Pilot Project Mapping Impervious Surface Areas Using DigitalGlobe's Satellite Multispectral Image Data, Hays, Kansas

By

Dr. Kenneth R. Neuhauser
Dr. Thomas Schafer
Dr. Richard Lisichenko
Dr. John Heinrichs

Mr. Tanner Nickelson
Mr. Garrett Thompson
Mr. Austin Rohr
Mr. Derek Clark

Department of Geosciences
Fort Hays State University
600 Park Street
Hays, KS 67601

Abstract

Classified satellite image spectral signatures were identified for the City of Hays, Kansas. Impervious and pervious surfaces and their approximate percentages were calculated for selected private and commercial lots utilizing multispectral satellite imagery, a remote-sensing software and a geographic information system. A multispectral 4-band image taken by the Quickbird satellite on March 16, 2005 was purchased from DigitalGlobe. Analyses indicate that the selected residential parcel has 26.7% impervious surfaces, 65.4% pervious surfaces, and 7.88% is not determinable. The selected commercial parcel has 74.7% impervious, 21.5% pervious, and 3.8% undeterminable surfaces respectively.

Introduction

In 1980, Denver passed an ordinance allowing the Wastewater Management Division (WMD) to bill residents to cover the costs of building and maintaining infrastructure that controls the flow of rain and melting snow, which is disrupted when land is developed. Though storm water billing brings in needed funds, the billing by impervious surfaces is often laborious. The mapping of every sidewalk, every patio, every roof, every parking lot, etc., takes quite a few people and time.

WMD worked with DigitalGlobe on a pilot program in 2004 to use multispectral satellite data to map impervious surface areas in five Denver neighborhoods. Their research had 95 percent accuracy according to DigitalGlobe's Jeff Liedtke, director of Civil Government Applications (Montandon, 2004). Liedtke said there are two components to mapping the impervious surfaces. One of which is the use of the satellite imagery and the second is running that image through an algorithm that classifies the image into impervious and pervious areas, and using DigitalGlobe's proprietary algorithm and special techniques (Montandon, 2004).

In 2005 Fort Hays State University submitted a grant to the Kansas Geological survey to conduct a pilot program in Hays, Kansas using a DigitalGlobe Quickbird satellite image (figure 1) and utilizing the remote-sensing software ENVI (version 3.6) and Environmental Systems Research Institute (ESRI) ArcView (version 9.1) software. The image was purchased from DigitalGlobe using in-house matching funds from a FHSU Graduate School Research Award and the Department of Geosciences at Fort Hays State University.

Our goal was to utilize GIS at FHSU and to bring to fruition the integration of the DigitalGlobe multispectral image with the analysis of ArcView in order to test the feasibility of calculating pervious and impervious surfaces. Further, we intend to present this methodology to the City of Hays should they wish to pursue a wastewater management initiative.

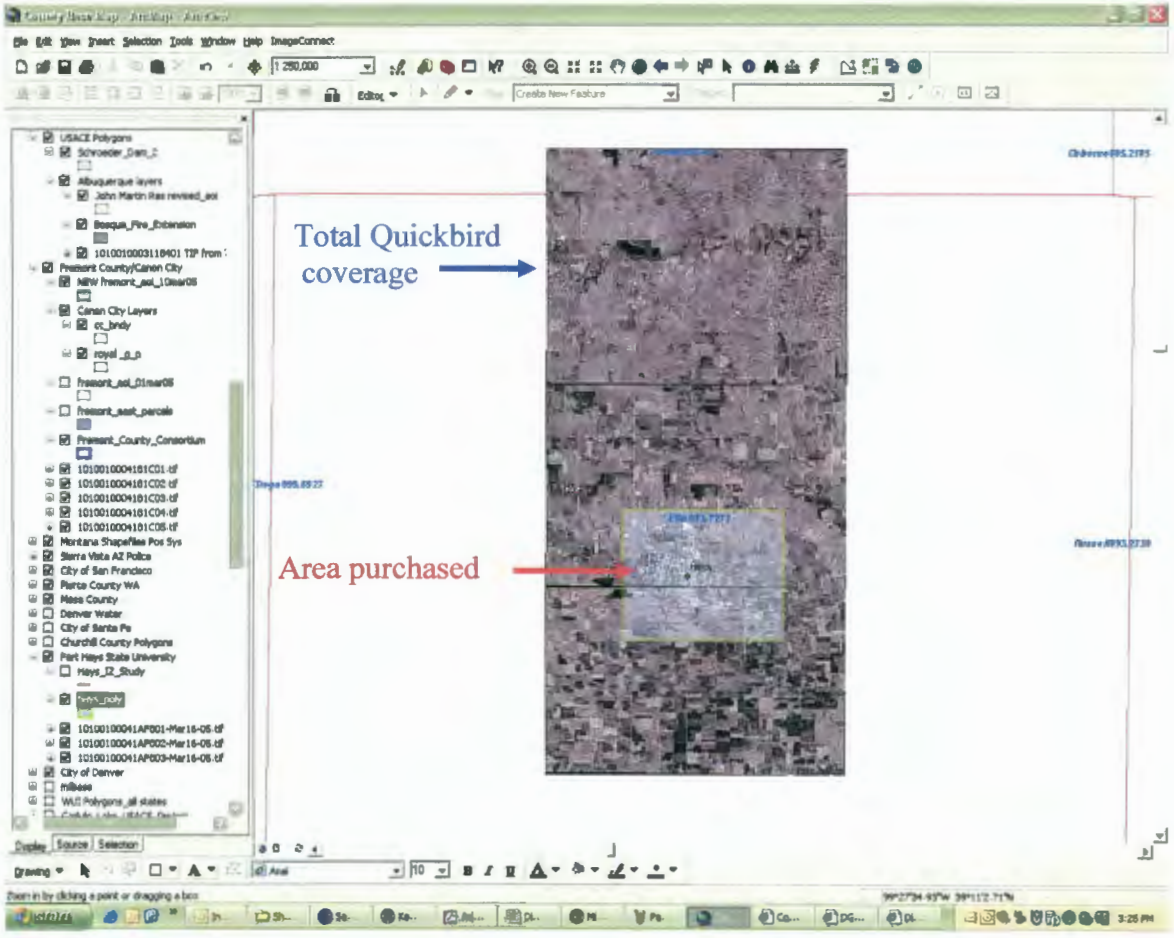


Figure 1 Screen capture from ArcView showing Quickbird coverage; arrow points to region centered on Hays, Kansas, purchased from DigitalGlobe.

Preliminary Work

Student members were selected by an interview process. Four students were chosen based on their remote sensing and GIS experience and teamwork skills. The students reviewed the ENVI remote sensing process, practiced identifying spectral signatures on a known image from a previous remote sensing class, and began processing the DigitalGlobe Quickbird multispectral image. The primary goal of this team was to create an accurate spectral classification of the City of Hays for the purpose of calculating the percentage of total impervious and pervious surfaces.

Methodology

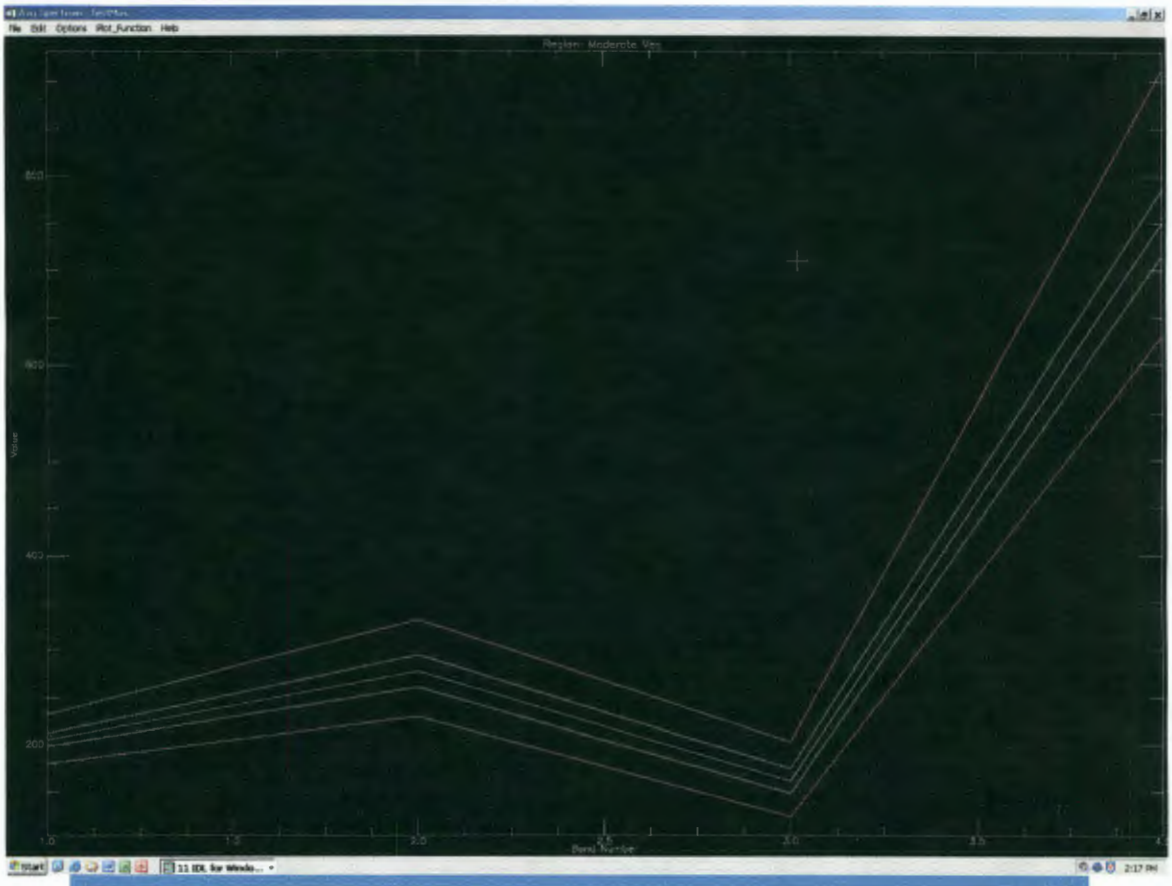
Remote Sensing Component:

See Appendix A for an outline format of the ENVI Remote Sensing process.

We created a spectral angle-mapper (SAM) classification scheme by gathering electromagnetic reflectance signatures of different materials (concrete, different grades of asphalt, soil, three different shades of vegetation, different colored shingles, etc.) off the Quickbird image. Since the Quickbird image contained the near infrared (NIR) wavelength, the team was able to use a reflectance other than just visible light which definitely helped in classifying soil and vegetation. The NIR reflects very well from the water in the epithelia cells of plants; thus, vegetated surfaces can be distinguished from non-vegetated surfaces very well. From these samples a classification image was generated. This image consisted of a visual display showing the probability that each surface within the image fell within a sample category of another surface. For example, with proper collection we could select a couple hundred pixels of sidewalk and the classification would do the rest of the work for us with the remaining three-hundred thousand pixels or so of sidewalk. This method, of course, is entirely dependent upon the purity of the sample.

We decided that the spectral angle-mapper classification in ENVI would be best suited for this project. Completing this process required the same basic steps as the previous classification. First, we had to 'collect' ROI's (Regions of Interest) so that we had a precise and accurate range of samples for each surface type in order to create a spectral library. The spectral library was used to apply the spectral angle-mapper classification. The reason that the spectral angle-mapper classification is not as prone to shadows is the fact that it is designed to be that way. SAM is much less sensitive than other classification methods. When a point is in a shadow or in different lighting conditions, its location in channel space simply shifts closer to the origin along the spectral vector. Since the angle of that vector is what the classification uses, the point is still classified the same (Appendix B). This classification assigns an ascending value to the electromagnetic wavelengths in an ascending order on the y-axis. By doing this, you put your lower values, such as red for the visible spectrum, on bottom and blue on top. Then the classification model assigns a value to each pixel based upon its albedo (level of intensity of reflection) on the x-axis. The classification can plot each pixel onto the graph and determine what the root color of each pixel is when this is mapped out. For example, a raw sample of cobblestone would show up on the lower end of the red spectrum. This

means that it would be lower on the y-axis. If it is covered in shadow then it would be located farther out on the x-axis. By drawing a perpendicular horizontal line through the point on the x-axis and hitting the y-axis you may find the most likely root color (spectral wavelength) of the shadowed feature. Figures 2a and 2b represent how a selected surface signature compares to the spectral library. The signatures are of a higher quality match when the lines are spaced close together (fig. 2a) or of a lower quality match when the lines are farther apart (fig. 2b). The best case scenario, which is not often acquired, is when all the lines overlay exactly. We conducted field 'ground-truthing' of both the commercial and residential parcels.



File Statistics Report

File

Filename: G:\geo_projects\KGS_impsrf\GISMaterialsCurrent\Quik
Region: Moderate Veg

Band	Min	Max	Mean	Stdev
1	180.000000	232.000000	205.409330	6.919754
2	230.000000	332.000000	277.341336	16.791990
3	124.000000	203.000000	161.617737	13.133081
4	630.000000	912.000000	750.778060	35.360361

Figure 2a - Example of a good spectral match.

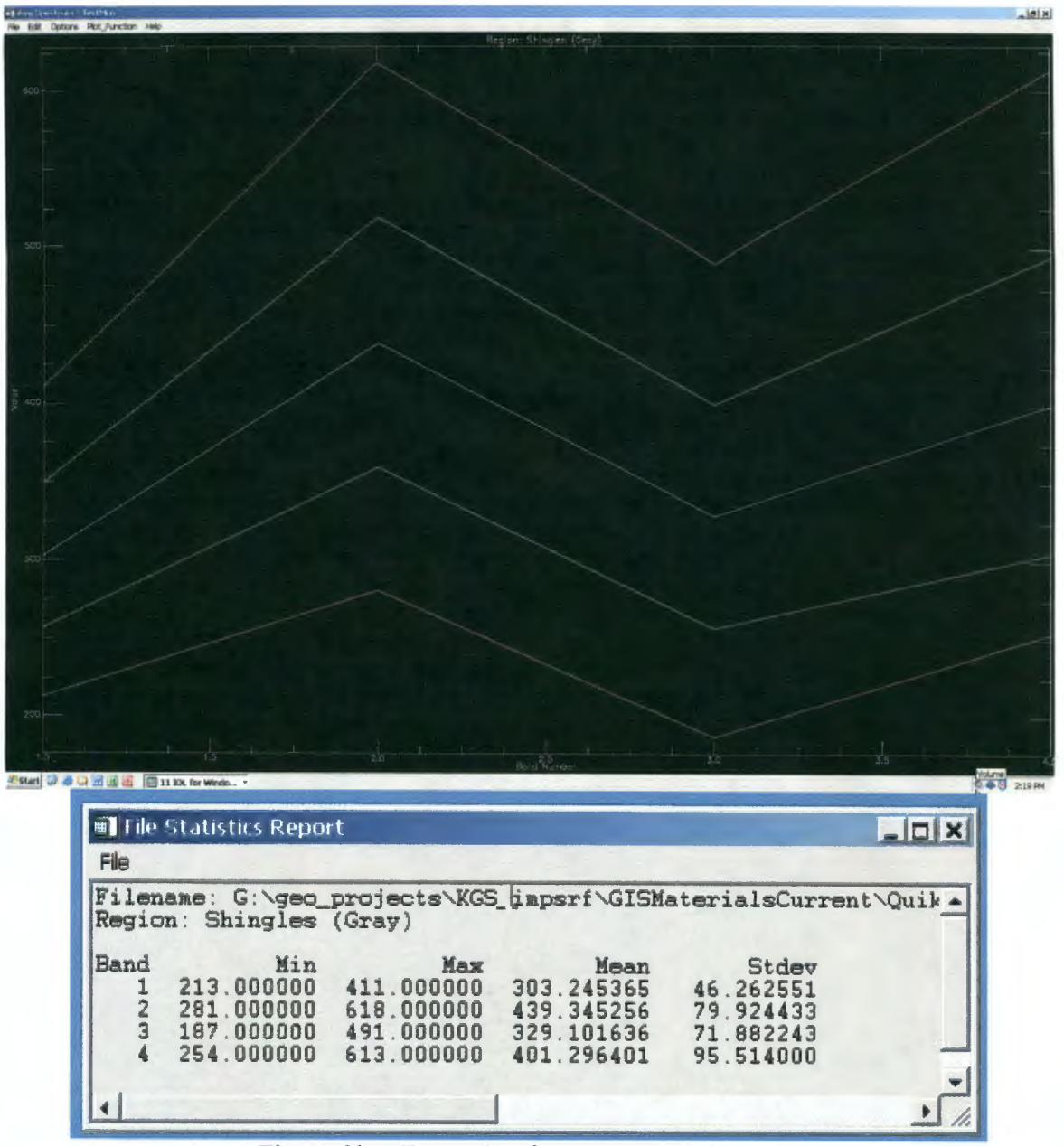


Figure 2b – Example of a poor spectral match.

After creating the spectral library and beginning the classification, we realized that the single Quickbird image file itself was far too large (3.2 Gb) for the MTech Model TX6C-L-M1G PC (Pentium-3 1-Ghz processors, 256 RAM, 30Gb hard drive) we used. Subsequently, we divided the image into twenty-five separate grid regions (figure 3) to reduce file size. This made importing the spectral libraries into ENVI workable. Grids were numbered 1-25 starting with top left in figure 3 and moving to right, down a row and left, down a row then right, etc. Grid 8 (figures 4 and 5) was selected because it had the mall shopping area which had a known amount of large impervious surfaces, residential area that had a known amount of large pervious surfaces, and they were within the same grid.

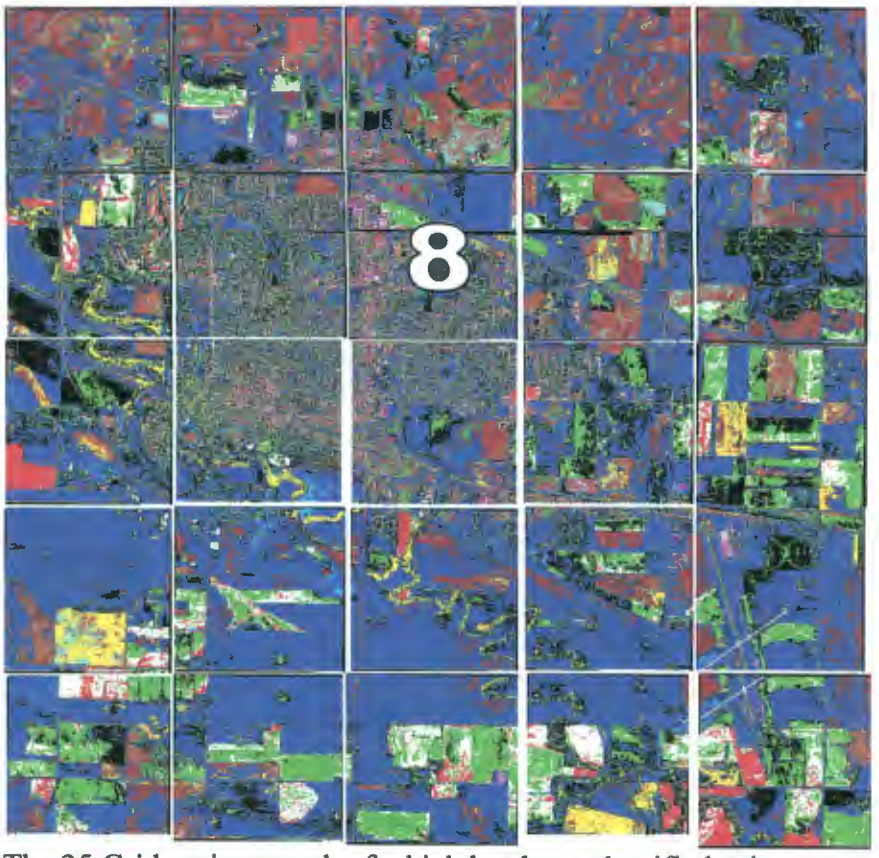


Figure 3 The 25 Grid regions, each of which has been classified using spectral-angle mapper routine in ENVI

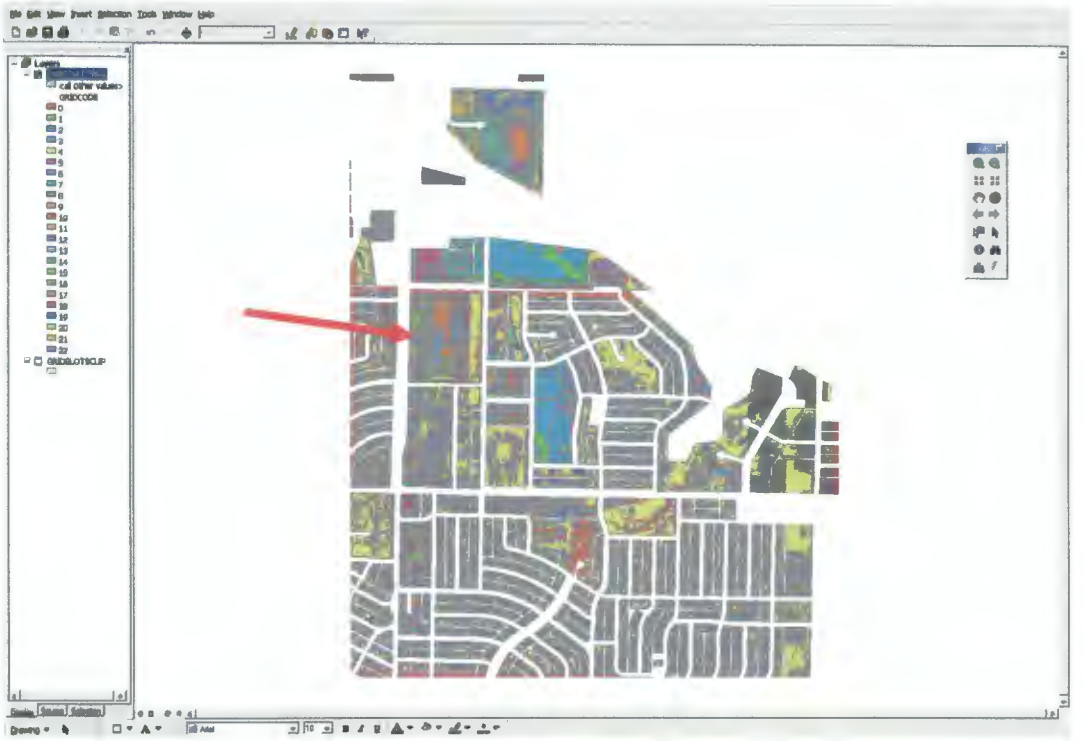


Figure 4 Grid 8 Lots & blocks with 25 classes spectral signatures
Arrow points to commercial parcel.

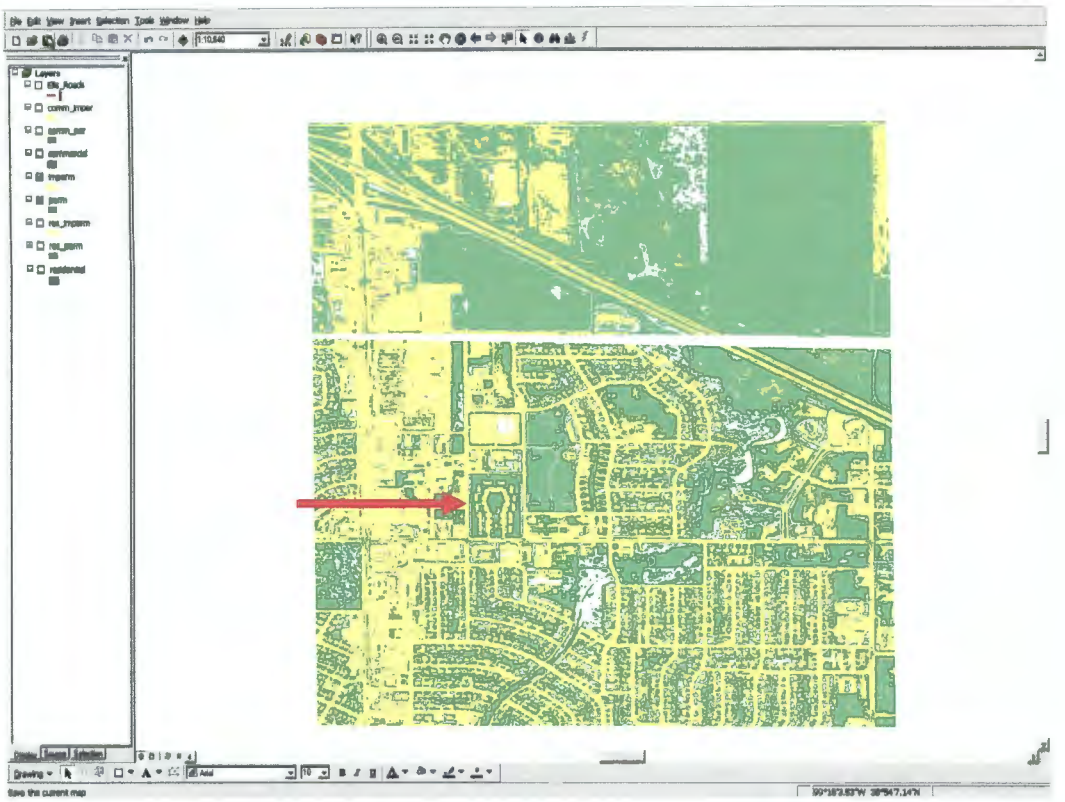


Figure 5 Impervious (yellow), pervious (green), and white = undeterminable
Arrow points to residential parcel.

GIS Component:

See Appendix C for an outline format of the ArcView process.

Property boundaries were obtained from Midwest Energy in AutoCAD forma. We edited the AutoCAD file with ArcMap to correct for any polygon errors. Minor projection discrepancies between the lots and blocks layer and the impervious-pervious layer were addressed through spatial adjustments (figures 6 and 7).



Figure 6 Overlay discrepancy of the lots and blocks layer (in black) and the classification image layer (in green).



Figure 7 Corrected overlay with proper alignment.

Two specific parcels were analyzed for the percentage of impervious and pervious surfaces. The first site was a private parcel (single owner) that developed the site into apartments (figures 8-10) and the second site was the commercial parcel of land known locally as "the Mall" (figure 11-13). The sites were selected because they were nearly free of obstructions such as trees and other features that would block the Quickbird satellite view.



Figure 8 True Color image (bands 3,2,1) of the selected residential parcel (center)

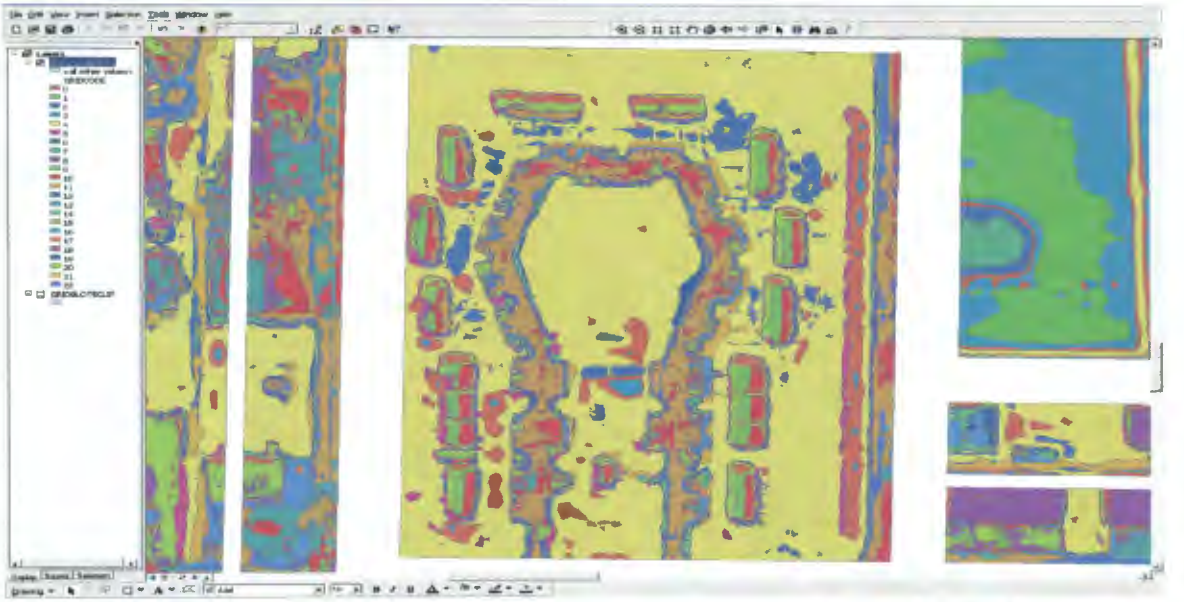


Figure 9 Classified spectral signatures of residential parcel in Grid 8.
See Appendix D for details of layer codes

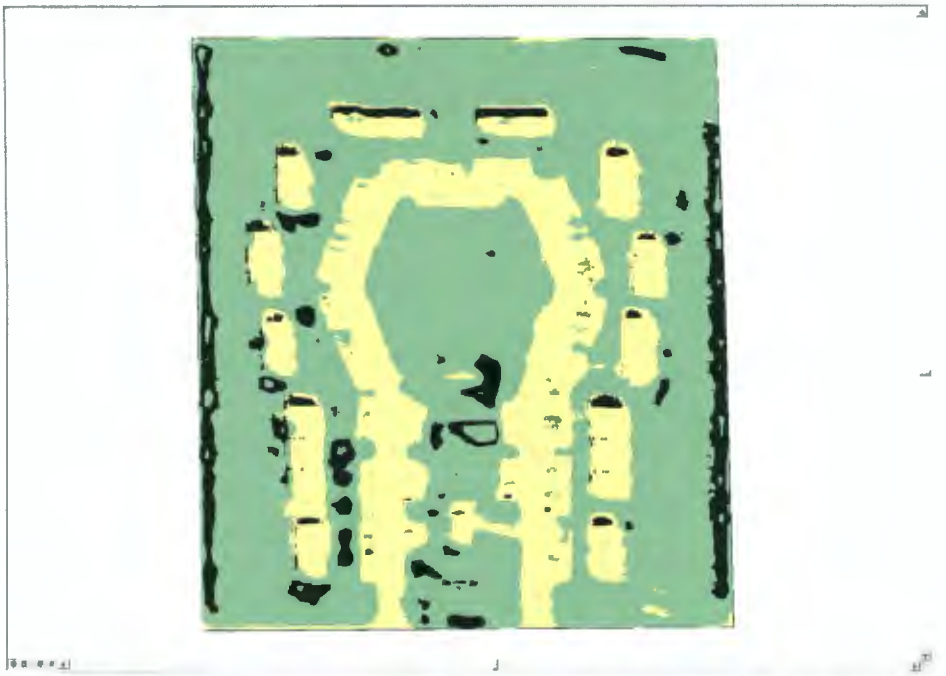


Figure 10 Impervious (yellow), pervious (green), and undeterminable (black) surfaces of residential parcel in Grid 8.



Figure 11 True color image (bands 3,2,1) of the selected commercial parcel (centered in right half of image).

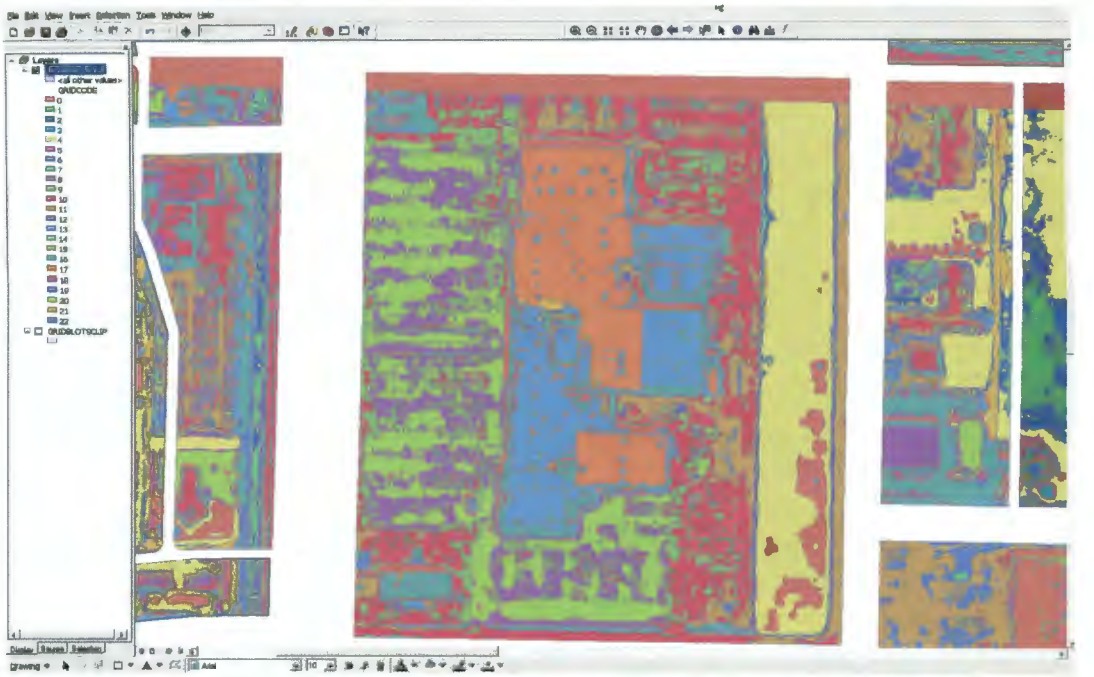


Figure 12 Classified spectral signatures of commercial parcel in Grid 8. See Appendix D for details of layer codes

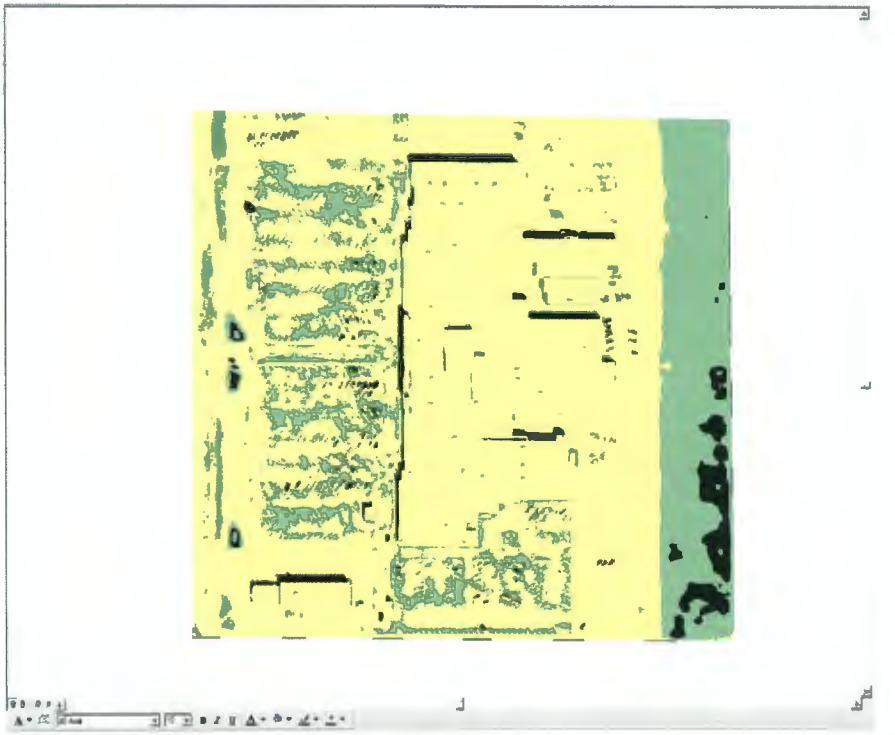


Figure 13 Impervious (yellow), pervious (green), and undeterminable (black) surfaces of commercial parcel in Grid 8.

Denver's WMD will continue purchasing aerial photography ($150,000 to $200,000) every two years. However, the City of Denver intends to purchase additional Quickbird satellite imagery because of its higher resolution (Montandon, 2005). The Department of Geosciences at FHSU hopes to purchase the remainder of the Hays area Quickbird image for the same reason. In addition, we intend to present a demonstration of this procedure to the City of Hays. Should the City of Hays decide to initiate a wastewater billing program, we hope they ask FHSU to do the GIS procedure for them.

Percent Analysis Calculations

ArcView 9.1 analyses indicate that the selected parcel for residential lots had 26.7% impervious surfaces, 65.4% pervious surfaces, and 7.88% was not determinable (figure 14). The selected commercial lot had 74.7% impervious, 21.5% pervious, and 3.8% undeterminable surfaces respectively (figure 15).



Figure 14 Residential:Top = Impervious calculation Bottom = Pervious calculation. Yellow = impervious, Blue = pervious, Black = undeterminable

Conclusion

Our intended goal was reached in that we were able to integrate the 4-band multispectral DigitalGlobe Quickbird image into the ENVI (version 3.6) spectral analysis process and subsequently into ArcView (version 9.1) in order to determine the percent area of impervious and pervious surfaces within a specific lot or parcel of land. The 'herring-bone' pattern of green on left half and south-central parts of figure 9 match the pattern of the slanted parking stalls. We believe that these represent oil leak stains from the automobiles and we speculate that this oil being an organic hydrocarbon has a similar spectral signature as vegetation and thus is similar to a pervious surface. However, visual inspection of the oil shows that most of the oil has embedded dirt and sand; and maybe that material is what is giving us the implied 'pervious' spectral signature. We believe that the ENVI classified spectral-signature values represent a quantitative process for a 92-96% level of classification accuracy as designated by the software. The integrity of the spectral signatures targeted in figures 9 and 12 were visually field checked and found to be comparable with the ArcView percent analyses.

Appendix A

ENVI Remote Sensing Process Outline:
Building a Library
-open ENVI and load image
-open the image in an RGB display
-bring up ROI tool
-build regions by taking random samples
-can use inferred for the sampling of vegetation
-look at the stats for each region
-if there are any peaks, pick a different sample
-save ROIs
-open the Spectral library builder and import your ROIs
-bring in all sample classes
-save spectral library
-bring in new spectral profile
-perform a spectral analysis
-clicking any pixel in the image will bring up a spectral curve as well as the class it is probably in.

Classifying an image
-choose the classification function in ENVI
-in the classification function use the supervised spectral angle mapper
-this is best for accurate classifications
-with max probability a spectral library is not needed, only the original ROI file is needed
-select the image to classify
-import the spectral library
-select it
-select all items (ROIs) within the file; this will produce a .bil file that has all regions classified into the sample classes set up in the spectral library.

Converting ENVI .bil files into GIS .shp files
-classify an image or bring in a classified image
-convert the classification to vector
-this will convert the file into polygonal form, but it will be saved as a .evf (an ENVI vector file)
-make note of the order that the classes are in and what they are because when they come into ArcMap they will only be numbers
-in the available-vectors list, select the classification to vector file
-then export the layers to shapefile and save file
-convert the map projection of this file to Lat\Lon
-convert this new file with projection information to vector; then convert it to a shapefile again; this creates two files, one in Lat\Lon and the other in UTM
-open ArcMap and bring in the shapefile just created
-by changing the display properties, all of the classes become visible.

Resizing and breaking down large images
-to resize data or to select a portion of the image to classify, use the resize data tool
-select the area to resize on the image then continue
-stack the layers using the 'layer stacking tool' in order to create one image file and not a separate image for each band that is contained in the image (i.e., the DigitalGlobe image is a very large 4-band spectral image)
-the overlay a grid on the image in order to create reference points and lines
-resize the image and select the area inside the grids; do this for each separate grid
-this provides accuracy with no overlap.

Appendix B

The Spectral Angle Mapper (SAM) is an automated method for comparing image spectra to individual spectra or a spectral library (Boardman, unpublished data; CSES, 1992; Kruse *et al* ., 1993a). SAM assumes that the data have been reduced to apparent reflectance (true reflectance multiplied by some unknown gain factor controlled by topography and shadows). The algorithm determines the similarity between two spectra by calculating the "spectral angle" between them, treating them as vectors in a space with dimensionality equal to the number of bands (*nb*). A simplified explanation of this can be given by considering a reference spectrum and an unknown spectrum from two-band data. The two different materials will be represented in the 2-D scatter plot by a point for each given illumination, or as a line (vector) for all possible illuminations (fig. 16).

Because it uses only the "direction" of the spectra, and not their "length," the method is insensitive to the unknown gain factor, and all possible illuminations are treated equally. Poorly illuminated pixels will fall closer to the origin. The "color" of a material is defined by the direction of its unit vector. Notice that the angle between the vectors is the same regardless of the length. The length of the vector relates only to how fully the pixel is illuminated.

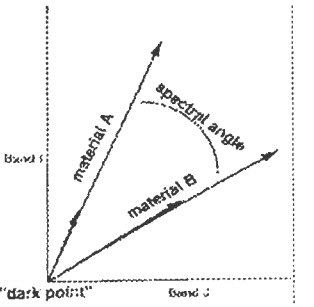


Figure 16
2-D scatter plot

Appendix C

ArcMap GIS Process Outline:
-go to add data and add in the classification Shapefiles (.shp) created; this will come in as polygon form
-open the properties menu for the shapefile (or layer as it is now called on the layers menu)
-go to the symbololgy and display by unique category; this will give each class a different color
-give each class a specific color if desired
-use the select by attribute function to select all impervious classes
-create a layer from the selected features and also export this new data as a shapefile
-use the select by attribute function to select all pervious classes
-create a layer from the selected features and also export this new data as a shapefile
-now the two new layers (imperv and perv), bring in the lots and blocks layer
-clip the lots and blocks to your original classification layer
-then clip the pervious and the impervious layers by the newly clipped lots and blocks layer; each lot and blocks polygon overlays the impervious and pervious layers and nothing else
-it is now possible to select a specific area to analyze
-from here, go through the selection and creation of layers steps listed above to break it down into as small areas of choice.

Final Area/Percent Calculation Steps:
(All layers projected as: NAD 1983 UTM Zone 13N)
(**residential** layer is polygon identifying the total area and perimeter of residential area)
(**res_permeable** layer contains polygons indicating areas of permeability)
(**res_impermeable** layer contains polygons indicating areas of impermeability)

A. Calculating Area for Each Layer

1) Open ArcToolbox (01 Open Arctoolbox)
2) Open "Spatial Statistic Toolbox" (02 Open Spatial Statistics Toolbox)
3) Open "Utilities" (03 Open Utilities)
4) Open "Calculate Areas" and enter **residential** layer for input feature class and identify the new layer as **residential_area**. (04 Calculate Areas)
5) This will calculate the square area of the perimeter of the residential area in the units designated by the projection (meters).
6) The new layer, **residential area**, is now added with its total square area identified in the table. (05 Area In Attributes)
7) Perform step 4 on **res_permeable**. Identify the new layer as: **res_permeable_area**.
8) Perform step 4 on **res_impermeable.** Identify the new layer as: **res_impermeable_area**.
9) Close ArcToolbox (06 All Areas Calculated)

B. Entering Total Area Value Into Attribute Tables of Other Layers

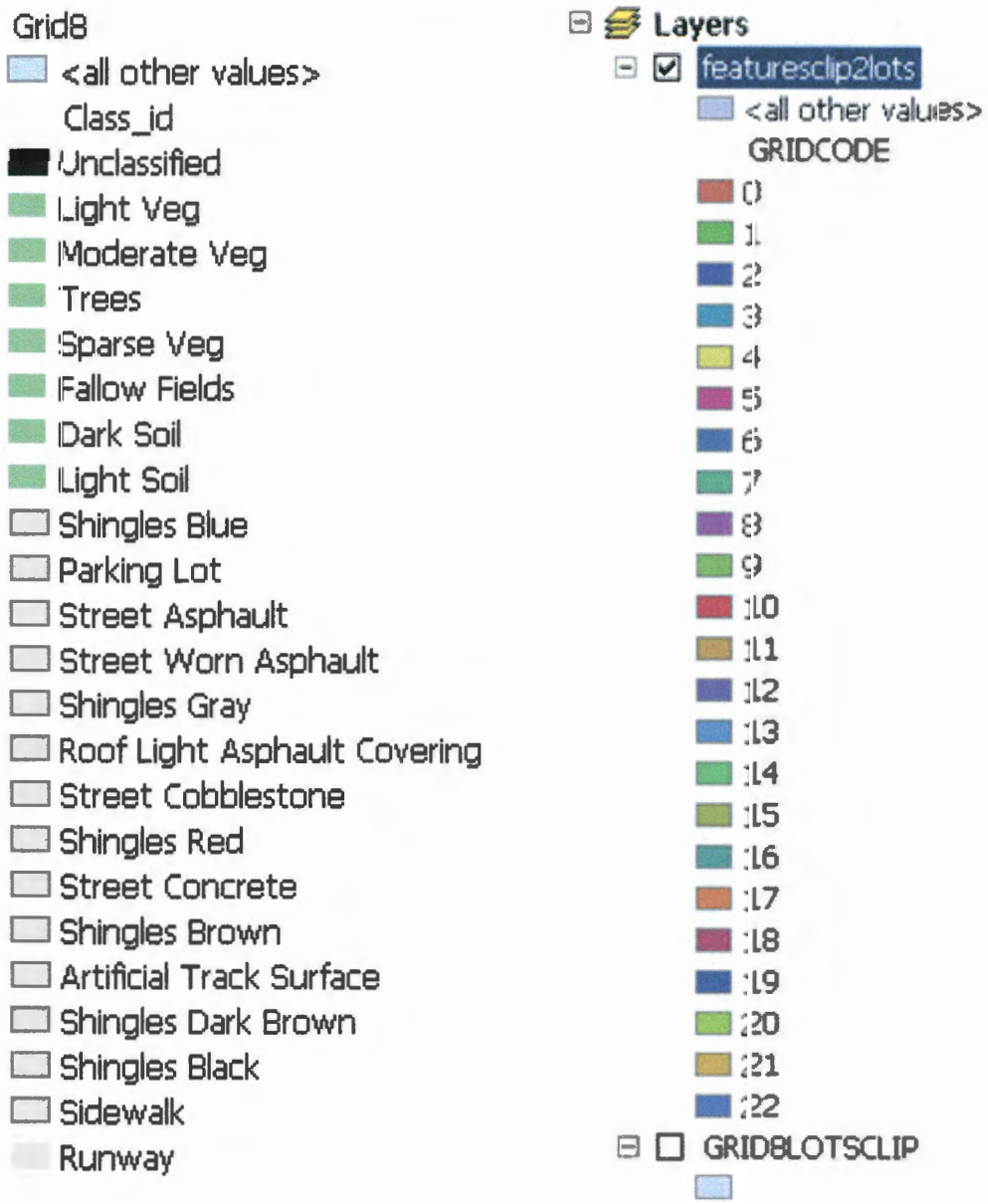
10) Open the attribute table for **residential_area** and record the area value.
11) This recorded total area value will be entered into the attribute tables for **res_permeable_area** and **res_impermeable_area**. To do so, right click on the respective layer's name in the table of contents and select "Open attribute table". For this example **res_impermeable_area** is used (07 Open Attribute Table)
12) Click on the "Options" Button and select "Add Field". Name the new field "Total_Area". Under "Type" identify it as "Float". "Precision" describes the total width (spaces needed) of the value entered. "Scale" describes the total number of places to the right of the decimal point allocated for the field values to be entered. It's not a bad idea to enter precision and scale values that are greater than needed when entering attribute data. (08 Create Total Area" Field)
13) If not already available, enable the "Editor" toolbar. In the "View" menu select "Toolbars" and "Editor" (Make sure there is a check next to Editor). The Editor toolbar should present itself in the user interface. (09 Open Editor Toolbar)
14) Go to the Editor toolbar and select "start editing" (10 Start Editing)
    a. Double click on the first cell in the field "Total_Area" and enter the recorded value. On the keyboard hit enter (11 Total Area Value Entered).
15) Go to the Editor toolbar and select "Stop Editing" This will save the entered data.
16) Perform steps 10-16 for any other relevant layer. For this example the other layer is **res_permeable_area**.

C. Calculating Final Percentages of Permeable and Impermeable Areas

17) Open the **res_impermeable_area** attribute table. Create a new field as described in step 12 with the following settings: Name: Area_Pnt, Type: Float, Precision: 20, Scale: 8.
18) Go to the Editor toolbar and select "Start Editing"
19) In the **res_impermeable_area** attribute table, right click on the field name "Area_Pnt" and select "Calculate Values". (12 Calculate Values)
20) Now it's time to calculate the percentage of impermeable area found within the residential area. The percentage equation must be generated the final value. Click on the following fields and mathematical operation symbols: F_AREA / Total_Area * 100. (13 percentage calculation). Select "OK"
21) The value in the "Area_Pnt" represents the percentage of impermeable land within the designated residential zone.
22) Go to the Editor toolbar and select: "Stop Editing"
23) Complete steps 18-23 for the **res_permeable_area layer**.

Appendix D

The table on the left of the actual impervious and pervious surface features. The table on right of the same layers represented in the figures 9 and 12.



References & Sources

DigitalGlobe Quickbird image
ENVI version 3.6
ArcView, v. 8.3 and 9.1, ESRI
AutoCAD.dxf - Midwest Energy
Montandon, E., 2004, Gently Down the Stream, Geo Info, Sept., pp. 38-40