and hydrology.
- Geologic mapping.
- Mapping urban land use (i.e. industrial, commercial, residential, etc...).
- Rural parcel mapping (delineating ownership and agricultural field boundaries).
- Georeferencing regulated facilities and point source data that have been located by conversions from public land surveys or address geocoding methods.
- Wetlands & land-cover mapping on DOQQs used in conjunction with NRCS color slides over several years.

Several applications were found to be not suitable with black-and-white DOQQ products, including:

- Remote sensed agricultural crop type and use mapping.
- Automated impervious surface mapping.

These applications will require multi-spectral imagery.

At the resolutions tested (half-meter and 1-meter), DOQQs are not ideal for the following mapping applications:

- Urban parcels.
- Utility features (i.e. utility poles and manhole covers).

These features will require higher spatial resolutions; 2-foot is typical.

Several issues need to be resolved before DOQQs can be successfully implemented throughout the state. These issues include 1) distribution format of the imagery, 2) tiling scheme, 3) default coordinate system, and 4) software and hardware requirements for use with DOQQs. These standards should be developed with input from a diverse group of users in order to reduce duplication of effort and the expense of fielding DOQQs.

DOQQs are suitable for organizations which require a highly accurate base on which to build geographically referenced datasets. Organizations will also be able to georeference existing datasets to the DOQQ base, thereby improving the spatial accuracy of the dataset.

I. INTRODUCTION

A. Background and History of Project

In 1993, the GIS Policy Board's Technical Advisory Committee (TAC) developed a long range plan for the possible acquisition of Digital Orthophotography Quarter Quadrangles (DOQQs). This plan detailed the costs, benefits, and implementation strategy for acquiring DOQQs in Kansas. It strongly endorsed the purchase of DOQQs in Kansas and stated that " it is not a matter of whether this rich resource should be part of database development plans, but rather how soon it can be acquired." The report described the potential of DOQQs as a "comprehensive solution to map revision problems and facilitates the maintenance and updating of the GIS data layers." It also outlined how DOQQs would serve as a base map to compile new data to meet program needs of agencies and assist policy makers and natural resource planners interpret abstract maps with digital aerial photograph as a backdrop. In the educational section, the report called for workshops to be held to help better understand the technology and to develop a demonstration pilot project. TAC member agencies would provide potential projects that could be tested and demonstrated with DOQQs. It concluded with a discussion of issues related to funding, cost share opportunities, and the role of DASC as a distributor.

1. Purpose and focus of the pilot project.

In September of 1993, the GIS Policy Board contracted with PlanGraphics to assist in the development of a strategy for the DOQQ pilot project in Kansas. A planning session meeting of TAC members which involved State, local, and private companies was held, and the following objectives were identified for the pilot project:

- Determine the technical requirements for the production effort.
- Demonstrate the value of DOQQ technology.
- Test hardware/software capabilities.
- Determine State/local/utility roles and requirements.
- Undertake and complete pilot application testing.
- Determine statewide costs.

This report also detailed the DOQQ products to be acquired, the options for contractors, and the key action items. To produce a list of applications to be tested, a DOQQ pilot project application questionnaire was developed and forwarded to all GIS Policy Board Member agencies. The list from this survey is on the following two pages.

2. Listing of DOQQ pilot applications, January 1, 1995.

Mapping Property Ownership Parcels
Use the DOQQ as a base for delineating parcels by either conflating existing digital parcel data or by developing the parcel base on the DOQQ using information taken from standard property ownership maps.

Transportation Network Conflation
Overlay and conflate the existing KDOT transportation features with the digital orthophotography to correct for positional errors. Join individual KDOT drawings to form a continuous transportation network for the pilot area.

Mapping Electric and Other Utility Features
This is primarily a large scale application whereby electric infrastructure and facilities, such as poles, corridors, transformer substations, etc. are identified and delineated using photo interpretation techniques on the digital orthophotography. In addition, identify and delineate other utility features, such as manhole covers, and create a network connecting the manholes.

Updating Agricultural Land Use
Determine agricultural land use from the digital orthophotography using photo interpretation techniques. This application will likely require some additional expertise in aerial photo interpretation since different crops are not always easily differentiated.

Conflating TIGER, DLGs, and Other Publicly Available Data
Corrected positional errors of publicly available GIS data such as TIGER and DLGs using the DOQQ as the base.

Wetlands and Other Land Cover Identification
Delineate wetlands and other micro-scale land cover features on the DOQQ using the large scale product. Land cover classifications would use standardized classification systems and would include high levels of detail.

Automated Impervious Surface Delineation and Measurement
Identify and delineate several known areas of impervious surface as polygons. Using raster image processing software, the pixel reflectivity for known impervious surfaces would be identified as a range of gray scale values. The software would then enclose all pixels with similar values within the boundaries of polygons. Topology would be developed, enabling the area of the new impervious surface polygons to be measured. The test will be checked for accuracy in the field by comparing the measured area of impervious surface to the automated delineation.

Mapping Geologic Boundaries
Geologic boundaries tend to follow landforms that are identifiable on digital orthophotography. It may be possible to map geologic boundaries using the DOQQ as a base map without extensive field work. The DOQQ would also be used to field check existing geologic information as well as serve as a reference map for field use.

Urban Land Use Update/Verification
The high resolution of the DOQQs allows users to determine urban land use (industrial, commercial, residential, etc.) at a large scale for a variety of urban applications.

Identification and Geo-referencing of Regulated Facilities and Point Source Pollution
Identify regulated facilities, such as wells, hazardous waste sites and landfills, on the digital orthophotography, using either existing maps or legal descriptions, or addresses as guides. This may also require overlay of TIGER data and address matching.

Image Draping over a Digital Elevation Model
Drape the DOQQs over a digital elevation model (DEM) for visual effect as well as for decision-making purposes. In addition to the DOQQ, drape other digital data on the DOQQ and DEM.

Common Base
In addition to these stand-alone applications, it would also be of value to demonstrate the utility of using the DOQQs as a common base map; for example, 1) overlaying parcels and soils for cadastral mapping and 2) overlaying impervious surfaces with TIGER data for storm water drainage analysis in urban areas.

DOQQ Product Review
Examine the positional differences between the various DOQQ products and experiment with DOQQ to produce a more usable product.

3. Seminar on digital orthophotography in 1993 (Dept. of Revenue host).

A seminar on digital orthophotographic imagery was held in Topeka, Kansas, on August 24, 1993. Guest speakers included Mr. Greg Tilley of Photo Science, Inc. and Mr. David Nystrom of USGS. This workshop was sponsored by the Kansas Department of Revenue and was held at the Kansas Historical Society's auditorium. Attendees included most State agencies and a good representation of local government and private industry. Technical sessions included topics such as what is an orthophoto, how do DOQQs differ from conventional aerial photos, and how is a DOQQ created. Application sessions addressed some of the uses for DOQQs (appraisal mapping, infrastructure mapping, planning, etc.). The final workshop topic was considerations for using and acquiring DOQQs. As discussed in the long range plan, the focus of this workshop was to educate potential users about this technology and its application.

4. DASC equipment acquisition for pilot project.

In April of 1994, the Data Access and Support Center (DASC) was awarded $14,500.00 to assist in the testing of the DOQQ pilot project. The purpose of this funding was to equip DASC with the necessary hardware and software to utilize DOQQs. DASC would work cooperatively with participating agencies to test their particular pilot application. The final product of this project would be a demonstration of DOQQ potential and a written report detailing DOQQs and their application.

5. GIS Policy Board's DOQQ Pilot Project Demonstration in 1994 (Kansas Geological Survey host).

On July 15th, 1994, DASC presented to the Policy Board and other interested organizations phase one of the DOQQ Pilot Project. The DOQQ standard product was demonstrated with a live interactive session of its utility with reference to the proposed projects. This demonstration went into detail showing how existing data could be used in conjunction with the DOQQs and how to capture new data sets. DOQQs were displayed using various formats with differing resolutions, compressions, and image formats. In addition several presentations were given by the Property and Resource Information Systems Management (PRISM) organization and Johnson County GIS Program. This was another opportunity to educate Policy Board and Technical Advisory committee members on the potential application of DOQQs.

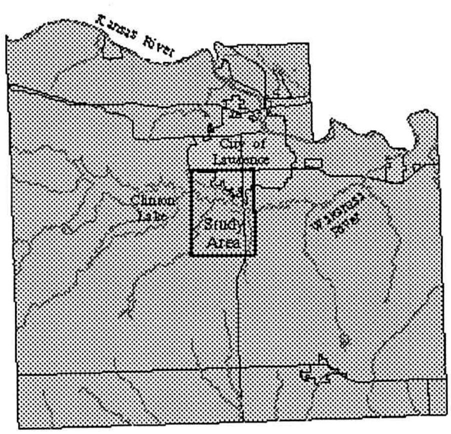
6. Receipt of all products from USGS.

Much of the work could not be done until all of the products were delivered to DASC. In January 1995, DASC received all the enhanced products from USGS for the DOQQ Pilot Project.

B. General Description of DOQQs

1. Study area.

When choosing a study area that would prove suitable for a wide variety of tests, the southeast portion of the Lawrence West quadrangle appeared to be a very strong choice because of the heterogeneous nature of its land use and cover, its proximity for field research, the amount of data available for this area, and the attention that was given to it due to recent issues in this region. Located just southwest of The University of Kansas in Lawrence, Kansas, this quadrangle was an ideal choice. It contains a good mixture of residential,



Pilot Project Study Area

commercial, agricultural, and natural land use. In addition, the quadrangle showed a physiographic diversity that would challenge the tested applications. It is located in the Wakarusa River valley and includes floodplain as well as 70-meters of local relief. The study area proved to be an excellent test site for this DOQQ pilot project.

2. Description of DOQQ Products.

Four products were created to test the effect that various resolutions, horizontal control, and altitude have on the application of the DOQQ. The four orthophoto products chosen for this study were: 1) standard USGS product, 2) standard USGS product with enhanced horizontal control, 3) half-meter resolution product, and 4) half-meter product flown at a lower altitude. Each image utilized a level-one 1:24,000 digital elevation model (DEM) with vertical points spaced every 30 meters to orthogonally rectify the photo's scanned diapositive. All the images were projected in the Universal Transverse Mercator (UTM) coordinate system using meters for both horizontal and vertical coordinates. UTM coordinate rectifications were given in both North American Datums (NAD) 1927 and 1983.

Standard digital orthophotos are tiled into 3.75-minute quadrangles (3.75-minutes of latitude by 3.75-minutes of longitude). A digital orthophotography quarter quadrangle is exactly one quarter of a USGS 1:24,000 topographic map. This product is often referred to as Digital Orthophoto Quarter Quadrangles (DOQQs) due to this tiling scheme. The intended scale of use for a DOQQ is 1:12,000, or 5.312- inches to 1-mile on a printed map. To facilitate tonal matching along DOQQ borders and for placing quarter quadrangle tic marks, each DOQQ has approximately 50- to 300-meters of overlap on each side. In its native format, DOQQ's file size is approximately 48-megabytes.

a. Standard USGS product.

- Existing black-and-white National Aerial Photography Program (NAPP) photography was utilized; this imagery was flown in 1991.
- One-meter ground resolution (image scanning resolution no greater than 32-microns).
- Photography must meet NAPP standards flown at an altitude of at least 20,000 feet with a 6-inch focal-length camera. The image must have photo-identifiable points and ground control coordinates.
- Radiometric image brightness values stored as 256 levels of gray scale saved as an 8-bit binary image.
- Level 1 Digital Elevation Model (DEM) of the same area as the DOQQ is required.

b. Standard USGS product with enhanced horizontal control.

- Same image as the standard product but incorporates GPS control points to potentially enhance spatial accuracy when orthogonally rectifying the image.

c. Half-meter resolution standard altitude.

- New black-and-white photography flown by M. J. Harden Associates, Inc. in 1994.
- Flown at 10,000 feet altitude, but scanned with each pixel set equal to half a meter.

d. Half-meter resolution low altitude.

- New black-and-white photography flown by M. J. Harden Associates, Inc. in 1994.
- Half-meter resolution product flown at 5,000 feet altitude.

Each product was delivered on 8mm tape in a band interleave by line (BIL) image format. This file contains four header records which describe the image characteristics such as: quadrangle name, date, production information, number of lines of data, number of pixels in each line, upper left pixel UTM coordinates, and ground distance for a pixel x and y dimensions. These data are necessary to retrieve and display the images in most GIS softwares. They must be extracted from the image file and placed into a separate header file for most GIS systems.

C. Software and Hardware Utilized by DASC to Test the Pilot Applications.

1. Hardware.

A UNIX Sun Sparc 10 workstation was used to test the DOQQs. This system was upgraded with a high resolution 24-bit color video card with monitor and 4-gigabytes of hard disk. In addition, 32-megabytes of memory was added to upgrade the system to 128-megabytes of system memory. These upgrades were acquired to handle the increased load caused by DOQQ processing on DASC's server. This is an ideal workstation configuration to analyze DOQQs, but unfortunately most organizations would not have this type of hardware. Smaller workstations are still capable of processing and viewing DOQQs but not as efficiently. DASC tested DOQQ on a typical personal computer (486DX/66 with 16MB RAM) and found the display and the refresh rates to be slow. DOQQs will have to be tiled differently to be effectively used on typical PC systems.

2. Software.

DASC utilized Environmental Systems Research Institute's (ESRI) Arc/Info to test the DOQQ products. The GRID module extension was required to do much of the DOQQ image processing. The TIN module extension was required to work with the digital elevation model (DEM). Most State agencies and some local governments utilize this software or have other software packages which have similar capabilities. A true image processing software that specializes with DOQQ manipulation would have been extremely helpful. This may be required in the future to process DOQQs into different projection systems and distribution formats.

II. ACCURACY OF DOQQ PRODUCTS

A. Discussion of Accuracy in General.

The first computer-processing step in producing a DOQQ is to scan the aerial photograph with a precision high-resolution scanner. Next, the output digital image is rectified through photogrammetric algorithms utilizing photo-identifiable ground control points, camera calibration and orientation parameters, and a digital elevation model. This highly accurate procedure corrects the image for distortion due to the aircraft's yaw, pitch, and roll; the perspective due to changes in elevation; and radial distortion of the camera lens. The final product is a highly accurate digital image that is tied to a real-world coordinate system and can be used in conjunction with other geo-spatial datasets.

Standard USGS Digital Orthophotography Quarter Quadrangles (DOQQs) must meet National Map Accuracy Standards (NMAS). The NMAS standard for products at the scale of 1:12,000 (1-meter resolution DOQQ) states that 90% of well-defined points tested must fall within 33.3-feet (1/30-inch) or approximately 11.0-pixels on the image (1-pixel is equal to 1-meter).

B. Accuracy Related to Horizontal Control.

One issue tested during the pilot project was to determine whether or not additional horizontal control would improve the accuracy of the standard DOQQ. In this experiment, control points were provided by Douglas County Public Works Department. These points were collected by M. J. Harden for a 1-foot resolution digital orthophotography project in the City of Lawrence. The coordinates were captured utilizing Global Positioning Systems (GPS) equipment that have centimeter accuracy. On the following pages are examples of one point from this database compared with the various digital-ortho imagery (Figures 1A - 1D). The control point selected is a sidewalk intersection in a residential portion of Lawrence, Kansas, in the northeastern part of the DOQQ. It is somewhat difficult to visualize on this graphically limited media, but there was a good fixed image signature for this feature on all the digital-ortho products. The sidewalk appears on the image as bright gray pixels and a house immediately below the sidewalk appears as dark-gray pixels.

1. Standard DOQQ versus the Enhanced Horizontal Control DOQQ.

The first two images (Figures 1A and 1B) are both standard DOQQs, but the latter has more horizontal control points. Steve Thompson of Kansas State University - Salina College of Technology acquired these additional control points in Douglas County utilizing global positioning systems technology (See Appendix A for a more detailed description of the GPS control point capturing process). Since this image was already flown, there were some problems finding photo-identifiable control points because significant change had occurred in this area since 1991. This team also laid out target control panels for the new photography that was acquired for the half-meter DOQQs.

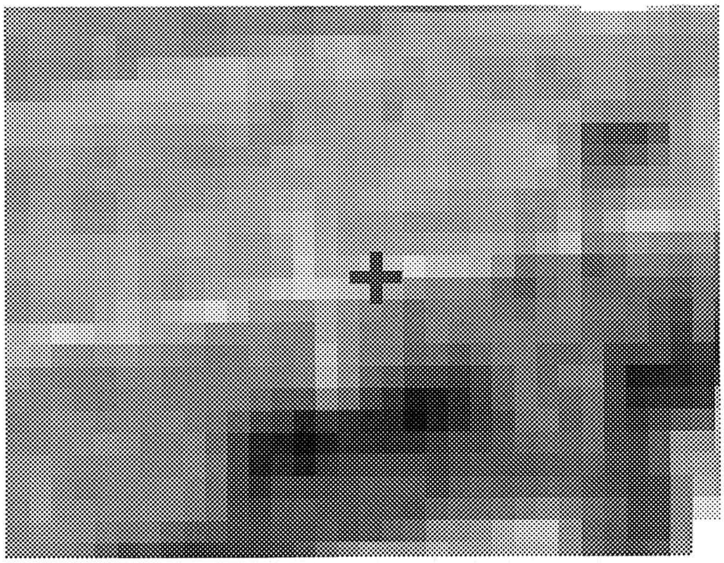


Figure 1A. 1-meter standard DOQQ.

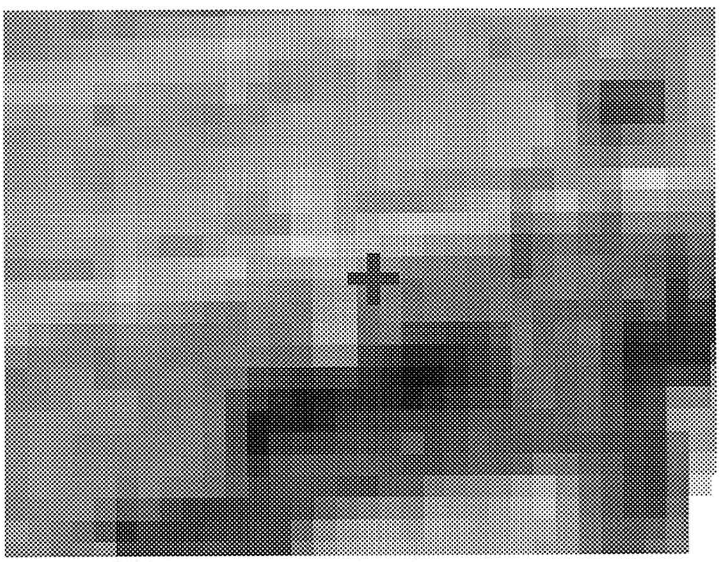


Figure 1B. 1-meter GPS control DOQQ.

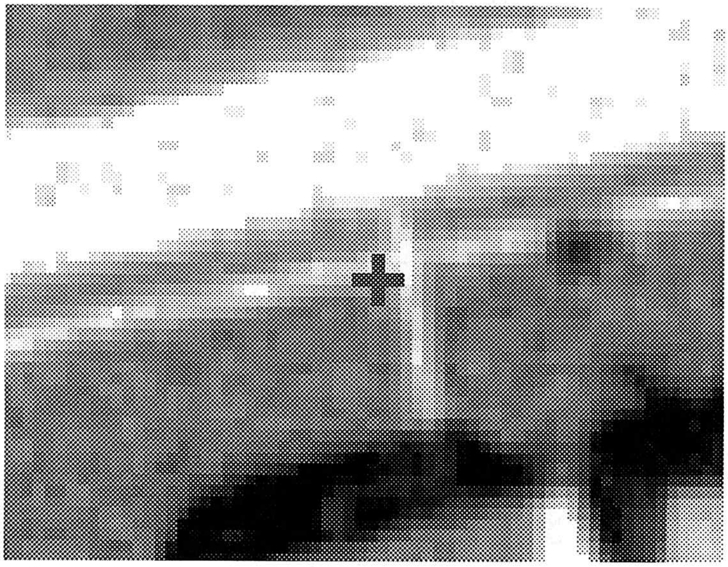


Figure 1C. Half-meter DOQQ captured at 10,000 feet of altitude.

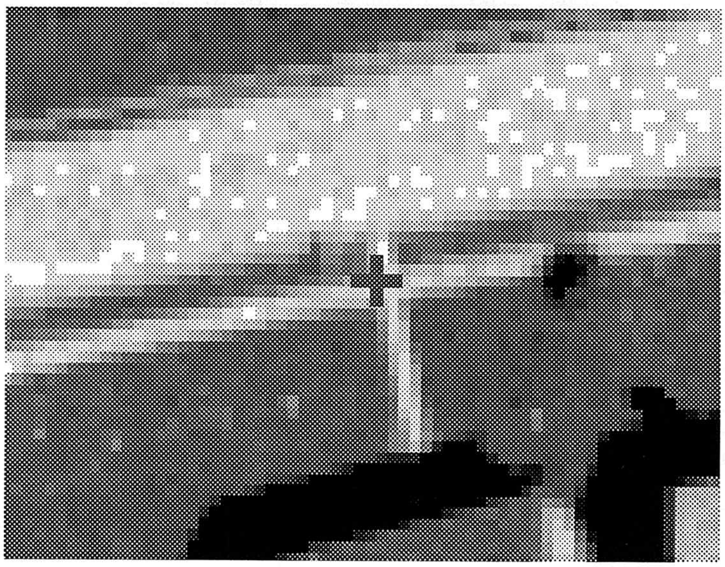


Figure 1D. Half-meter DOQQ captured at 5,000 feet of altitude.

As one can quickly see, the sidewalk is difficult to pin-point. Most sidewalks are approximately 1-meter in width, and with a 1-meter pixel width these images are not of high enough resolution to precisely identify the sidewalk location. In addition, the bright reflectance signature of the sidewalk carries over into the surrounding pixels washing out the sidewalk edge. Aside from these facts, there seems to be minimal gain from the increased accuracy and density of the control points at this resolution. Both images deviate from the control point by 3-meters, but in differing directions.

A correlation and scattergram analysis was performed on these two images. A correlation coefficient of 0.95696 was calculated when comparing the pixel values between the two images. A value of 1.0 would mean the two images are exactly the same, so with this value the images appear to be similar. It was expected that the images would be fairly similar since they both were derived from the same image, but a coefficient this high was not predicted. On a scattergram analysis (not shown) the corresponding values for each pixel in the image are plotted on a separate axis (x=standard DOQQ, and y=enhanced control DOQQ). If the images are identical, the plot will be a 45-degree line. If the results are scattered, the images differ greatly. The plot from this analysis demonstrated that once again the images are similar but with some exceptions. The level of importance of these anomalies is something that is yet to be determined and is beyond the scope of this report.

Lastly a random sample area was cut from each of the images. The sample area from each DOQQ was split down the long axis and each adjacent half was viewed for noticeable differences (Figure 2). On the samples provided, the southeastern half of the snapshot is from the DOQQ with enhanced horizontal control, and the northwestern half is from the standard DOQQ. There are no noticeable shifts along the traverse line. This is illustrated by the snapshot provided; notice that the roadway pavement edge does not shift.

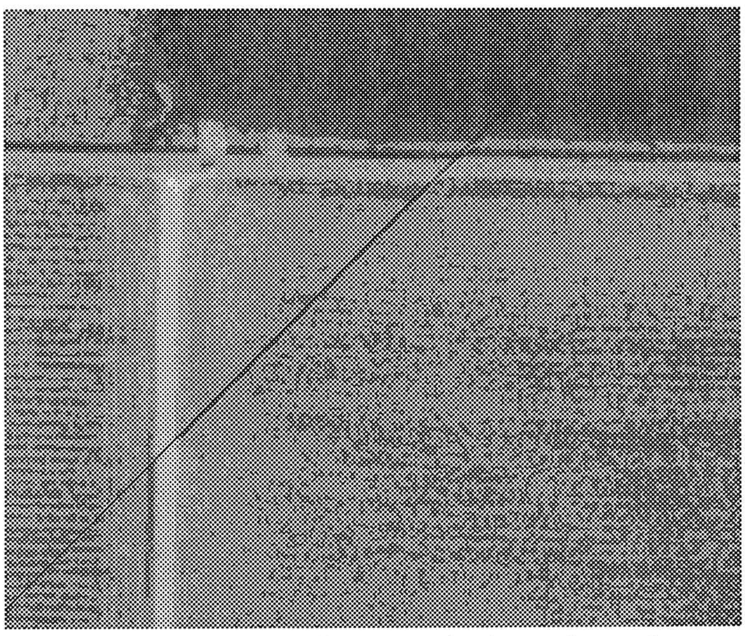


Figure 2. Sample traverse line - standard vs enhanced control.

2. Differences between 1-meter versus half-meter DOQQs.

The differences between the 1-meter and half-meter are quite dramatic. The half-meter resolution definitely begins to delineate features to a much greater certainty than the 1-meter. One can easily visualize the sidewalk intersection and nearby roadway on the half-meter product. This increase in resolution comes at a cost. A typical half-meter DOQQ image is approximately four times the size of a standard DOQQ (160MB verses 40MB). This size of image file can be difficult to manage, and potential users must weigh the value of the resolution versus the demands this size of image will place on the system. The improvement in accuracy can be associated with two factors, the increase in the spatial resolution resulting in an improved signature for features on the imagery, and the improved horizontal control utilizing GPS technology.

3. Differences between high-altitude versus low-altitude DOQQs.

The two half-meter images demonstrate the difference flying altitude has on the accuracy of the DOQQ (Figures 1C and 1D). The low-altitude (5,000 feet) DOQQ has the control point on the intersection of the sidewalks, much closer than any of the previous images. In addition, the low-altitude image tends to delineate edges more prominently and there is a greater variation of reflectance values within homogeneous regions (examine the street gray-value distribution). Examining the same sample traverse as used earlier, there is a noticeable shift on the roadway edges (Figure 3). This illustrates the differences between the two products and clearly demonstrates that positional control has changed. The half-meter low altitude is more accurate than any of the other DOQQ products. This can be demonstrated by examining another set of control views showing how the panel marker in the street intersection is near the center on the control point for the low-altitude DOQQ (Appendix B, Figures 6A and 6B). One factor that needs to be examined further is the effect low altitude has on the perspective corrections in areas that have large local relief.

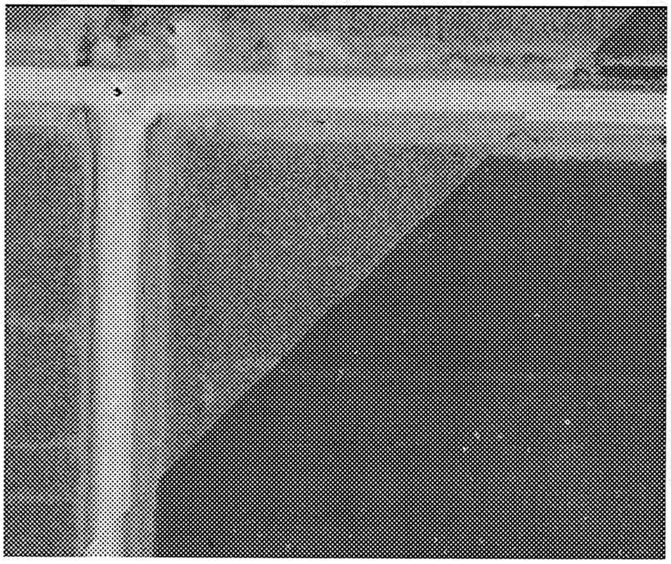


Figure 3. Sample traverse line - half-meter low vs half-meter high altitude.

C. Conclusion.

All of the tested DOQQs meet the national map accuracy standards for their scale. Additional control points were sampled and snapshots are provided in Appendix B. These additional snapshots support the conclusions in this report. Improved horizontal control in conjunction with increased spatial resolution results in higher spatial accuracy of the DOQQ product. Although the low altitude half-meter DOQQ has better horizontal control, this does not necessarily equate to a more usable product. Many projects, especially in rural area analysis, do not require that level of control or spatial resolution. In the next section we will examine the application of the pilot projects with each of these products.

III. APPLICATIONS (based on the recommended set provided by TAC members)

A. Mapping Property Ownership Parcels.

1. Conflate existing digital parcel data.

Parcel data for the Lawrence West region were provided by Dennis Albers, Douglas County Appraisers Office's GIS Administrator. These data were not georeferenced, but had the location of section corners identified. Mr. Albers exported the data from a Microstation into a DXF format with separate layers for each feature type. Utilizing these section corners the database was imported into Arc/Info and georeferenced to the USGS Public Land Survey 1:24,000 Digital Line Graph using a projective transformation into the UTM coordinate system. Once geo-referenced, the data could be overlaid on the DOQQ. Since the parcel database is fairly large, only a small area within the study area was selected. The selected area included rural and urban development and had significant changes due to development.

This procedure produced very good results. The existing parcel data matched the Standard DOQQ to a high level of accuracy. Parcel fence lines from deed records and front easements matched the image fence lines requiring very little editing, if any. One major problem was the age of the photography. In regions where there has been urban sprawl and increased development, the 1991 photography was difficult to use. However it was adequate for use in rural regions. Although these photographs are old, they were much better than the 1986 photography which the appraiser's office was using. For rural parcel mapping, the half-meter imagery provided much better horizontal control, but this level of accuracy is not required.

In addition to the above test, the entire Douglas County DOQQ database was converted into a TIFF image format and mastered on CD-ROM so it could be utilized on the county appraiser's office GIS system (Intergraph MGE). Mr. Albers projected the DOQQs into their county-wide grid control system (state plane feet) and clipped the images to the quarter quadrangle boundary to save space. This process resulted in surprisingly favorable results and only required minor adjustments. After projecting, sections were compared between the images and grid to ensure that they met county standards of not being more than 13-feet from the section grid control. If the image fell outside this tolerance, the grid control system was re-examined and the image was reprocessed. Only four quarter quadrangles required this additional processing. This was mainly a result of difficulties in determining section locations in and around Clinton Reservoir.

Mr. Albers felt that the 1-meter standard DOQQ was adequate to map agricultural use in rural areas, but would not work in urbanized areas. The resolution of half-meter DOQQ provided more information in urban areas, however the 1-foot digital orthophotography would be much better. One-foot digital orthophotography was available for the City of Lawrence and was found to have extremely detailed imagery. Parcel mapping in highly urbanized areas will demand the highest spatial resolution available (2-foot is common for urban mapping).

2. Develop new parcel information on the DOQQ.

When working with the DOQQ, the Douglas County Mapper felt that mapping agricultural use lines would be much easier because one can visually see features referenced. The visual impact of the DOQQ is a factor which aids in mapping and analysis. How much time and resources this will save is difficult to estimate, but there is definitely a benefit to mapping heads-up on a photo base versus using a digitizing tablet. It also makes a good supplement when mapping from deeds.

Several problems were identified when working on this parcel project that are related to the way in which the Standard DOQQ product is delivered. Most parcel maps in rural areas are tiled in 4-mile regions across the county using section lines as the borders. DOQQs are tiled into quarter quadrangle which most counties' staff are unfamiliar with and often segments public land survey sections. Tiling the DOQQ by township would be a much better alternative. The overlap on the DOQQ is not required for parcel mapping and requires extra storage space. This overlap should be clipped from the images. Lastly, the DOQQs are projected in UTM meter coordinates; however, most counties map parcels in state plane feet coordinates. Either the county parcel maps or the DOQQs will have to be converted to a common projection system and units that can be agreed upon.

B. Transportation Network Conflation.

1. Overlay and convert existing Kansas Department of Transportation (KDOT) features with the DOQQ to correct for positional errors.
Note: A detail transportation network was not available for this study area.

In April 1994, the DASC Programmer David Hogben and the former State GIS Coordinator Cy Smith demonstrated the utility of DOQQs to the Kansas Department of Transportation staff. This workshop examined some of their sample data that were rectified from Microstation digitizer inches to real-world coordinates and overlaid on a DOQQ base. Unfortunately no detailed transportation data are available for the Douglas County area. The study area contained only three major roadways, all of which appeared to line-up fairly well with the DOQQ. During the demonstration, Dave Hogben illustrated how other databases could be overlaid and corrected on the DOQQ.

In addition, KDOT's Division of Aviation acquired DOQQ products from DASC for the Lawrence Airport where they were doing studies on the utility of DOQQs with KDOT Intergraph mapping software. The department was testing the product to see how it could aide the inventory of airports and associated data. They were also examining the product for its utility in measuring runways and airport planning. They found the DOQQ to be very useful, but that it would require greater resolution than the 1-meter data, since airport their studies are done at a micro level.

C. Mapping Electric and Other Utility Features.

1. Identify and delineate electric facilities, such as poles, corridors, transformer substations, etc. using photo interpretation techniques. In addition, identify and delineate other utility features, such as manhole covers, and create a network connecting the manholes.

The goal of mapping utility features was to develop a continuous network of electric facilities by delineating features such as poles, and transformer substations on the DOQQ. In addition, manholes would be delineated and a network would be created to link them together.

The 1-meter digital DOQQ does not allow for any real mapping of utility features due to the relatively large pixel size (resolution). As a rule of thumb, features must be at least 2-pixels in size in the longest direction to be detectable on any kind of image. For the 1-meter DOQQ this means that features must be at least 2-meters wide to even be visible. Even if a feature is visible, this does not mean the feature can be identified. More electric utility features were visible on the half-meter digital DOQQ, but they are still not identified with a high level of certainty.

The most easily identified features are poles, primarily because of their long shadows. Poles with relatively short or no shadow and those falling in the shadows of buildings cannot be detected. Of those utility poles that are visible, they may be confused with other features such as traffic and light poles. Once again the half-meter low altitude was better in identifying features such as telephone poles. Figure 4 shows a portion of the half-meter digital DOQQ. At the center of the photo a pole can be detected because of its long shadow. This pole is easily identified because it is in the open and its shadow is relatively long. Other poles are not as easily seen.

Figure 4. Half-meter low-altitude DOQQ with telephone pole.

Manholes cannot be identified with certainty. Their presence is enough to generate reflectance values different from neighboring pixels, but they are easily confused with other relatively small features such as benches, signs, and small trees. Overall, mapping of utility features from 1-meter or half-meter DOQQs is not suggested. A much finer pixel resolution will be required and this will be too costly to produce on a statewide basis.

D. Updating Agricultural Land Use.

1. Determine agricultural land use from the DOQQ using air photo interpretation techniques. This application will require some additional expertise in aerial photo interpretation since different crops are not always easily differentiated, especially when using a single band image.

For the most part, agricultural land use cannot be determined using single band imagery. Utilizing texture analysis and some limited field work, DOQQs can be used to determine land cover type such as row crops, grasslands, and wooded regions. It also can be used to determine types of agricultural conservation and irrigation practices. To determine the type of crop growing would require multi-spectral imagery. Currently, Natural Resource Conservation Service (NRCS) uses color slides to determine crop types. A color DOQQ would be required to do this type of analysis properly. DOQQs can be used to determine the field boundaries, and when used in conjunction with color slides, could produce an accurate field boundary database with crop type defined. The DOQQ is an excellent base to delineate field boundaries, but would not be useful in determining crop types. There is no need for any higher resolution than the 1-meter, since it provided the needed accuracy and resolution to locate field boundaries.

E. Conflating TIGER, DLG, and Other Publicly Available Street Centerline Data.

1. Correct for positional errors of publicly available GIS data such as TIGER and DLGs using the DOQQ as the base.

While a road coverage at 1:24,000 scale would have been preferred to use for this exercise, only the Digital Line Graph (DLG) and Topographically Intergrated Geographic Encoding Reference System (TIGER) road coverages at 100,000 scale were available to DASC. Overlaying the DLG-100K roads coverage and the TIGER roads coverage showed rather distinctive errors in the digital data. While some of the discrepancies were due to changes and additions in the road network because of the difference in date between the TIGER and DLG coverages and the DOQQ aerial photography, much of the positional error can be attributed to the 1:100,000 scale at which it was digitized. The main roads overlaid fairly well for the rural and urban areas. Some of the smaller neighborhood roads and rural roads tended to deviate over 30-meters with rather irregular and curvilinear digitizing. While the errors fall well within National Map Accuracy Standards, plus or minus 50.8-meters for both coverages that were created at 1:100,000 scale, cities and towns interested in more accurate GIS applications such as pavement management and 911 routing would probably find the error level to be a major obstacle.

For this reason, an attempt was made to conflate the DLG and TIGER datasets to overlay more accurately with the DOQQ. ESRI's Arc/Info with the ArcTools extension was used to perform the conflation procedure on both coverages. The entire DLG road network was edited to reflect the street centerline of the DOQQ. For a non-experienced digitizer, the procedure took approximately 3-hours for the entire quarter quadrangle. A more practiced user should be able to complete it in much less time. Some of the delay can be attributed to panning around the orthophoto images, which range in size from 48- to 190-megabytes. Most corrections required adding pseudo nodes or more vertices to the arcs in the DLG coverage, but in some instances lines and nodes had to be moved to reflect their true location.

Next, an attempt was made to digitize all the road networks off the DOQQ to compare the raw heads-up digitizing time taken to complete the quadrangle to the conflation time. The procedure took almost the same amount of time, although the biggest problem lies in trying to discern public routes compared to private residential or commercial roads. When comparing the two, the latter method yielded more lines with better accuracy although it contained no attribute information.

F. Wetlands and Other Land Cover Identification.

1. Delineate wetlands and other micro-scale land cover features on the DOQQ using the large-scale product.

This study area contains several rivers and small creeks that are easily identified. These features are periodically masked by vegetation and can be difficult to pin-point. Potential wetlands are visible on the image, but will require field investigation to verify.

Another consideration is whether the DOQQ photography was acquired during a wet, normal, or dry rainfall period. This can greatly affect the extent of the wetlands on the DOQQ. In order to correctly map wetlands, several years worth of photography, spanning various levels of rainfall, will be required to determine an average wetland extent. Once again the DOQQ would be better utilized as a base to map wetlands while consulting NRCS color slides over several years in conjunction with supporting field investigations.

G. Automated Impervious Surface Delineation and Measurement.

1. Identify and delineate several known areas of impervious surface as polygons. Using raster image processing software, the pixel reflectivity for the known impervious surfaces will be identified. The image processing software will be used to enclose all pixels of similar value within the boundaries of polygons.

Topology will be developed to enable area measurement of the new impervious surface polygons. The test will be checked for accuracy in the field by comparing the field-measured area of an impervious surface with the automatically identified area.

The goal of this application was to develop an automated method for delineating impervious surfaces in an urban area. Because the digital DOQQs are stored as a raster image composed of pixels with an associated reflectance value, the pixels can be grouped or classified based on the reflectance value of the pixel. An ideal classification of impervious surfaces would consist of roof tops, streets, parking lots, and other impervious surfaces.

Relatively complex image classification such as that discussed above usually relies on pixel reflectance values across a range of different wavelengths. Images containing reflectance values in different wavelengths are said to be multispectral because they contain multiple recordings for a pixel, one value for each range of the spectrum used. Such images are recorded by satellites with sensors capable of recording reflectance values in different parts of the spectrum. Because the digital DOQQ is created from black-and-white photographs that are not capable of recording multiple values of a pixel, the DOQQ contains only one value for each pixel. The result is a gray scale image with reflectance values ranging from 0 (darkest) to 255 (lightest). The only type of classification possible for images with one value for each pixel is called a density slice and does not permit the differentiation of impervious surfaces.

A hypothetical example may be used to illustrate the problems of using the density slice classification. If an impervious driveway has the reflectance value of 128, using the density slice method, all pixels with the value of 128 would be classified as impervious on the image. The problem is that other pervious surfaces, such as grasses or trees, also contain the value 128. The result is that impervious and pervious surfaces cannot be differentiated in any automated manner.

In the testing, pixel values 60 through 65 were located on several grassy areas and should be considered pervious. However, when all pixels with the values 60-65 were turned a different color to highlight their different classification, some pixels clearly fell in impervious areas, especially along building edges. Although impervious surfaces could not be delineated based on the pixel values alone, they may be delineated by manually adding vectors to delineate polygons of different impervious surfaces.

H. Mapping Geologic Boundaries.

1. Map geologic boundaries utilizing a DOQQ as a base map.

A geologist typically works in the field with a 1:24,000 USGS topographic map as a reference. He/She surveys the area and delineates various contacts and other geologic features on the topographic map. If this map is out of date, it is often difficult to orient the map to the ground and define boundaries accurately. Geologic boundaries tend to follow landforms that are identifiable on aerial photographs. Therefore, it is possible to map geologic boundaries using the DOQQ as the base map without extensive field work as proved by the many geologists who perform geologic interpretation using aerial photography.

In this experiment the standard DOQQ product was printed at a scale of 1:12,000 on a 400dpi plotter. Rather than taking a topographic map out in the field, the geologist would utilize the printed DOQQ. Dr. Dan Merriam, Senior Scientist, Geologic Investigations - Kansas Geological Survey, experimented with this method by mapping the geology within the study area. He found that the DOQQ alone was not sufficient. The geologist required contour lines to locate the contacts accurately. A DEM could be used to produce digital contours that would be plotted in conjunction with the DOQQ; this product would be much more useful.

After surveying and mapping the geology on the paper map, the geologist would heads-up digitize the geology on the digital image. This is a major advantage over traditional methods, since the geologist may make alterations from the hand-drawn map based on information drawn from the image. The resulting digital geologic map was found to be more detailed than maps from traditional methods. The 1-meter DOQQ was found to be more than adequate for this type of mapping. The geologist noted that it was difficult to map in some of the urban fringe areas because a significant amount of development had occurred since 1991.

I. Urban Land Use Update/Verification.

1. Update existing land cover datasets.

Currently the only land cover database available for Kansas is the 1:100,000 land cover database produced by Kansas Applied Remote Sensing (KARS). This dataset was derived from multi-spectral satellite imagery with a spatial resolution of 30-meters. Utilizing a 1-meter resolution DOQQ to revise this dataset would not be advised. The dataset has distinct grid boundaries based on the 30-meter pixels and would require extensive re-digitizing to smooth the edges. It should be noted that this dataset did thoroughly delineate the photo-identifiable land cover types and matched the DOQQ very well.

2. The high resolution of DOQQ allows users to determine urban land use (industrial, commercial, residential, etc.) at a large scale for a variety of urban applications.

Mapping urban land cover and use from the DOQQ base is very easy. Users can identify areas with large facilities such as parking lots or buildings from their reflectance signatures. This is a time-consuming process because the user needs to pan and digitize boundaries across the entire area of interest. Utilizing existing digital parcel data and extracting land zoned for various uses would be a suggested method. The user could overlay this information and make corrections to boundaries and attributes in much the same manner as with the parcel dataset. Unfortunately there is no automated way to classify a single band image for urban landuse. This would require a multispectral image.

J. Identification and Geo-referencing of Regulated Facilities and Point Source Pollution.

1. Identify regulated facilities, such as wells, hazardous waste sites, and landfills, on the digital orthophoto using either existing maps, legal descriptions, or addresses as guides.

The Right To Know (RTK) database was developed by Dr. Ling Bian, Assistant Professor, Department of Geography, The University of Kansas. These data were derived from address descriptions from Kansas Department of Health and Environment, which were address-matched with the 1992 US Census TIGERcenterline files. This method of geocoding introduces some error due to methods used to address match and the quality of the TIGER database. Address-matching techniques estimate the location by segmenting the centerline database line, which contains the business/house address, into equal portions based on all the address possibilities. For example, if a portion of a street has left side address ranges of 701 to 799 (all odd numbers) and the address to match is 725, the geocoding process will produce a point which is one quarter of the way up the street, when the actual business/home could be located on the corner. Using address-matching techniques in conjunction with DOQQs, address locations can be quickly and accurately sited. The user would process the addresses then overlay the result on the DOQQ and edit any discrepancies. When geo-correcting the RTK database, most of the points were found to be located near but not on the actual business. The points were easily moved and located right on top of the regulated facility. The 1-meter DOQQ proved to be more than suitable for this operation. This same process can also be used to geocorrect locations of photo-identifiable sites which have legal descriptions. Sites such as oil wells, electrical sub-stations, center-pivot irrigation systems, and large water wells can be geocorrected. After the legal description has been estimated into a latitude and longitude, using LEOII software, the result can be edited in the same manner as described above.

K. Digital Elevation Model Applications.

One of the integral parts of DOQQ generation is the development of a 1:24,000 Digital Elevation Models (DEM). DEMs are used to rectify the image for elevation distortions and can be delivered as part of the DOQQ acquisition. DEMs can be manipulated and used for analysis and to create new GIS datasets.

1. Generating Contour Lines.

There are a wide variety of uses for detailed contour maps. A few examples are soil erosion potential modeling, urban/rural planning, view shed analysis, and general base map information. DEMs are databases that have regularly spaced point elevations across a quadrangle. On 1:24,000 DEMs, elevations are sampled every 3- meters. With the use of Arc/Info, up to 3-meter interval contour line coverages can be generated. Arc/Info's TIN module can read the information contained in a DEM file and create interpreted contour lines. The x and y coordinates of the contour lines are determined from the DEM grid coordinates, and the z value (meters of elevation) is approximated by interpolation between adjacent sample points. One should be careful when using these data since this is an interpretive process and many small landform features will not be identified. In addition, there are a variety of ways the DEM could be generated, each producing a differing quality product.

Contour lines for the Lawrence West Southeast Quarter Quadrangle were generated and compared to the contour lines on the corresponding USGS 1:24,000 topographic map. When comparing the delineation of major land forms, the digital contour lines matched closely with that of the hard-copy contour lines; however, there were some discrepancies noticed between the two line coverages when examining specific areas. Minor topographic features were not often identified and the interpretive process had difficulties generating useful contours in flat regions such as floodplains. Overall the process of converting a 1:24,000 DEM to 3-meter contours was fairly easy and yielded a very usable product.

2. Developing Lattice Surface Models

Lattice surface models are described by ESRI's technical documentation as "the surface interpretation of a grid, represented by equally spaced sample points referenced to a common origin and a constant sampling distance in the x and y directions." Surface models allow for advanced analysis such as view shed analysis, determination of slope and aspect, watershed delineation, and analytical hill shading. A lattice surface model would be an ideal tool for soil conservation scientists to use when determining soil-erosion potential, or for urban planners to use when determining the suitability for development of a particular site. Arc/Info's GRID module and its associated map algebra language provide the necessary tools with which to develop and analyze surface models. Utilizing the DEM for the study area, a lattice surface model was created.

3. Draping Images

Once surface models have been created from DEMs, the corresponding image or a coverage can then be draped over the surface model to obtain a realistic 3-D view of the earth's surface. Image draping not only provides a pleasing visual effect, but can also aid in the decision-making process by giving GIS professionals an accurate 3-D perspective of the area they are studying. In addition to the DOQQ, other digital data such as road and stream networks, political boundaries, soils, and land cover can be draped over the surface model to provide an even more realistic view of the surface of the earth. Arc/Info provides a wide range of tools with which to perform image draping and related 3-D modeling and analysis. In the index of this report, there is an example of an image drape. The region displayed is the Lawrence West quarter quadrangle (study area) viewed from the southwest corner with a vertical exaggeration of 5x.

IV. SECONDARY ISSUES

Beyond accuracy and difference in spatial resolution of DOQQs there are several issues that need to be addressed concerning the distribution and packaging of the digital data. This is discussed in the following section.

A. Image Formats and Compression.

One of the biggest problems in using the DOQQs or any other raster image base is their size. When heads-up digitizing on a photo base, a user frequently has to redisplay, pan, and zoom. Most low-end PCS would have a problem manipulating and displaying a 48-megabyte image let alone a 190-megabyte image. These images can be compressed and resampled through various techniques to reduce the overall size. These techniques, however, can reduce the quality and accuracy of the image. In this section we will review secondary issues such as image formats, compressions, resampling, tiling methods, and distribution methods.

1. Supported formats.

One image format for the orthophoto product is Band Interleaved by Line (BIL). Unfortunately, this format utilizes no compression and tends to make very large files. The typical BIL DOQQ is about 48-megabytes in size. To transfer a typical county's DOQQs such as Douglas County takes approximately 2.2-gigabytes of storage space, which is just over the size of one low-density 8-mm tape or four 74-minute compact disks. By employing compression methods such as Joint Photographic Experts Group (JPEG) or LZW (software inventor's initials), the standard image size can be reduced from 48- to 8-megabytes. Band Interleaved Line (BIL), Tagged Image File Format (TIFF or TIF), and JPEGs File Interchange Format (JFIF or JFF) seem to be the standard image format for DOQQs and most GIS software support one or all of these formats. The USGS standard distribution format is JFIF with JPEG compression.

2. Lossy compression.

Problems can occur when using the JPEG compression format because it is a lossy format, meaning that the compressed image loses some of its information. The JPEG method uses an irreversible block-based compression algorithm that adjusts adjacent pixel values in the image to reduce the size. Through a process of generalization, the compression routine examines the image for areas that have similar reflectance values and assigns an average value for that region. When writing the image to a file, rather than writing each cell value, it writes an expression for that region such as 25 cells with a gray value of 252. This reduces the overall physical image size dramatically. The user does have some control over how much generalization will occur. When writing a JPEG compression file, the user can adjust this quality setting. Reducing the quality setting causes the image to be more generalized, resulting in a smaller file size. Below is a table listing the various file sizes with decreasing levels of quality. A 1-mile by 1-mile area was selected to test the visual changes that occur with decreased quality.

Quality Setting (%)	File Size (bytes)
100	674,138
90	299,927
75	175,968
50	108,988

No visual changes could be detected in our study area with a quality setting of 50% or higher, unless the user zoomed to a specific area and an extremely large scale. This would not be done by most typical users. With less than 50% quality more visual changes could be detected. Most of these changes are indistinguishable to the human eye, but can cause some problems when performing operations such as density slices. Overall, this format dramatically saves disk space. In the above example, with a 75% quality setting, the orthophoto was reduced by one-fourth of its raw file size.

The USGS CD-ROM release copies which are delivered in JFIF format are approximately 3.5-megabytes in size for a full DOQQ (compared to 48-megabytes for BIL). USGS CD-ROM distribution utilizes a quality factor of 30. This dramatically reduces the file size, but sacrifices image quality. Tests conducted by M. J. Harden Associates, Inc., indicate that plots of compressed versus uncompressed DOQQ are not as good. Tonal increments in the pixel are lost and the resulting compressed image plot has more contrast than the uncompressed image plot.

A major problem with this format is that most GIS software have yet to support JFIF format. Since USGS has selected it as the distribution format of choice for DOQQ, it is believed that in the near future most GIS software will include JFIF support. USGS has provided a conversion software to export the JFIF file into several more common image formats.

3. Non-lossy compression.

Formats such as TIFF with Lempel-Zev-Welch (LZW) compression can reduce the file size and do not alter the actual image. These formats implement on-the-fly compression. Utilizing compression such as LZW, software compress and de-compress the images when saving and displaying the image (much like software tools such as disk doubler). This can save hard disk space, but causes added demand on the CPU. We found most GIS software support the TIF format, but many do not support the compression (LZW or PackBits) unless it is licensed by the user. DASC does not have a license for LZW, so this could not be tested.

B. Resampling and Spatial Resolution.

1. Utility of greater than 1-meter DOQQs.

High-resolution DOQQs prove to be more useful when attempting to extract urban features such as utility poles, fire hydrants, impervious surfaces, and street center-lines. However, the size and resolution of the orthophotos can become a negative factor in their use. Features such as geology tend to be rather generalized and definitely do not require 1-meter resolution. If this is the case, the size of the DOQQ can be greatly reduced by resampling the standard DOQQ from 1-meter to a much larger resolution.

2. Results.

It has been noted that due to their size, DOQQs are rather unmanageable (approximately 48-megabytes) for most users that are not using a workstation or high-end Pentium PC. One potential solution to alleviate this problem would be to resample the images from 1-meter pixels to 2-meter, 3-meter, or 4-meter pixel sizes. As one can expect in a two-dimensional space, the size of the images decreases geometrically as the pixel size increases. The following chart shows the decrease in file size for the 1755 SE quad (this quarter quad has been clipped to the exact boundaries which has reduced the flight line overlap):

Spatial Resolution (meters)	File Size (bytes)
1	39,560,768
2	9,890,192
3	4,397,670
4	2,473,432

Obviously, as the pixel size increases the image size decreases geometrically. At 3- or 4-meter pixel size the image is significantly reduced in size so that even a 386/33Mhz computer can display it without too many problems. The 2-meter image has been displayed and used as a backdrop in ArcView II on a 486/66Mhz computer with 16-megabytes of RAM, which might be considered a reasonable machine to perform heads-up digitizing on, as well as conflation of existing datasets on the orthophoto base. For features such as property boundaries in urban or suburban areas, resampling will not be advantageous. However in rural areas, property delineation could be greatly aided by resampling. Other features such as soil, geologic, and land-use boundaries do not need the spatial resolution because of the already somewhat inexact nature of the features. Upon examination of each of the resampled DOQQs for an area roughly one-quarter of a mile in area, it appears that the 4-meter pixel size is too crude to exactly delineate precise linear features such as road center lines and railroads. Buildings start to take on a crude and pixilated look which rapidly degrades as the accuracy decreases. There is definite value in decreasing the spatial resolution for specific projects that do not demand the level of accuracy in a standard DOQQ. Future changes in computer technology may make the spatial resolution a moot point as the ability and power of computers grow.

C. Distribution Considerations.

1. Tiling methods.

The standard distribution format for the orthophotos is one-quarter of a 7.5-minute quadrangle plus overlap. Standard USGS 1:24,000 quadrangle maps are divided into four equal parts to make Digital Orthophotography Quarter Quadrangles (DOQQs): northeast, southeast, northwest, and southwest. Each BIL DOQQ is roughly 48-megabytes in size which tends to restrict their distribution and use. The quarter quadrangle tiling scheme is an administrative project management decision rather than an end-user supported decision. The USGS systematically divided the country into 7.5-minute quadrangles. However, most end users in the state do not work in this type of tiling scheme.

To make a more usable product, it is recommended that the standard USGS DOQQ be re-tiled into a user-supported system. It has been suggested that the DOQQs be split by legal boundaries such as the Public Land Survey townships. This seems to be the most logical method since the largest group of potential users of this product are counties who map frequently within legal boundaries. More study needs to be done in this area to determine what is the best tiling system for the widest audience of users. This is also necessary to reduce duplication of effort across the state since many users may eventually need a re-tiled database.

2. Coordinate systems.

The USGS standard distribution for DOQQs as well as other datasets, such as the 1:24,000 DEMs and DLGs, is the Universal Transverse Mercator (UTM) projection system with coordinates in meters. Some agencies and private companies use the State Plane Feet coordinate system which presents a problem when incorporating DOQQs into their database. To be of use, the DOQQ will have to be projected to fit their coordinate system. Benchmark tests on a Sun Sparc 10 Model 512 showed that projecting an image/grid from UTM to State Plane in Arc/Info took over 4-hours. While Arc/Info can accomplish this task, it is not the ideal software to project images. Custom software that specializes in DOQQ projections would be preferred.

UTM also causes a problem when doing analyses that cross UTM zones. For instance if a user was doing a study around the Delaware Basin, they would have to contend with a UTM zone change that splits Nemaha and Jackson counties down the center. The UTM zone changes on the 96- and 102-degree west longitude medians in Kansas. Datasets in differing UTM zones cannot be edge-matched and cannot be used with one another. The data would have to be projected into the same zone or a common projection system. State Plane also splits Kansas into northern and southern zones using county lines as the dividing point. Because images are fairly difficult and time consuming to re-project, a common projection system that all potential users can agree on should be established.

3. Time of capture.

The DOQQ standard product images were captured in 1991, while the enhanced products were captured in 1994. Review of these images shows that significant changes have occurred during the three years. Most of the changes have occurred due to urban expansion from Lawrence, Kansas. Rural regions did not have any major changes that could be identified. It is apparent that highly developed urban regions will require frequent DOQQ updates. Rural regions may only require new DOQQs every 10-years.

4. Differences in tonality.

Throughout the analysis of this study, it was noticed that some images were darker than others. Even within images there are some differences, especially when there were several images used to mosaic the DOQQ. These differences can cause problems when studying textures and reflectance signatures. Some software can adjust these differences, but only across the whole image. Major shifts in brightness values should be sent back to the developer to be corrected.

5. Distribution methods.

a. File size.

As mentioned before, the orthophotos are approximately 48-megabytes in size for a quarter quadrangle. With different tiling methods, their size could potentially drop dramatically. Also, using different image formats with compression, such as JFIF or TIFF with LZW, could decrease the size. One of the most important factors to consider is how this valuable resource can be put into the hands of the users across the state. Some factors to consider that limit DOQQ use are that many users do not have the necessary tools to manipulate DOQQs (changing image formats, re-tiling, etc.) or the hard disk space to store them locally on their computer.

b. Media.

Presently there are only two types of media which prove to be effective in distributing orthophotography: 8-mm tapes and CD-ROMs. 8-mm tapes are becoming more commonplace on workstations and can hold 2- to 5-gigabytes of data. CD-ROMs can hold 650-megabytes, are less costly, and allow the user to access data more quickly. CD-ROMs are also beneficial since the user can access the data directly off the CD; no hard disk space is required. Most operating systems require only basic commands to mount a CD, while tape media requires users to deal with cumbersome restore commands such as tar and device dump.

CD-ROMs are the ideal media to distribute DOQQs as long as the data are provided in a manner which is directly usable by the requestor. If they have to change the image format to be compatible with their software or re-tile the data to fit their database scheme, CD-ROMs are not as effective. Meetings involving all levels of potential users need to be held to determine optimal distribution formats for the DOQQs.

c. Network.

Network transfer of DOQQs can bring a system that does not have the latest 100-megabytes/second transfer capabilities to a crawl. Users in a network should be conscious of transferring files because of their impact on all other machines on the same sub-network. Eventually, much of the Internet backbone will be composed of fiberoptic lines which can transfer files as large as the orthophotos without significantly impacting other users, but currently, transferring large-image files across the network is not recommended.

D. Software/Hardware Considerations.

For many users who do not have the budget to afford a high-end workstation, the DOQQs can prove to be too unwieldy to use or store on a basic PC. Users who have a 386DX/33 computer with 4-megabytes of memory could probably still examine the images, but the display and refresh will be extremely slow. A more ideal configuration to view DOQQs would be at least a 486DX2/66 with 8- to 16-megabytes of memory and a local-bus video card. Users planning to actually do analysis or heads-up digitizing on the images should invest in a Pentium 90 or better with 16- or more-megabytes of memory and at least a 2-megabyte VRAM local-bus VESA or PCI accelerated video card. All systems should have a CD-ROM drive to read CDs. This drive should be a quad-speed or better since the images will be read directly off the CD. The user will also need plenty of hard disk space to save images, if required, and GIS databases for editing. A gigabyte hard drive is suggested, as well as a large monitor (minimum 17-inches). A typical PC system with this ideal configuration will cost approximately $3,500.00. While a high-end desktop workstation could cost as much as $20,000.00.

When selecting a software, ensure that it supports multiple image formats. The software should support one or more of these formats: BIL, JFIF, or TIFF. In addition, the software should provide for some image tools to adjust the image brightness values and color map. The software should allow the user to backdrop the images so that editing and digitizing can be done on top of it. Most of these features are available with software provided by ESRI, Intergraph, and Map/Info.

V. SUMMARY

A. Heads-up Digitization.

Heads-up digitizing provides a very convenient and more accurate method of data capture than traditional hand digitizing of printed material. While DOQQs have some minor problems related to their size and tiling convention, they do have the convenience of the user seeing the features being digitized. The speed of digitizing off the screen appears to be much faster, especially for attributing points, lines, and polygons as they are digitized. DOQQs also offer much more accuracy with the 1-meter photo base than traditional methods. Although DOQQs for the study area are four years old, they are much more current than USGS 7.5-minute quadrangles. The Lawrence West Quadrangle map was dated 1950 with photo revisions in 1967 and 1978. DOQQs provide a more effective means of updating existing databases or capturing new information than traditional methods.

B. Use as a Common Base Map.

DOQQs are an ideal base with which to reference new and existing data; however, not all of the existing data should be conflated to the DOQQ base. Some databases such as TIGER and Land cover had different design goals and were not intended to have 1-meter accuracy. This does not prohibit these databases from being used in conjunction with DOQQs; rather their inherent deficiencies should be viewed in light of their intended scale of use. DOQQs will also serve as a good base to georeference data which has yet to be tied to real-world coordinates. Users of CAD systems which have this type of data could reference the data to the image using projective transformations.

C. Recommendation of Different DOQQ Products.

The 1-meter standard product was found to be more than suitable for rural database development and analysis. There was no practical gain from the increased horizontal control on the 1-meter product. For general studies such as urban development projects and development of zoning boundaries, 1-meter DOQQs could serve a role. Most urban database development and analysis of images will require high-resolution digital orthophotography. The half-meter low-altitude DOQQs were an improvement from the 1-meter product, but 1-foot digital orthophotography would be ideal. Urban parcel and infrastructure mapping and planning will demand a higher resolution adequate for their needs.

D. Issues Needing Decision or Standard.

Throughout this report there were several discussions related to problems implementing DOQQs statewide. These issues will require further study and eventually a standard should be developed. These issues are:

1) Supported image format(s).
2) Tiling structure(s).
3) Projection and coordinate systems.
4) Distribution media.
5) Recommended hardware and software requirements.
6) Quality-control system for review of DOQQs.

A forum of all concerned parties should be involved in this process to draft a solution in the best interest of all levels of Kansas government.

APPENDIX A

Global Positioning Systems (GPS) Control Points

1. Control for the 1-meter GPS DOQQ.

Using the Southwest Lawrence 7.5-minute Quadrangle and the 1991 digital imagery on a GRASS workstation, 15 photo-identifiable points were selected throughout the full quadrangle. Then, KSU-Salina GPS crews visited these sites and obtained GPS coordinates. The field locations of the control points were determined by using a printed copy of the DOQQ as a guide. In several cases new points had to be selected because the site had changed since the 1991 photography. Aschtech and MEXII brand geodetic receivers with a reference receiver (base station) at the Lawrence Airport were used. GPS crews spent 30-minutes with the field receivers on each of the points capturing coordinate information. Differential GPS techniques were used to determine the final coordinates of the GPS control. The GPS coordinates should be accurate within 1-foot of the true coordinates. Finally, the GPS coordinates were compared with the coordinates from the standard DOQQ using the GRASS software.

2. Control for the half-meter DOQQ products.

For the new photography that was being flown for the Pilot Project, GPS crews with help from the Douglas County Public Works Department set control panels and obtained GPS coordinates for these locations. To determine the coordinates of these panels, differential GPS techniques were used with two reference base stations and 1-hour of collection at each point. Most of the control panels were set over section corners, but some had to be offset because the corner was on a gravel road and the signature would be difficult to identify on the photography. The resulting GPS coordinates should be within centimeters of the true coordinates.

APPENDIX B

Additional Control Point Views

On the following three pages are several views of the differing DOQQ products which were used to compare horizontal accuracy. Refer to section II, B of this report for further explanation. Figures 5 A-D are of a section corner along U.S. Highway 59, south of Lawrence, KS.

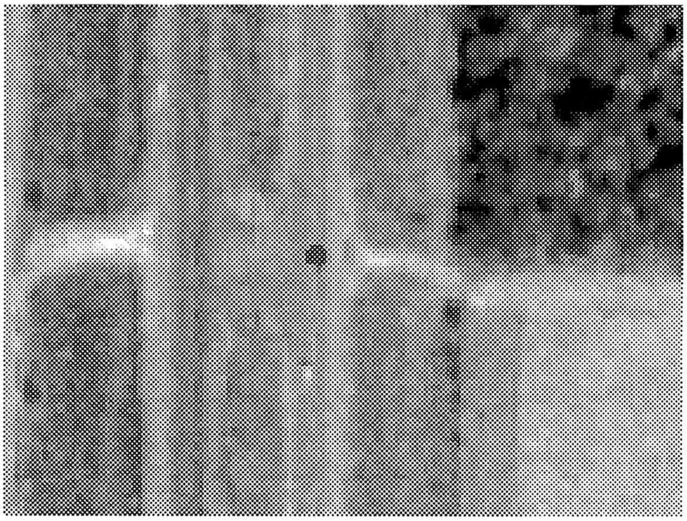


Figure 5A. 1-meter standard DOQQ.

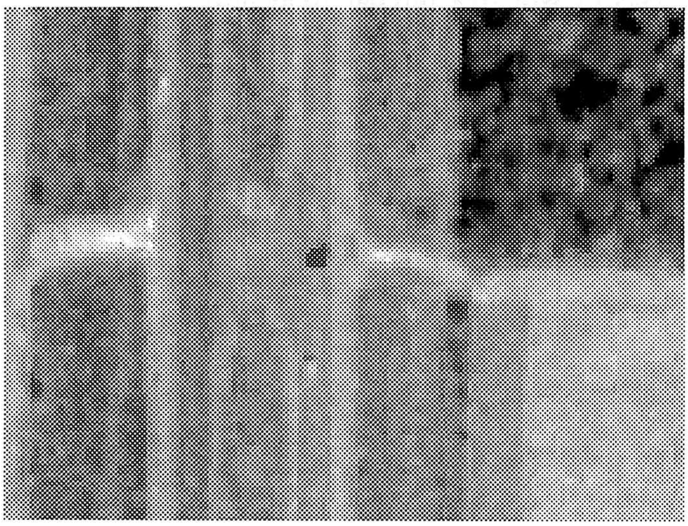


Figure 5B. 1-meter GPS control DOQQ.

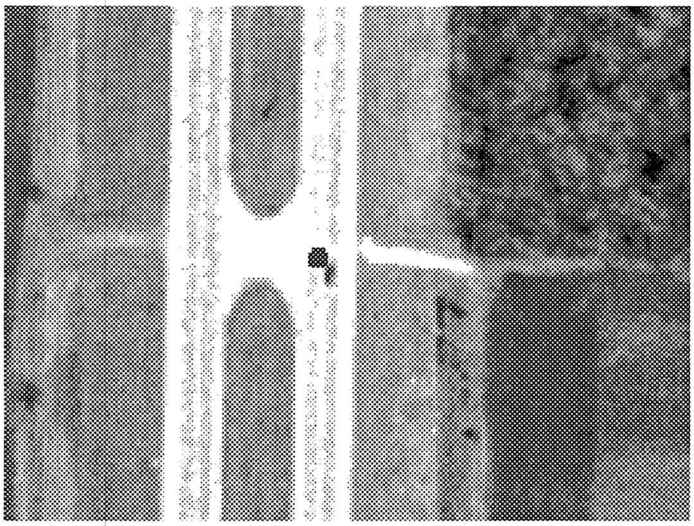


Figure 5C. Half-meter DOQQ captured at 10,000 feet of altitude.

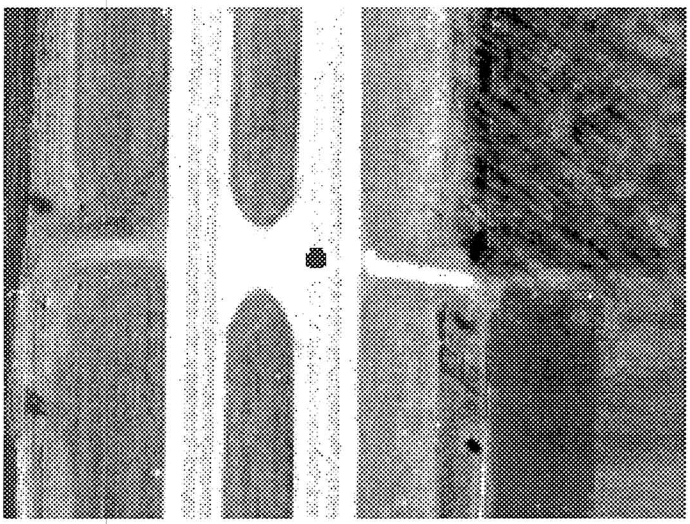


Figure 5D. Half-meter DOQQ captured at 5,000 feet of altitude.

Figures 6A and 6B illustrates the accuracy of the low altitude versus the high altitude DOQQ product. The images are of a roadway intersection (Iowa and 31st Streets) in Lawrence, KS. Located in the center of this intersection is a "Y" shaped marker painted on the pavement. The control point on the low altitude (5,000 feet) DOQQ is almost in the center of the marker.

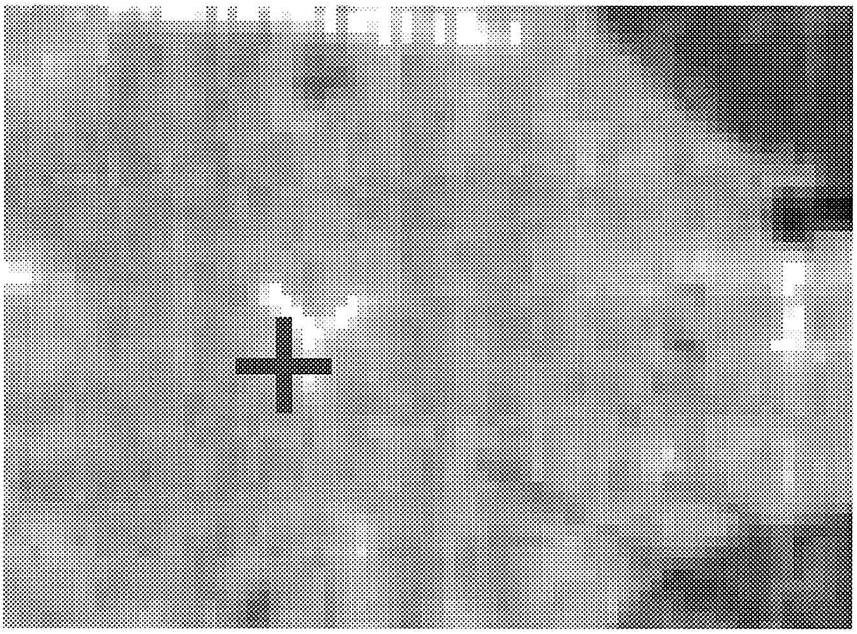


Figure 6A. Half-meter DOQQ captured at 10,000 feet of altitude.

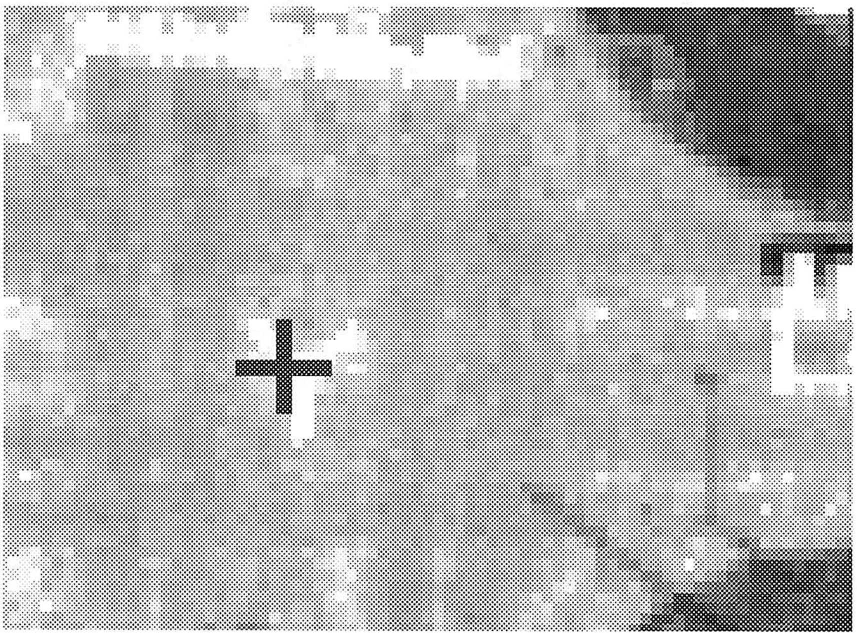


Figure 6B. Half-meter DOQQ captured at 5,000 feet of altitude.