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HIGH RESOLUTION MAPPING LAND COVER CLASSIFICATION OF THE HOMINY CREEK WATERSHED

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Executive Summary

To protect water quality and control erosion and associated sedimentation, the best management practices must be applied for the use of land for agriculture, industrial, and urban growth. In order to do so, a detailed, accurate, and repeatable land use and land cover maps of those areas having direct impact on water quality must be prepared. Improving degraded watersheds and streams require accurate and current land use and land cover (LU/LC) data. The objective of this project was to create a detailed land use/land cover for the stream riparian zones and the adjacent environment using the latest high-resolution remote sensing data, and compare the results with those derived from lower resolution and more conventional satellite and aircraft imagery. The high-resolution imagery used was the IKONOS 4-meter multi-spectral (MS) imagery along with 1-meter panchromatic data. The target spatial resolution for this classification was approximately four meters. The lower resolution imagery used for comparison included 30-meter Landsat TM, 20-meter SPOT4 imagery, and 1-meter Color Infrared Digital Orthophoto Quarter Quad, (CIR DOQQ). A LU/LC classification scheme appropriate to hydrologic analysis was developed and used for the comparison classification. The higher resolution of the IKONOS imagery as compared to the more conventional imagery types such as Landsat and SPOT naturally lends itself to more detailed classifications. The following major categories were used as a classification scheme: Impervious Surfaces, Water, Agriculture, Grass/Open space, Deciduous Forest, Coniferous Forest, Mixed Forest, and Bare/Disturbed Soil. Extensive field data obtained using GPS and photo interpretation were integrated for the accuracy assessment of LU/LC data and validation. The final best LU/LC classification derived from IKONOS 4-meter MS imagery was achieved with 77% overall accuracy.

In this study, IKONOS imagery provided an effective means of obtaining accurate and detailed LU/LC data within the stream buffer zones as well as the “difficult to assess areas”, such as land cover types in urban watersheds. IKONOS was particularly effective at delineating impervious surfaces prevalent in urban areas, which are problematic to map from other low resolution remotely sensed data. However, IKONOS classifications

based on single date imagery have some limitations with regard to other LU/LC classes. The delineation of bare and disturbed soils proved problematic. Bare and disturbed soils are a small part of the total proportion of the area within a watershed but these areas play a critical role in water quality and sediment load. Bare and disturbed soils are nearly identical spectrally and are often misclassified with fallow agriculture due to the short temporal cycle and the similarity of spectral signatures. Additionally, grass and open space, which are commonly a significant part of an urban/suburban watershed, are often confused with agriculture. Due to the seasonal nature of agriculture, using multi-date imagery could be effective in distinguishing agriculture from the grass/open space class and from the bare/disturbed soil class. This will also account for the removal of changes due to the short temporal cycle in these classes.

While IKONOS imagery proved to be an effective data source to quantify land use composition within an urban watershed, this analysis of LU/LC only provided a mapping of the watershed land use composition at a single point in time, commensurate with the objective of this project. To completely understand the impact land use has on water quality, it is important to accurately assess the type and position of changes occurring within the watershed. This can be accomplished through change detection using remotely sensed imagery. Currently, most LU/LC change detection studies have used lower resolution imagery. However, lower resolution imagery proved incapable of accurately detecting small-scale or mixed detailed LU/LC classes that fall below the resolution of the imagery but still may be significant contributors of upland sediment load. Recommendations for future studies include the use of multi-date IKONOS imagery with multivariate image analysis, and use of proprietary fusion techniques to access the utilization of IKONOS in improving LU/LC classifications within an urban watershed, and identify LU/LC changes. Other new high resolution satellite imagery, which offer comparable results to IKONOS and that has recently (2002) become available to the public, such as SPOT-5, is recommended as an alternative to a cheaper and more routinely available source of data for such studies. The SPOT-5 satellite has 10-meter multispectral and 2.5-meter panchromatic imaging capacity. Furthermore, with the advanced data fusion techniques that we have developed at North Carolina State University's Center for Earth Observation (CEO), it is possible to fuse the 10-meter multispectral imagery with the 2.5-meter panchromatic imagery provided by SPOT-5 while preserving the spectral integrity of multispectral data. Conventional fusion techniques that are used commercially for fusing panchromatic and multispectral data permanently alter the spectral characteristics of multispectral data, therefore making this data unfeasible for image classification and modeling. The technique that we have developed at CEO (patent pending) functions to effectively fuse the panchromatic and multispectral data while preserving the spectral integrity of multispectral data and therefore making the image classification for mapping LU/LC change detection and modeling feasible. LIDAR (Light Detection and Ranging) data is also recommended to be incorporated into both image classification and change detection datasets to provide high-resolution mapping of headwater stream networks throughout the watershed, thus providing accurate and detailed connectivity between stream networks and adjacent land use classes. Ancillary data could be used to improve the classification of shadowed areas within the IKONOS imagery. An attractive data type for this purpose is radar data. Radar data is insensitive to time of day, weather conditions, and solar insulation. The Canadian Radarsat can provide eight-meter spatial resolution data that would be helpful for resolving problems in shadow areas. The use of additional historic data to assess LU/LC changes is also recommended. In summary, the methods outlined in this paper along with the high resolution IKONAS data have produced a highly detailed and accurate high-resolution land cover classification for the stream buffer zones and the adjacent areas in Hominy Creek watershed. The innovative procedures used have allowed for the improvement of spatial resolution without sacrificing high spectral resolution. We expect this approach to be quite applicable to other watersheds with similarly good results.

Acknowledgments

The results reported here were generated through the research project funded by the University of North Carolina Water Resources Research Institute (WRRI). We would like to thank Dr. Kenneth H. Reckhow, Director of WRRI and Dr. Greg Jennings, Associate Director of WRRI for their support and cooperation in this project. The views expressed in this report are those of the authors and do not necessarily reflect the views of WRRI or any of its sub-agencies. The authors would also like to thank Dr. Stacy Nelson and Ms. Linda Babcock of the Center for Earth Observation (CEO) for her help on this project.

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1.0 INTRODUCTION

The conversion of rural land to urban land results in an increase in erosion, storm water discharge, and a general degradation of stream and watershed quality. Programs concerned with improving these degraded watersheds and streams require accurate and current land use and land cover (LU/LC) data. Previous projects that have used remote sensing to determine LU/LC have had only limited success due to the limited resolution of available imagery (e.g. 20 or 30 meters). The overall goal of this research is to evaluate the higher resolution imagery presently available in producing detailed LU/LC mapping of environmentally sensitive areas in detail. The high-resolution imagery used in this project was IKONOS multi-spectral imagery (4-meter multi-spectral spatial resolution). The specific goals of this research were three-fold. The first goal was to determine if high-resolution spatial data adds additional quantifiable spatial and spectral advantages over lower resolution spatial data in the monitoring and delineation of stream buffers. The second goal was to develop a procedure using the high-resolution imagery to efficiently create the best possible LU/LC map for such purpose. The last goal was to determine if spatially improved imagery created from fusion of IKONOS 4-meter MS imagery with IKONOS 1-meter panchromatic imagery results in an improved classification as compared to classification from IKONOS 4-meter MS. To fuse the multispectral image with the panchromatic image, a new fusion method developed by CEO (patent pending) was used in addition to the existing fusion methods (i.e., principal component analysis (PCA) fusion method). The IKONOS imagery was compared against Landsat TM, 20 meter resolution, SPOT4 imagery, 30 meter resolution, and color infrared digital orthophoto quarter quad, (CIR DOQQ), and 1 meter images created from fusing IKONOS MS imagery with IKONOS panchromatic imagery.

2.0 OBJECTIVES

The specific objectives of this study included: (1) Detailed characterization of LU/LC in stream riparian buffers; (2) mapping in detail the land use/land cover surrounding streams; (3) assessing the effectiveness of new high-resolution remote sensing data sources for providing information that can lead to determining minimum effective buffer widths and buffer assessment and management; (4) making recommendations for the use of very high resolution remotely sensed imagery to provide detailed LU/LC data in a wide range of applications affecting water quality, such as stream sedimentation studies, forest logging monitoring, and urbanization studies; and (5) publication and presentation of findings in national scientific conferences and journals.

The deliverables include a remote sensing-aided methodology and spatial information system for high-resolution mapping and monitoring of LU/LC along with the digital and conventional maps of buffer zones in the study area.

3.0 STUDY AREA

The study area for this project is the Hominy Creek watershed near Wilson, NC (Figure 1). The 14-digit Hydrological Unit Code (HUC) for the watershed is 03020203020040. The Hominy Creek watershed is in Sub-basin 07 of the Neuse River Basin. The study area is approximately 11 by 4 miles (17.7 by 6.4 km), containing approximately 238400 acres (96477 ha). Wilson, NC has a population of 44,500. The watershed contains a mix of urban, suburban, and rural land use areas.

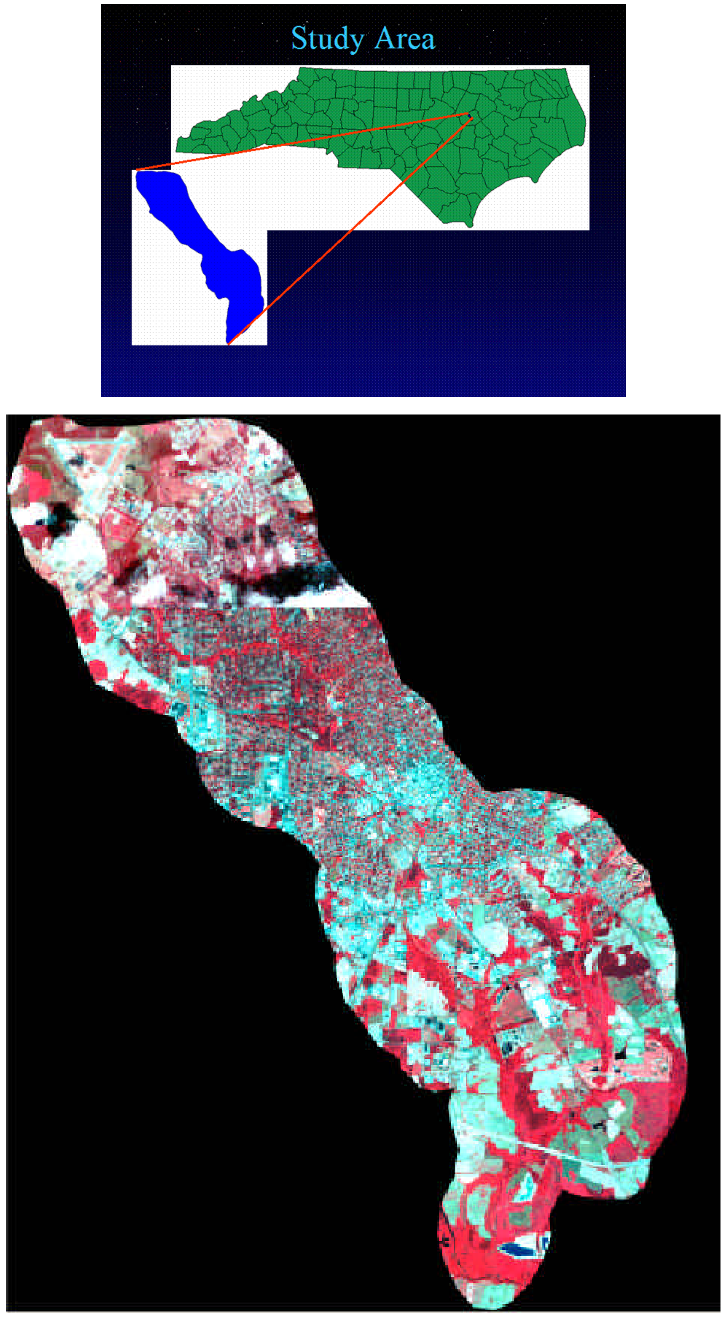

Figure 1. **False Color Composite of the Hominy Creek watershed study area.**

3.1 Data Used

Based on the research objectives of comparing the data from a new source (IKONOS) to data from conventional sources as Landsat and SPOT in the production of LU/LC mapping the following data were used:

A. GIS Data

1) From GIS coverages, a polygon file for the study area was derived. The study area is within Wilson county. The boundary of the coverage is as follows:

   X_{min}: 701965 Y_{min}: 211615   (Upper left corner)

   X_{max}: 711778 Y_{max}: 224859   (Bottom right corner)

   Projection information:

Georeferenced to	: State Plane (SP)
Datum	: NAD83
Zone number	: 4901 (North Carolina)
Map units	: Meters

2) Stream centerline data was obtained from Environmental Protection Agency's (EPA) reach files which are publicly available.

B. Remote Sensing Data (Figure 2).

1) Color Infra-red Digital Ortho Quad, CIR DOQQ, created from scanned NAPP CIR photographs. The CIR DOQQ were created from scanned NAPP CIR photographs in a previous CEO research study, see CEO Technical Report 217. The acquisition date of these photos is January 26, 1998.

2) Landsat Thematic Mapper (TM) imagery, Multi Spectral 30 meter spatial resolution. The acquisition data of this imagery is winter of 2001

3) SPOT 4 imagery, multi-spectral with 20-meter spatial resolution, developed by the French Centr National d'Etudes Spatials.

4) IKONOS imagery, Multispectral, 4-meter spatial resolution. The acquisition date of this imagery is May 20 of 2002.

5) IKONOS imagery, panchromatic, 1-meter spatial resolution. The acquisition date of this imagery is May 20 of 2002.

6) IKONOS 4 meter MS imagery fused with IKONOS 1-meter using CEO's fusion method. This data is derived from the IKONOS imagery.

7) IKONOS 4 meter MS imagery fused with IKONOS 1-meter using traditional Principal Component Analysis fusion methods.

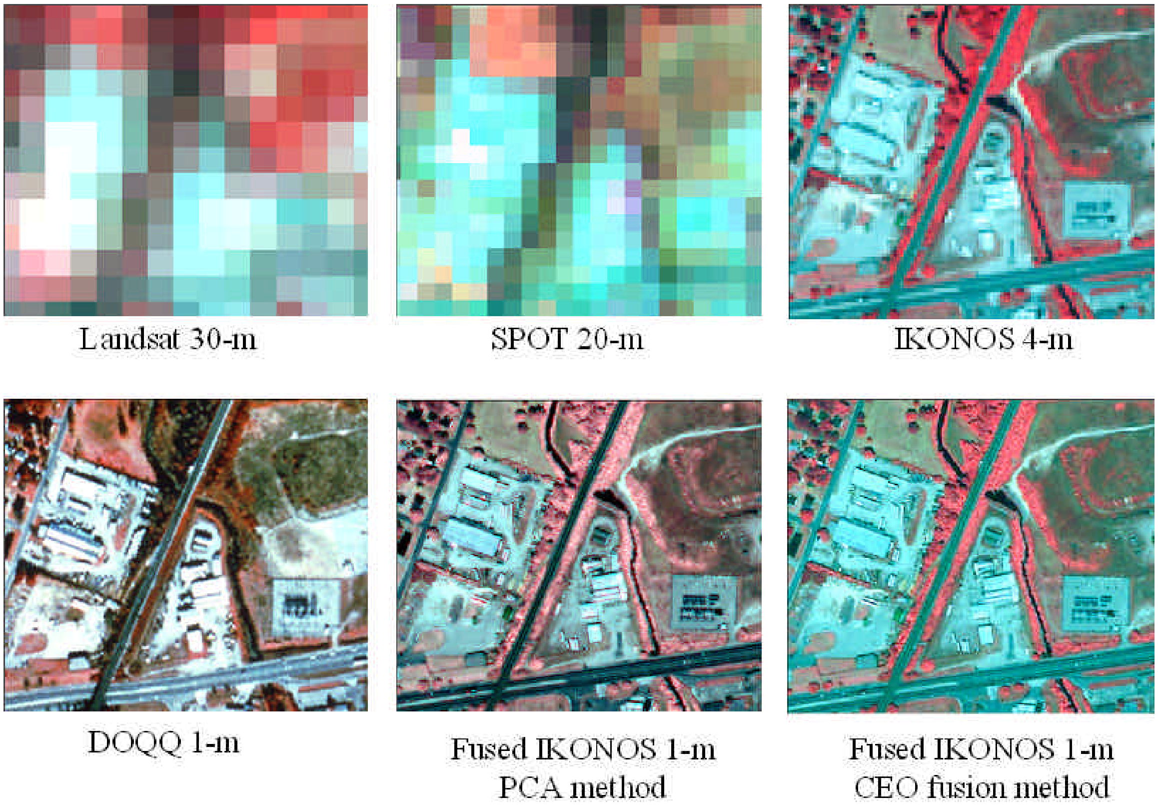

Figure 2. False color composite representations of remotely sensed data used in this study. Scene is a subset of the study area. The difference in spatial resolution is apparent in these images.

4.0 METHODS

The project was divided into five stages consisting of the preprocessing of the various imagery, the creation of the stream centerline data, the LU/LC classification of the various imagery types including the enhanced classification of the IKONOS imagery, the accuracy assessment of the classifications, and the creation of the stream buffer and stream buffer data:

1) Pre-processing – Obtaining the different imagery, georeferencing the various imagery to a common coordinate system, and removal of the clouded and shadowed areas from the IKONOS imagery.
2) Creation of stream centerline data.
3) LU/LC classification to compare the various imagery types – First, a supervised classification was performed on the various imagery types in order to compare the resulting classifications from the different image types. Then, enhanced

classification of the IKONONS MS image was performed. This supervised classification was performed on the IKONOS using a Bayesian classification and additional GIS filtering.

4) Accuracy assessment – Developing an estimate of the accuracy of the different classifications.
5) Creation of stream buffers and stream buffer LU/LC maps and the resulting stream buffer data.

4.1 Pre-Processing

Initial steps of data analysis in remote sensing involve data acquisition and preprocessing, geometric and radiometric corrections. Data acquisition and preprocessing include sub-setting or creating data mosaics, checking cloud coverage before acquisition, replicating the questionable (i.e., cloud, shadow, etc.) pixel values.

4.1.1 Georeferencing

The acquired images were georeferenced for use in this project. Georeferencing is the process of transforming all the project images into a common reference datum. Georeferencing is performed by choosing a reference image, the IKONOS 4m MS image in this case. The reference datum used in this project is NAD83 with meters as the distance unit. Ground control points (GCPs) were then chosen. GCPs are points that can be accurately determined for both the reference image and the image to be transformed. Once the GCPs are chosen, a transformation model was chosen. Generally, a 1^{st} or 2^{nd} order polynomial is sufficient to correct for moderate distortion in a relatively small area such as a quarter of a Landsat TM theme (Jensen, 1996). For our project either a 2^{nd} or 3^{rd} degree polynomial transformation was chosen to georeference all the project images. The lower polynomial was always favored unless the higher polynomial transformation improved the RMS error significantly. We selected the lower order polynomial transformation function once a minimum threshold was achieved. The root mean square, RMS, was evaluated to determine the amount of distortion not corrected by the transformation. The resulting (RMS) error of any of the transformation was always less than the spatial resolution of the image being transformed. In most cases the RMS was closer to half the spatial resolution of the image being transformed. For example the RMS of the CIR DOQQ image which has a spatial resolution of 1 meter was .55 meters using 71 ground control points (GCP).

4.1.2 Masking of Areas Obscured by Clouds and Shadows

Space Imaging, the suppliers of IKONOS imagery, specify that their imagery will contain less than 20 percent of the image area obscured by clouds and shadows (Space Imaging, 2003). The IKONOS imagery we obtained from Space Imaging did contain areas obscured by clouds and shadows. Our preliminary classification suggested, masking out the cloud and/or shadow obscured areas before performing the final classification.

An unsupervised classification was performed in hopes of obtaining a signature of the clouds and shadows cast by the clouds. An unsupervised classification creates classes by grouping pixels with similar spectral characteristics in a spatial domain. An unsupervised classification requires no *a priori* knowledge of the image and requires little initial input from the analyst. The resulting cloud and shadow classes created from the unsupervised classifications contained small areas of shadows created mainly by buildings and trees in addition to the large clouded areas. The intent of this processing step was to exclude only the areas obscured by the clouds and the clouds' shadows. Since these smaller shadowed areas created by buildings and trees needed to remain for the final classification it was decided not to use these unsupervised classes as a mask. Instead, the cloud and shadow mask area was created using heads-up digitizing using the unsupervised signatures and the original IKONOS imagery as a guide to determine the masked area. See Figures 2 and 3 as an example of the shadowed and clouded areas and the imagery with the clouds and shadows masked.

Figure 3. IKONOS imagery showing clouded and shadowed areas.

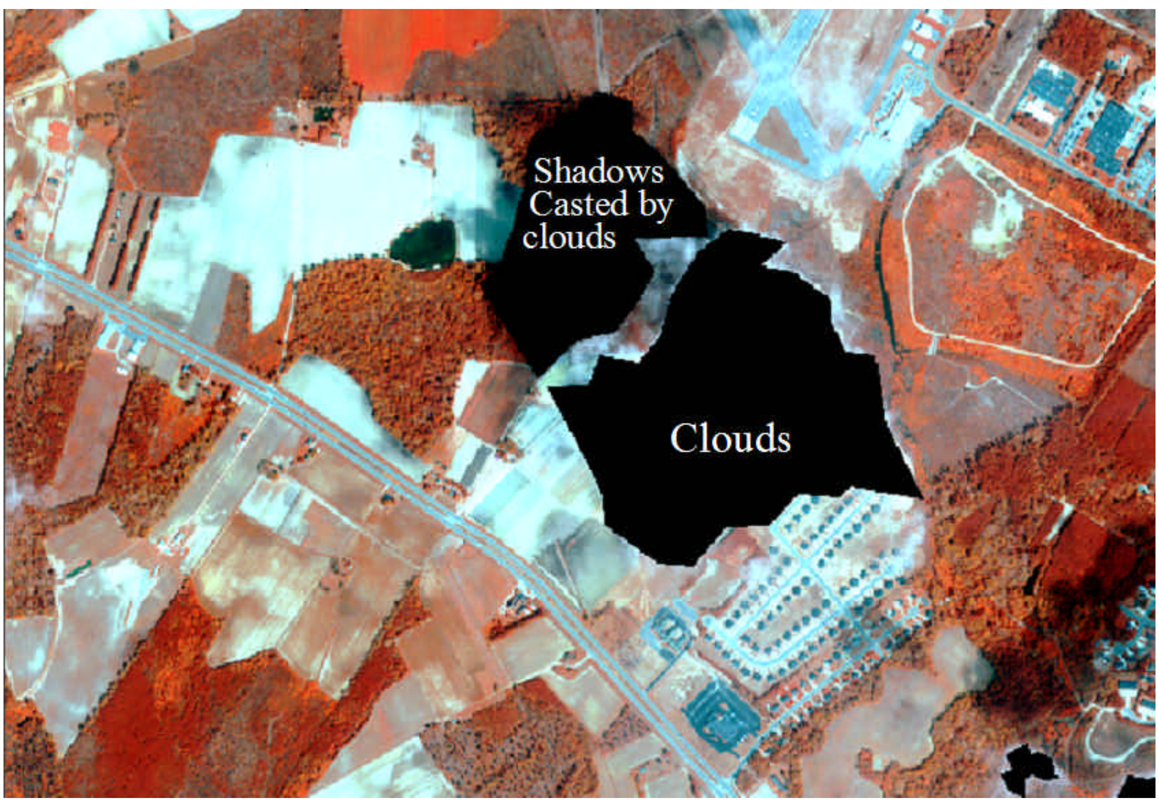

Figure 4. IKONOS imagery showing that clouded and shadowed areas are masked out.

4.2 Stream Centerline Delineation

The main source of stream centerline data was obtained from the EPA Reach File (Version 3.0), known as RF3, is a national hydrologic database that interconnects and uniquely identifies the 3.2 million stream segments or "reaches" that comprise the Country's surface water drainage system (EPA, 2003). On a experimental basis (outside the scope of this project), we used LIDAR data to locate the streams more precisely as described later in this report.

4.3 Classification Systems

In this section, the Land use/land cover classification scheme developed and used in this project and all image classification systems are describe.

4.3.1 Land Use/Land Cover Classification Scheme

The land cover classification system, described later in this section, used in this project was chosen such that the resulting classified map would be appropriate for use in detailed hydrologic studies. The higher resolution of the IKONOS imagery, as compared to the more dated imagery types such as Landsat and SPOT, lends itself to more detailed classifications. Instead of classifying at the landscape level a more refined classification system is proposed. Many of the commonly used classification systems such the United States Geological Survey (USGS) Land Use/Land Cover Classification system (Anderson et al., 1976; USGS, 1992) classify land use and cover at the landscape level. For example, the USGS classification system divides urban and built-up land into classes such as Residential and Industrial. Residential and Industrial classes are made up of differing proportions of impervious areas such as rooftops, streets, and driveways and pervious areas such as grassed areas, wooded area, agricultural areas, and disturbed areas. Instead of classifying by the type of urban area, the proposed classification divides the urban areas into more detailed land cover types. This type classification could be used for hydrologic analysis as found in “Urban Hydrology for Small Watersheds, TR-55” (USDA 1986), an USDA publications which contains a land cover classification scheme, used in hydrologic analysis in small urban watershed. TR-55 presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs and storage volumes within small urban watersheds. The following is the initial proposed classification scheme. This scheme was derived largely from examination of previous classification schemes used by CEO in previous LU/LC classification research projects, (CEO TR 217) and also by examining and modifying the TR-55 scheme into classes that could best be distinguished using remotely sensed imagery.

1. Impervious areas
   1.1 – Paved parking lots, roofs, driveways.
   1.2 – Streets and Roads, paved, gravel, dirt
2. Open Space – Maintained lawns, golf courses, cemeteries, and parks
3. Forest
   3.1 – Deciduous
   3.2 – Coniferous
   3.3 - Mixed forest
4. Agricultural Lands
   4.1 – Fallow, bare soil
   4.2 – Row crops
   4.3 - Small Grains
   4.4 – Pasture, grassland, range
5. Newly Graded areas – Construction sites, dirt roads,
6. Water – Ponds, lakes, and streams

Following is a summary of the classification parameters.

- All final LU/LC classifications used a supervised classification, using maximum likelihood classifier, either un-weighted or weighted (Bayesian). An unsupervised classification was used in during the preprocessing stage of the project. See the section below for more details of the different classification methods used in the project.

- Generally, common signatures were used for all training areas for all the image types. In some cases, due to differing dates of acquisition of the various images, land uses changed making some signatures invalid for some images. These signatures were deleted and alternate signatures were collected. Due to differing spatial resolution some training areas that were appropriate for the high-resolution IKONOS were not appropriate for the lower resolution of the SPOT and Landsat images. These signatures were deleted and alternate signatures were collected.

- At least sixty training areas were used for each of the classifications. To maintain homogeneity multiple smaller training sites were chosen over larger training sites. The spatial resolution of the imagery type was often a controlling factor when choosing training sites. With IKONOS imagery it is possible to choose a single residential rooftop to be used as a training site, while it is difficult with Landsat imagery with its higher spatial resolution to use a single residential rooftop as a training site.
- There was a minimum of five training areas for each class. In most cases there were more than five training areas for each class. When there were several distinct signatures within a class, at least five signatures from each distinct signature within the class were collected. For example, agriculture largely consisted of two distinct signatures, agriculture with crop cover and agriculture with no cover. At least five training areas were collected for each of the two distinct signatures.
- The error assessment was based on 500 reference points (see accuracy assessment below), with a minimum of 50 points in each class.
- Reference points were generated using stratified random point generator with each class containing at least 50 reference points.
- The reference points were photo-interpreted from IKONOS PCA fused imagery. The 4-meter MS IKONOS imagery was fused with the 1-meter panchromatic IKONOS imagery to create a 1-meter fused MS image. This fused image is visually more interpretable than either the 4-meter MS image or the 1-meter panchromatic image. PCA fused imagery can result in new images that can be more interpretable than the original image (Jensen 1996). The use of photo-interpreted reference points combined with a subset of the points field-verified has been used in previous CEO research projects (CEO TR 217) with success.

The interpretation was verified in the field using a limited number of reference points. Sub-meter accurate GPS was used to locate the field reference points.

4.3.2 Unsupervised Image Classification

An unsupervised classification requires little initial input from the analysis and requires no *a priori* knowledge of the site. The analyst usually only specifies how many classes are created during the unsupervised classification. In an unsupervised classification the classification algorithm uses numerical operations to create natural groupings based on the spectral characteristic of the imagery. After the initial classification the analyst then assigns these natural spectral classes to the information classes of interest (Jensen, 1996).

4.3.3 Supervised Image Classification

In supervised classification, knowledge of the land cover types are known *a priori*. Specific sites within the study area that are known to represent the subject classes are used as training sites. The classification algorithm to create the LU/LC map of the entire study area uses these training sites' spectral signature to classify the entire image. The analyst more closely controls a supervised classification than an unsupervised classification. The maximum likelihood decision rule is the specific algorithm used to derive the final LU/LC from the training sites. The maximum likelihood decision rule is one of the most commonly used algorithms for supervised classifications. It is a parametric method that uses the mean, variance and covariance in its computations. It assumes that the training data statistics for each class in each band is normally distributed. For the analyst this means he should chose the most homogenous training sites as possible. In order to maintain homogeneity, it is usually best to pick many smaller training sites rather than few, but larger training sites.

4.3.4 Bayesian Image Classification

The Bayesian classification scheme is a refinement of the maximum likelihood decision rule. A Bayesian classification uses the maximum likelihood decision rule, but additionally assigns weights to the different training sites, (Jensen, 1996). For example, in a typical urban/suburban study area there will be higher percent of impervious surfaces than what would be found in a remote forested study area. The Bayesian scheme takes advantage of this knowledge and it will favor the impervious surface signature within a urban/suburban environment. The Bayesian classification scheme requires *a priori* knowledge of the distribution of the subject classes.

4.4 Accuracy Assessment

To provide an estimate of the accuracy of the classification, both ground and photo reference points were compared to the classified values. 500 points were interpreted from the PCA fused imagery. Total of 140 points were visited on the ground. The high-resolution imagery, 4 meters, used in this project required an equivalent level of accuracy in the location of ground control points. The coordinates of the ground points were located using either a meter or sub-meter GPS system. The majority of the ground truth points (115) were collected with a Leica 500 series RTK, real-time kinematic, GPS system capable of collecting sub-centimeter accurate positions. The RTK system consisted of a base station positioned on an NGS benchmark located at the Wilson County Airport. A roving GPS unit was used to collect the ground truth positions. With no obstructions centimeter accurate positions were obtained. Ground truth points located under canopy or other obstructions were collected with a minimum accuracy of one meter. Additionally a Trimble TDC1 GPS receiver was used to collect 25 GCP's. The points collected with the Trimble system had an accuracy of approximately 1 meter.

4.4.1 Error Matrices

An error matrix for each thematic map was generated using 500 sample points and 8 land cover classes. Error matrix is a square array of numbers set out in rows and columns that express the number of sample units (pixels, clusters, or polygons) assigned to a particular category in one classification relative to the number of sample units assigned to a particular category in another classification (Congalton, 1991).

An error matrix is a very effective way to represent map accuracy in that the individual accuracies of each category (class) are described along with both omission and commission errors. In addition to these accuracy measures, overall accuracy, producer's and user's accuracy were also produced

4.4.2 Kappa Analysis

Overall Kappa statistics and individual Kappa values for each class are calculated for the thematic maps. *Kappa coefficient* measures the difference between the agreement of the reference data and classification results and the chance agreement of the reference data and a random classifier (Congalton, 2001). It is expressed as either a percentage or a value between 0.0 and 1.0 where a higher percentage or value represents greater agreement or accuracy. It incorporates commission and omission error while overall error only incorporates the diagonal elements of the error matrix (Khorram, *et al.*, 1999).

4.5 Creation of Stream Buffers and Extraction of land Use / Land Cover Data within Buffers

Stream buffers are created in ArcGIS (ESRI?) environment. Three buffer zones were created using 50, 100, and 300 feet distance to stream centerline. These buffers were overlaid on top of thematic maps (LU/LC maps) created from remotely sensed data to extract land use / land cover statistics such as the percent impervious cover within 50 ft to the streams.

5.0 RESULTS

The results include the classified maps depicting the land use / land cover categories of interest with the accuracy assessment parameters such as error matrices, Kappa statistics, and user's and producer's accuracies with specific confidence intervals.

5.1 LU/LC Classification Results

Two sets of classifications were performed. The first set of classifications was used to make the comparisons between the classifications derived from the different image types, IKONOS, SPOT, Landsat TM, CIR DOQQ, and CA fused IKONOS imagery. The second set of classifications was performed only using the IKONOS imagery. The purpose of these classifications was to determine the best use of IKONOS imagery to derive LU/LC classifications. Additional processing steps were taken in the second set of classifications to improve the IKONOS derived LU/LC classification.

5.1.1 Comparison of the Classifications Resulting From the Different Image Types

Thematic maps based on supervised classification of various images are given in Figure (5). Figures following to Figure 10 are larger representations of the thematic maps based on various data types (Figures 6, 7, 8, 9 and 10). These figures show a subset of the study area.

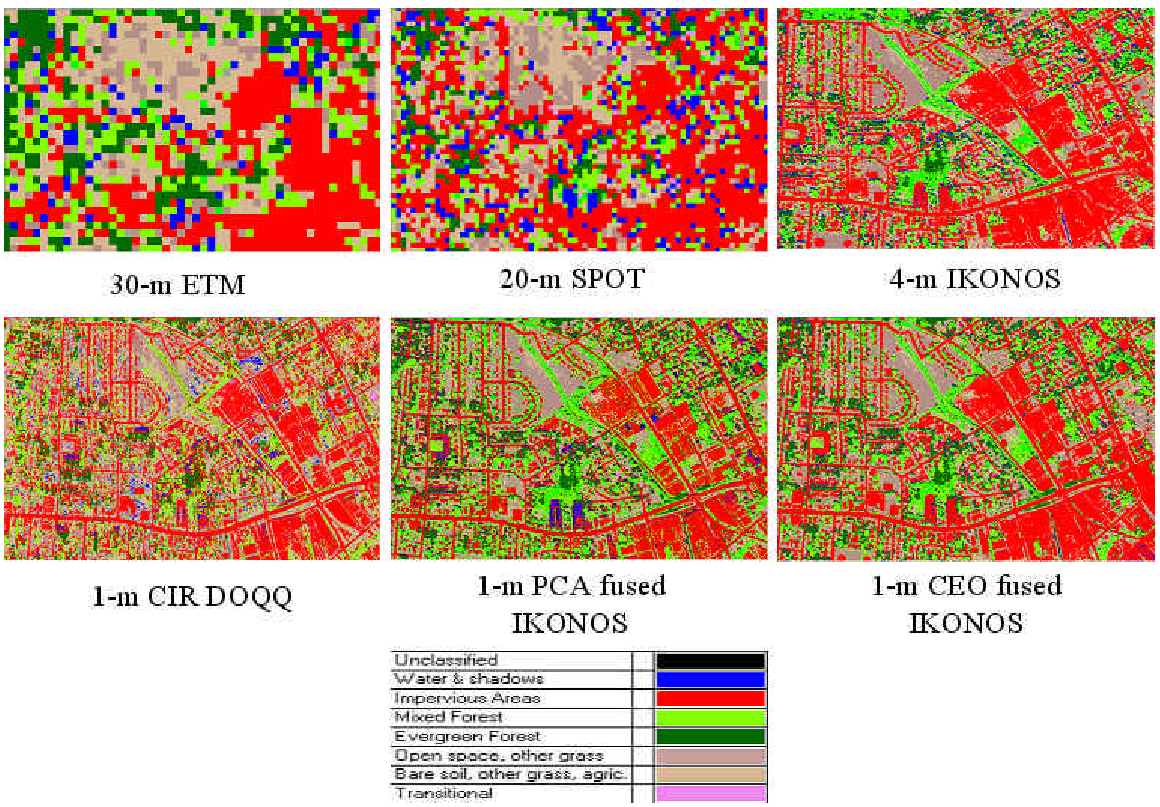

Figure 5. Thematic maps based on various remotely sensed data types. Impact of spatial resolution is quite apparent in these images.

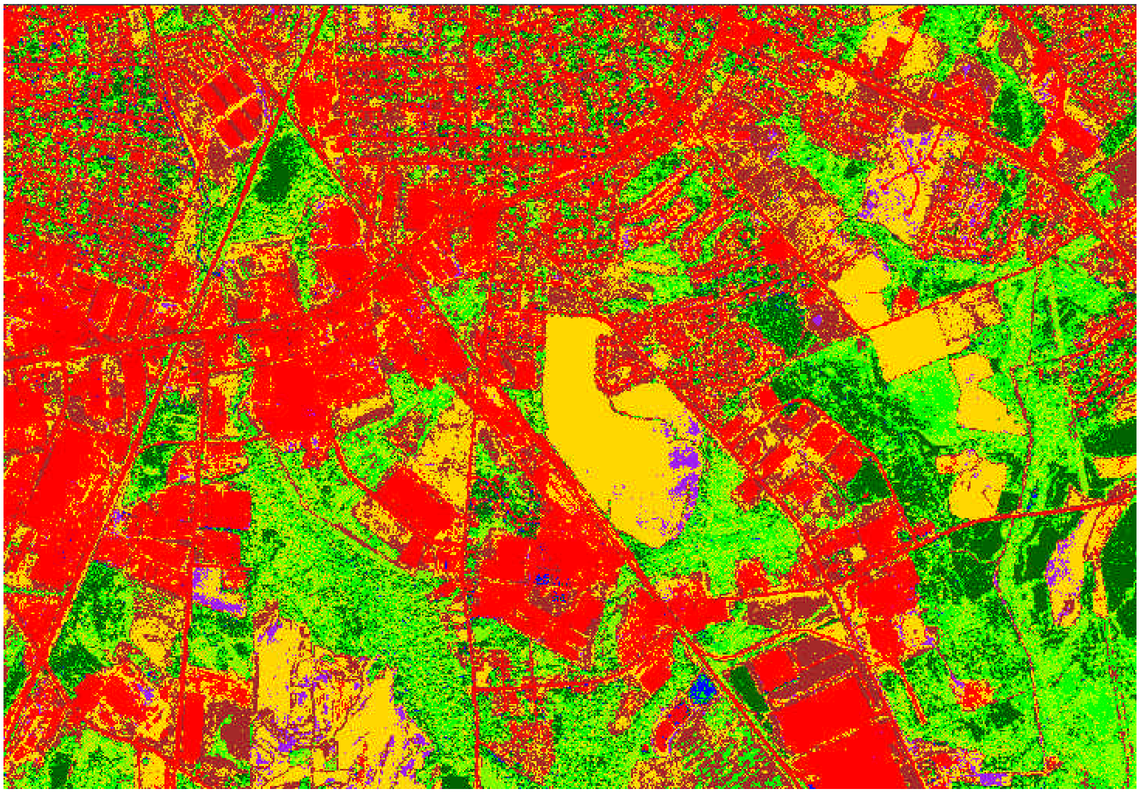

Figure 6. Thematic map based on 4-meter IKONOS image classification.

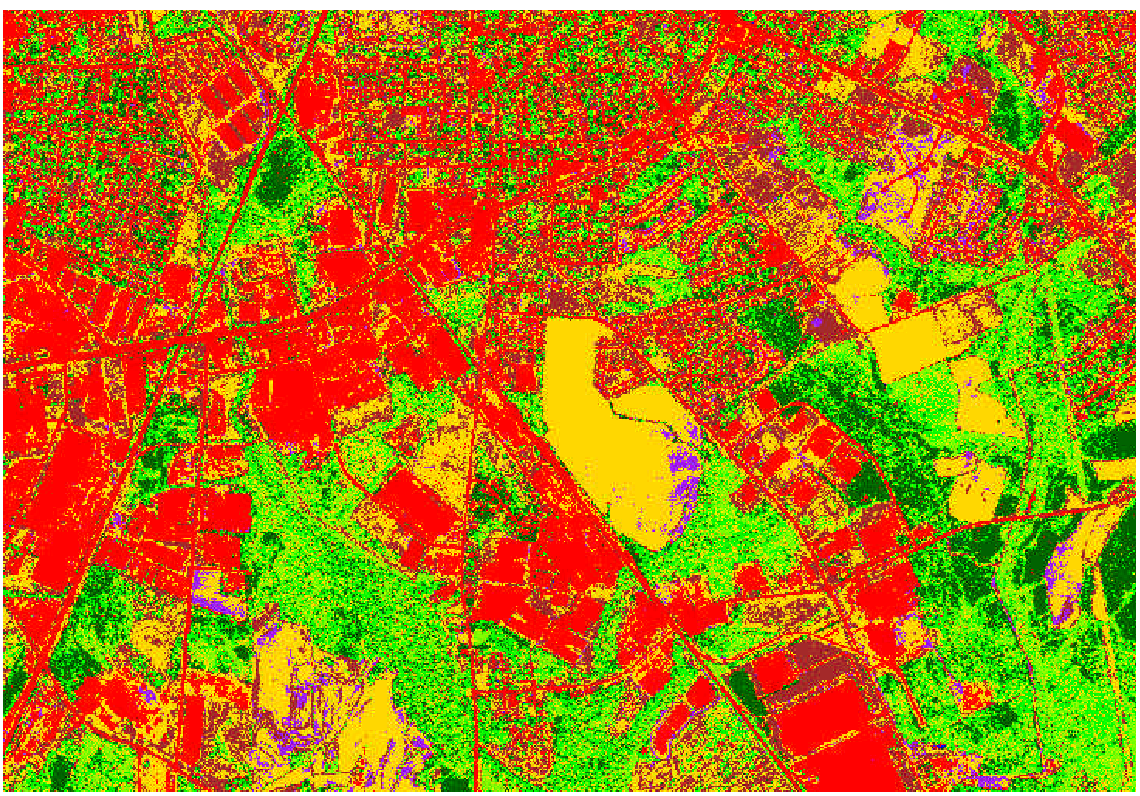

Figure 7. Thematic map based on 1-m fused IKONOS image (CEO's fusion) classification.

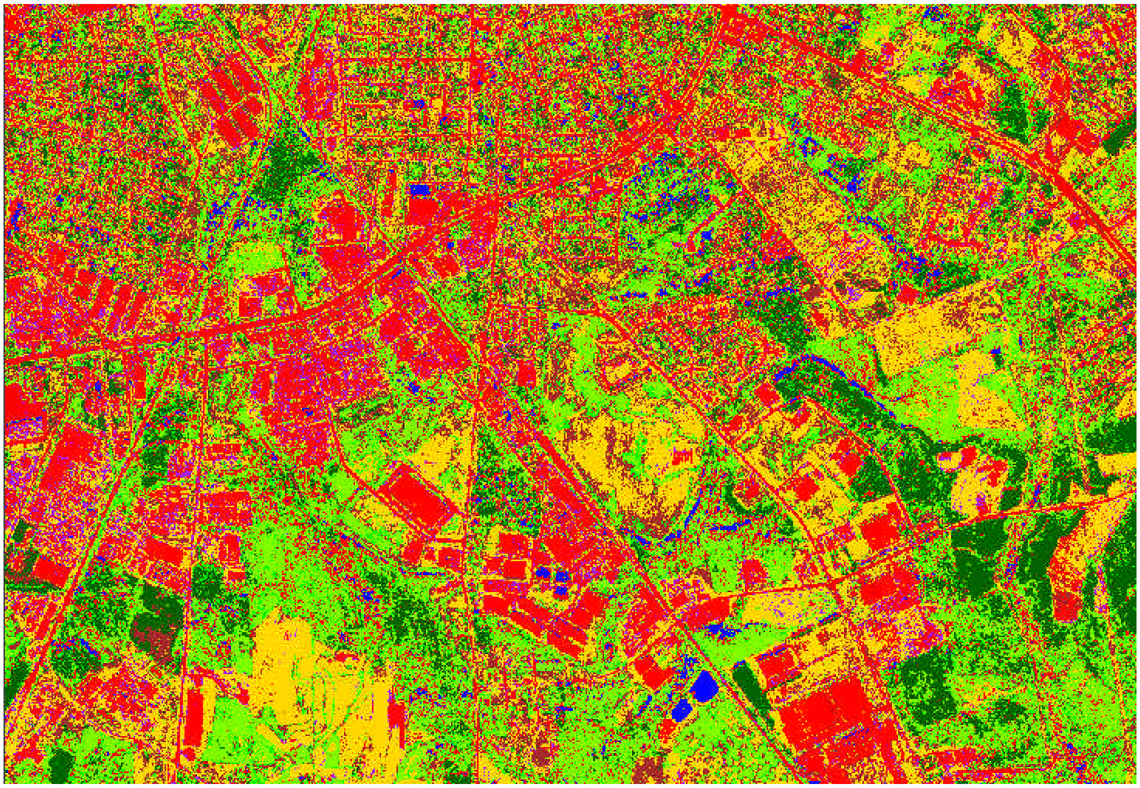

Figure 8. Thematic map based on 1-meter color infrared DOQQ classification.

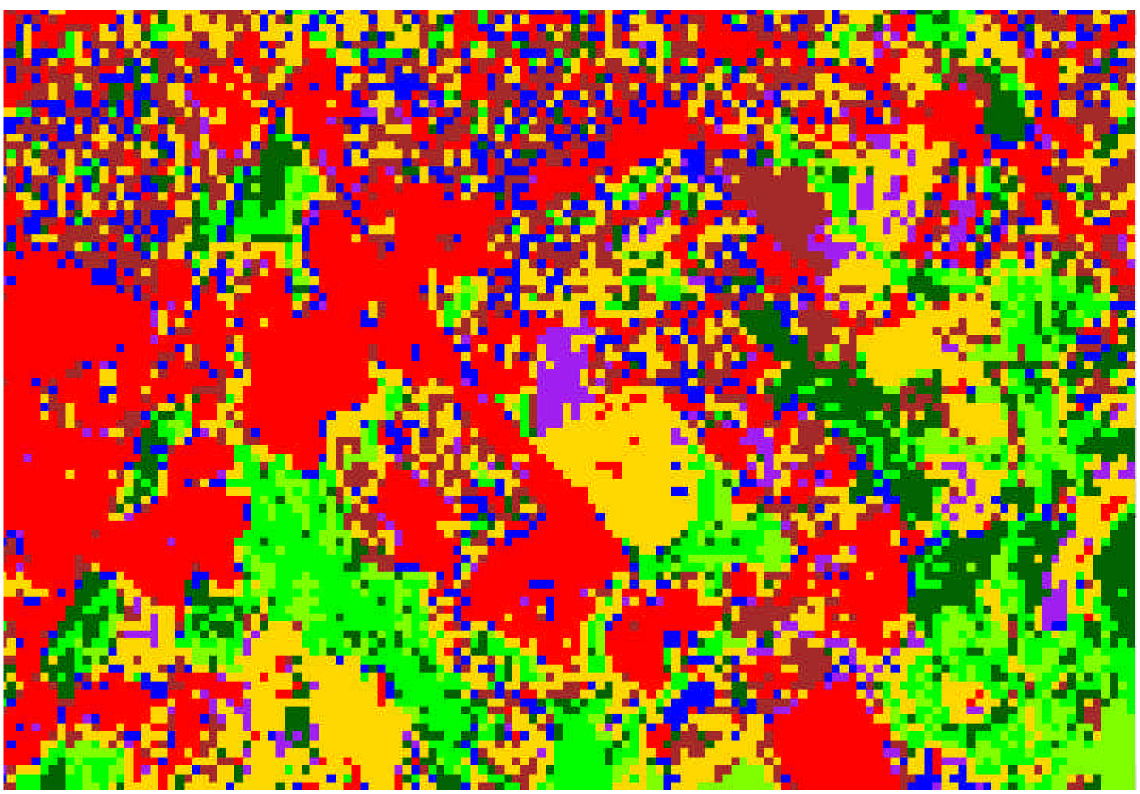

Figure 9. Thematic map based on 30-meter Landsat classification.

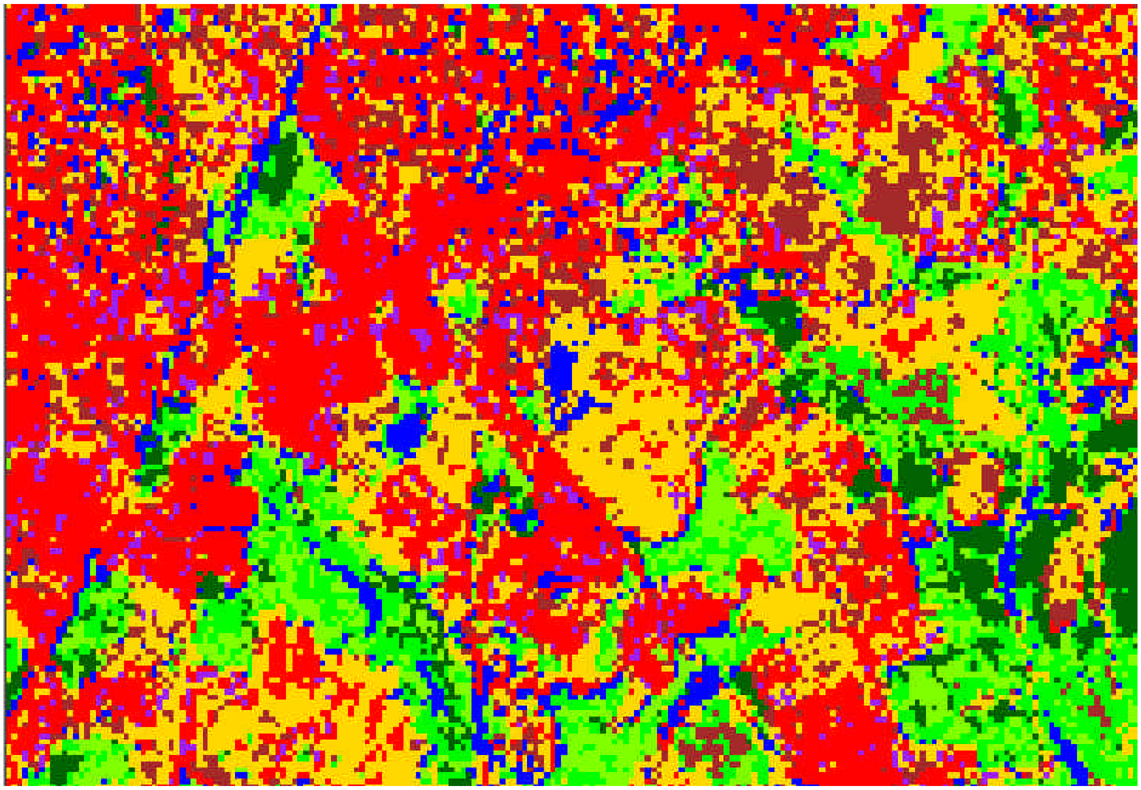

Figure 10. Thematic map based on 20-meter SPOT classification.

The following tables (1 and 2) show the overall classification accuracy results and associated error matrices. IKONOS 4m, (64% overall accuracy) and IKONOS 1m fused (63% overall accuracy) using CEO's fusion method provided equal results. Classifications from IKONOS 4m resulted in significant improvements over Landsat TM (44% overall accuracy), SPOT (40% overall accuracy), and CIR DOQQ (51% overall accuracy). Color infrared DOQQ provided better results than both SPOT and Landsat.

Table 1. Comparison of the accuracy of the supervised classifications of the various imagery types.

Overall Accuracy Results – Supervised Classification			
	Overall Accuracy (%)	**K-hat (%)**	**95% CI**
IKONOS 4M	64	58	± 4.207
IKONOS 1M Fused, CEO	63	58	± 4.222
SPOT	40	30	± 4.301
Landsat TM	44	34	± 4.723
CIR, DOQQ	51	42	± 4.382

Table 2. Error matrices for the thematic maps produced from various image types.

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Thematic map produced from 4-meter IKONOS multispectral imagery

Classified Data	W	IS	AG	GR	FD	FC	FM	B	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
Water, W	**40**	0	0	0	0	0	0	0	40	40	80.00%	100.00%	100%
Impervious Surfaces, IS	4	**58**	2	9	1	3	2	1	80	58	82.86%	72.50%	68%
Agriculture, AG	0	5	**64**	16	4	0	6	11	106	64	64.00%	60.38%	50.5%
Grass/Open Space, GR	0	4	10	**40**	3	8	5	3	73	40	58.82%	54.79%	47.7%
Forest, Deciduous, FD	0	0	0	0	**39**	0	23	0	62	39	78.00%	62.90%	58.8%
Forest, Coniferious, FC	0	2	1	1	2	**38**	7	0	51	38	60.32%	74.51%	70.8%
Forest, Mixed, FM	6	1	1	2	1	14	**26**	0	51	26	37.68%	50.98%	43.1%
Bare/Disturbed Soil, B	0	0	22	0	0	0	0	**15**	37	15	50.00%	40.54%	36.8%
Column Total	50	70	100	68	50	63	69	30	500	320			

(Columns W through B: Reference Data)

Overall Classification Accuracy = 64.00%

Overall Kappa Statistics = 58.31%

Thematic map produced from 1-meter fused IKONOS multispectral imagery (CEO's method)

Classified Data	W	IS	AG	GR	FD	FC	FM	B	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
Water, W	**49**	0	1	0	0	0	0	0	50	49	98.00%	98.00%	97.8%
Impervious Surfaces, IS	1	**51**	1	2	0	3	0	1	59	51	72.86%	86.44%	84.2%
Agriculture, AG	0	8	**57**	25	6	1	10	8	115	57	57.00%	49.57%	37%
Grass/Open Space, GR	0	4	11	**34**	6	1	0	1	57	34	50.00%	59.65%	53.3%
Forest, Deciduous, FD	0	0	0	0	**35**	0	19	0	54	35	70.00%	64.81%	60.9%
Forest, Coniferious, FC	0	1	1	5	0	**40**	9	0	56	40	63.49%	71.43%	67.3%
Forest, Mixed, FM	0	1	3	2	3	18	**31**	0	58	31	44.93%	53.45%	46%
Bare/Disturbed Soil, B	0	5	26	0	0	0	0	**20**	51	20	66.67%	39.22%	35.3%
Column Total	50	70	100	68	50	63	69	30	500	317			

(Columns W through B: Reference Data)

Overall Classification Accuracy = 63.40%

Overall Kappa Statistics = 57.68%

Thematic map produced from 1-meter CIR DOQQ image

Classified Data	W	IS	AG	GR	FD	FC	FM	B	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa
Water, W	**4**	4	0	2	7	5	7	0	29	4	80.00%	13.79%	12.9%
Impervious Surfaces, IS	1	**59**	4	3	2	3	6	2	80	59	64.13%	73.75%	67.8%
Agriculture, AG	0	9	**57**	27	5	3	4	2	107	57	53.27%	53.27%	40.6%
Grass/Open Space, GR	0	1	22	**31**	1	8	3	0	66	31	38.27%	46.97%	36.7%
Forest, Deciduous, FD	0	3	9	6	**32**	14	17	0	81	32	60.38%	39.51%	32.3%
Forest, Coniferious, FC	0	1	0	4	3	**47**	6	1	62	47	52.22%	75.81%	70.5%
Forest, Mixed, FM	0	3	5	7	3	10	**19**	0	47	19	30.65%	40.43%	32%
Bare/Disturbed Soil, B	0	12	10	1	0	0	0	**5**	28	5	50.00%	17.86%	16.2%
Column Total	5	92	107	81	53	90	62	10	500	254			

(Columns W through B: Reference Data)

Overall Classification Accuracy = 50.80%

Overall Kappa Statistics = 42.15%

Table 2. Continuing from previous page) Error matrices for the thematic maps produced from various image types.

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Thematic map produced from 30-meter Landsat multispectral image

	Reference Data								Classified	Number	Producers	Users	
Classified Data	**W**	**IS**	**AG**	**GR**	**FD**	**FC**	**FM**	**B**	Totals	Correct	Accuracy	Accuracy	Kappa
Water, W	**25**	11	5	7	0	5	2	3	58	25	50.00%	43.10%	37%
Impervious Surfaces, IS	1	**39**	5	19	2	2	1	5	74	39	55.71%	52.70%	45%
Agriculture, AG	19	7	**82**	20	10	10	17	13	178	82	82.00%	46.07%	33%
Grass/Open Space, GR	0	6	2	**13**	3	4	8	1	37	13	19.12%	35.14%	25%
Forest, Deciduous, FD	0	0	1	1	**14**	8	11	1	36	14	28.00%	38.89%	32%
Forest, Coniferious, FC	1	3	1	2	3	**23**	12	1	46	23	36.51%	50.00%	43%
Forest, Mixed, FM	0	2	0	2	18	11	**18**	0	51	18	26.09%	35.29%	25%
Bare/Disturbed Soil, B	4	2	4	4	0	0	0	**6**	20	6	20.00%	30.00%	26%
Column Total	50	70	100	68	50	63	69	30	500	220			

Overall Classification Accuracy = 44.00%

Overall Kappa Statistics = 34.21%

Thematic map produced from 20-meter SPOT multispectral image

	Reference Data								Classified	Number	Producers	Users	
Classified Data	**W**	**IS**	**AG**	**GR**	**FD**	**FC**	**FM**	**B**	Totals	Correct	Accuracy	Accuracy	Kappa
Water, W	**18**	2	4	4	0	7	6	1	42	18	36.00%	42.86%	36%
Impervious Surfaces, IS	11	**48**	7	24	2	5	4	6	107	48	72.73%	44.86%	35%
Agriculture, AG	21	8	**51**	20	10	4	11	13	138	51	62.96%	36.96%	23%
Grass/Open Space, GR	0	5	14	**9**	2	1	1	1	33	9	14.75%	27.27%	16%
Forest, Deciduous, FD	0	0	1	0	**18**	10	20	0	49	18	36.73%	36.73%	29%
Forest, Coniferious, FC	0	3	0	1	3	**23**	4	2	36	23	40.35%	63.89%	59%
Forest, Mixed, FM	0	0	0	2	14	7	**13**	2	38	13	22.03%	34.21%	24%
Bare/Disturbed Soil, B	0	0	4	1	0	0	0	**2**	7	2	7.41%	28.57%	24%
Column Total	50	66	81	61	49	57	59	27	450	182			

Overall Classification Accuracy = 40.44%

Overall Kappa Statistics = 30.39%

The first error matrix shows the classification accuracy results for the IKONOS 4-meter classification (Table 2). The table shows that the IKONOS classification was best at distinguishing the water and impervious surfaces classes. The table shows that there is confusion between the agriculture class and the bare/disturbed soil due to fallow fields and disturbed soil having similar signatures. Additionally, agriculture is confused with the grass/open space class, as urban grass areas have a similar signature as agriculture with certain crop covers. Additional processing as described later was performed to improve these confused classes. There is also some confusion within the forest classes. Both coniferous and deciduous forest class were confused with the mixed forest class.

With high-resolution imagery such as IKONOS it may be appropriate not to have a mixed forest class. At 4 meters resolution individual trees can be distinguished. In terms of water quality issues and other hydrologic analysis there is probably no advantage in distinguishing between forest types. The classification scheme in TR-55 makes no distinction between forest types. It may be more appropriate in terms of water quality and other hydrologic analysis to attempt to distinguish between different age classes of forests.

The second error matrix shows the classification accuracy results of the thematic map created from the fused IKONOS image based on CEO's fusion method. The overall accuracy of this thematic map was consistent with the results of the IKONOS 4m classification. Utilization of the fused imagery did not improve the overall classification accuracy in comparison to the IKONOS 4m classification. However, the fusion technique did improve the classification accuracy of all the individual classes with the exception of agricultural and grass/open space classes. The decrease in classification accuracy in those two classes compensated for the improvement in other classes. Generally, the agricultural class was misclassified as grass/open space or bare/disturbed soil. This is due to the fact that small grass or bare soil patches in agricultural areas are more readily detected in fused imagery with increased spatial resolution. Greatest contribution of CEO fusion method was in impervious class. Impervious areas are detected in more detail from CEO fused IKONOS imagery.

Third matrix shows the classification accuracy results for the color infrared DOQQ classification. The CIR DOQQ classification was more accurate than both the SPOT and Landsat derived classification. The CIR DOQQ classification was less accurate than the IKONOS derived classification. The CIR DOQQ accuracy was consistently less for all classes in comparison to the IKONOS classification.

The fourth matrix shows the classification accuracy results for the Landsat TM classification. Landsat was much less effective at classifying all classes except for agriculture as compared to IKONOS. Landsat was especially ineffective in distinguishing the grass/open space as compared to IKONOS. This ineffectiveness is largely due to the lower spatial resolution of Landsat. The grass/open space class consists of many small patches especially in an urban environment. Landsat was more effective than IKONOS in distinguishing agriculture. This is likely related to the IKONOS image acquisition date rather than any spectral/spatial advantage of the Landsat imagery. The IKONOS imagery was obtained in early spring when there would be a higher percent of fallow fields than in summer imagery. These fallow fields caused confusion with the Bare/disturbed soil class. Much of the error in IKONOS's classification of agriculture occurred due to the confusion of fallow fields with bare/disturbed soils.

The last matrix in Table 1 shows the classification accuracy results for the SPOT XS classification. SPOT's overall accuracy was slightly less but very comparable to Landsat's accuracy results. SPOT was more effective at distinguishing impervious surfaces than Landsat. The effectiveness of mapping impervious surfaces is probably related to the greater spatial resolution of SPOT in comparison to Landsat. SPOT was less effective as compared to Landsat in distinquishing the different vegetated classes. While SPOT has a higher spatial resolution than Landsat it does not have the spectral resolution of Landsat. The greater spectral resolution of Landsat results in the more accurate classification of the vegetated classes. SPOT was less effective in mapping all classes except for the agricultural class in comparison to IKONOS. As explained in the previous paragraph much of the error in IKONOS's classification of agriculture is probably related to the date of imagery acquisition rather than spectral or spatial advantages of the SPOT imagery.

5.1.2 Classification Results for IKONOS 4-meter Multispectral Imagery Using a Bayesian Classifier and Additional GIS Processing.

After the comparative classifications were completed additional processing steps were taken in an attempt to improve the IKONOS 4m LU/LC classification. The purpose of the previously discussed classifications was to compare the results of classifications using different imagery types, while using a consistent classification methodology. The purpose of the following classifications is to determine if additional processing techniques could be used to improve the IKONOS 4m derived classification. Much of the confusion of the IKONOS 4m LU/LC classification came from the confusion between classes of greatly disparate frequency within the watershed, such as fallow agriculture and bare soil. For example, occurrence of bare/disturbed soil class is very small compare to agricultural class. Because these classes confused with each other, giving less weight to Bare/disturbed soil class would reduce classification errors of agricultural areas into bare/disturbed soil class. Thus, a Bayesian classification scheme which weights classes based on frequency could be used to improve the final LU/LC map. In order to use the Bayesian method one analyst needs to have certain knowledge of the occurrence frequency of the subject classes within the watershed. CEO has created highly detailed LU/LC classification mapping within this watershed in previous research projects (CEO TR 217). This data was used to derive *a priori* weights for the Bayesian classification.

The classification scheme was changed slightly for the second series of classifications. In the first set of classifications the different imagery types were taken at different times. In the first set of classification which used different imagery taken at different times of the year for agricultural fields that may be fallow in one image could contain crop cover in other imagery. In terms of comparison it was better to have a single agriculture class for the first set of classifications. The second set of classifications only used a single date IKONOS imagery. The agricultural class was subdivided into two classes, fallow agriculture and agriculture with crop covers. Since there is only one image type taken at a single date subdividing the agriculture class into two classes, fallow and crop cover, results in a more detailed classification. In terms of water quality and hydrologic analysis there is not a lot of advantage in distinguishing the different forest classes so in the following classifications the deciduous, coniferous, and mixed forest classifications were merged into a single forest classification.

One of the main areas of confusion in the previous IKONOS classification was the confusion between fallow agriculture and bare/disturbed soil. The classification overestimated the amount of bare/disturbed class, classifying areas of fallow agriculture as bare/disturbed soil. Bare/disturbed soils are a relatively small proportion of the total watershed area while fallow agricultural areas can be a significant proportion of the total area of the watershed. Because of this unequal proportion of areas between the two classes it was thought that a Bayesian, or weighted, classification could significantly improve the classification. A previous LU/LC mapping project provided a-priori information about existing land use in the watershed. This *priori* knowledge was used to determine the weighting parameters in the Bayesian classification.

Another area of confusion in the initial classification was the confusion between grass/open space and agriculture with crop cover. The Bayesian classification minimized this confusion somewhat. A further processing step was taken to try to improve the classification in these classes using a GIS overlay technique. A mask of the urban area within the watershed was created, and used to mask out improperly classified agriculture areas that should have been classified as grass, open space. Table 3 and 4 show overall accuracy measures and matrices for the thematic maps created from 4-meter IKONOS multispectral imagery using different classification procedures described above.

Table 3. Overall accuracy measures for the thematic maps based on 4-meter IKONOS multispectral imagery using different supervised classification methods.

IKONOS 4-meter Overall Accuracy Results – Supervised Classifications			
	Overall Accuracy (%)	**Kappa (%)**	**95% CI**
Unweighted	74	67	± 3.854
Bayesian	76	70	± 3.743
Bayesian + GIS Filtering	77	71	± 3.688

Table 4. Error matrices showing classified results compared to 500 randomly determined sample sites on the IKONOS 4-meter multispectral image using *weighed classification and GIS decision, unweighted supervised classification,* and *weighted (Bayesian) supervised classification* methods.

IKONOS 4-meter MS Unweighted Supervised Classification

		W	IS	AF	AC	GR	F	B	Tot	User's Accuracy%
	Water, W	**40**							40	**100**
	Impervious Surfaces, IS	4	**58**	1	1	7	5	1	77	**75.3**
Classified	**Agriculture, Fallow, AF**		4	**45**	2	1	2	10	64	**70.3**
Data	**Agriculture, Cover, AC**				**14**	14	3		31	**45.2**
	Grass/ Open Space, GR		4	1	11	**41**	16	4	77	**53.3**
	Forest, F	6	4		2	5	**156**		173	**90.2**
	Bare/ Disturbed Soil, B			23				**15**	38	**39.5**
	Total	50	70	70	30	68	182	30	500	
	Producer's Accuracy (%)	**80**	**82.9**	**64.3**	**46.7**	**60.3**	**85.7**	**50.0**		**73.8**

IKONOS 4-meter MS Weighted (Bayesian) Supervised Classification

		W	IS	AF	AC	GR	F	B	Tot	User's Accuracy%
	Water, W	**38**							38	**100**
	Impervious Surfaces, IS	3	**57**	1	1	8	5	1	76	**75**
Classified	**Agriculture, Fallow, AF**		4	**56**	2	1	1	13	77	**73**
Data	**Agriculture, Cover, AC**				**14**	10	1		25	**56**
	Grass/ Open Space, GR		5	1	10	**45**	16	5	82	**55**
	Forest, F	9	4		3	4	**159**		179	**89**
	Bare/ Disturbed Soil, B			12				**11**	23	**48**
	Total	50	70	70	30	68	182	30	500	
	Producer's Accuracy (%)	**76**	**81**	**80**	**47**	**66**	**87**	**37**		**76**

IKONOS 4-meter MS Weighted + GIS Filter Supervised Classification

		W	IS	AF	AC	GR	F	B	Tot	User's Accuracy%
	Water, W	**38**							38	**100**
	Impervious Surfaces, IS	3	**57**	1	1	7	5	1	75	**76**
Classified	**Agriculture, Fallow, AF**		1	**56**	2			10	69	**81**
Data	**Agriculture, Cover, AC**				**12**	6	1		19	**63**
	Grass/ Open Space, GR		5	1	12	**50**	17	5	90	**56**
	Forest, F	9	4		3	4	**158**		178	**89**
	Bare/ Disturbed Soil, B		3	12		1	1	**14**	31	**45**
	Total	50	70	70	30	68	182	30	500	
	Producer's Accuracy (%)	**76**	**81**	**80**	**40**	**74**	**87**	**47**		**77**

Based on the accuracy assessments, a thematic map with the highest accuracy was selected for extracting stream buffers land use land cover (LU/LC) characteristics. The thematic map based on supervised weighted classification with GIS verification was the most accurate among various methods. Percent LU/LC types for the entire watershed, and within 50, 100 and 300 feet of buffer zones are shown on the following table (Table 5).

Table 5. Summary of LU/LC percent coverage at differing buffer distances to stream centerline.

Land Cover Class	% Cover Entire Watershed	% Cover 50' stream buffer	% Cover 100' stream buffer	% Cover 300' stream buffer
Water	0.6	1.5	1.1	0.7
Impervious Surfaces	21.4	5.0	6.8	11.5
Agriculture, Fallow	7.9	0.8	1.1	2.0
Agriculture, Cover	6.8	4.0	4.1	4.7
Grass/Open Space	24.1	15.8	16.7	20.4
Forest	32.5	72.4	69.4	59.0
Bare/Disturbed Soil	3.3	0.4	0.7	1.8
Clouds/Shadows	3.5	?	?	?

Land Cover Class	Area (acres) Entire Watershed	Area (acres) 50' stream buffer	Area (acres) 100' stream buffer	Area (acres) 300' stream buffer
Water	1466	62	87	169
Impervious Surfaces	50960	200	541	2666
Agriculture, Fallow	18735	34	89	461
Agriculture, Cover	16247	163	326	1081
Grass/Open Space	57453	637	1324	4729
Forest	77484	2920	5498	13671
Bare/Disturbed Soil	7837	16	59	427
Clouds/Shadows	8246	?	?	?
Total	**238427**	**4032**	**7925**	**9391**

6.0 DISCUSSION OF RESULTS

The use of IKONOS multi-spectral imagery resulted in a more accurate LU/LC map as compared to the other imagery used in this research (Landsat TM, SPOT, and scanned CIR DOQQ). Although the CEO technique used for fusing IKONOS imagery did not improve the overall accuracy of the classification, it improved the accuracy of individual classes except agriculture, deciduous and evergreen forest classes (Table 6). This improved accuracy of the IKONOS classification is most apparent in an urban environment where there is a large proportion of impervious surfaces.

Table 6. Highest classification accuracies for individual classes based on data sources. Accuracy values are average of three accuracy parameters; Kappa statistics, Producer's accuracy, and User's Accuracy (From table 2).

	Best Classification Accuracy (Average of Kappa statistics, Producer's, and User's Accuracies)	**Image Type Producing the Result**
Water	97.93%	IKONOS 1-meter (CEO's fusion)
Impervious Surface	81.17%	IKONOS 1-meter (CEO's fusion)
Agriculture	58.29%	IKONOS 4-meter
Grass / Open Space	54.32%	IKONOS 1-meter (CEO's fusion)
Forest, Deciduous	66.57%	IKONOS 4-meter
Forest, Evergreen	68.54%	IKONOS 4-meter
Forest, Mixed	48.13%	IKONOS 1-meter (CEO's fusion)
Bare /Disturbed Soil	47.06%	IKONOS 1-meter (CEO's fusion)

IKONOS MS imagery produced a more accurate classification than Landsat TM, SPOT, and color infrared DOQQ imagery. While more costly than the other imagery in the first glance, the IKONOS derived classification may be a more cost effective means of producing LU/LC data especially in an urban environment. There are actions that could be taken to improve the resulting classification. These actions include:

?? Using multi-date imagery will result in better classifications especially when attempting to distinguish between fallow agricultural areas and disturbed/bare soils. Using imagery taken during different seasons would be useful in distinguishing between deciduous forests and coniferous forests. Multi-date imagery would also help in removing the clouds or a better chance for obtaining cloud-free imagery.

?? Obtaining accurate stream buffer LU/LC data is dependent on the resolution of the source imagery. For instance, small streams are not discernable using 30-meter Landsat TM or 20-meter SPOT 4 data. Additionally the accuracy of the LU/LC stream buffer mapping is dependent on the accurate location of the stream network and the resulting stream network buffer. Most publicly available stream centerline data is of low horizontal accuracy in comparison with the 4m resolution IKONOS data (Figure 11). Publicly available LIDAR data could be used to derive a more accurate stream buffer. LIDAR data together with watershed modeling software could be used to derive a stream centerline of comparable accuracy to the IKONOS 4m resolution data (Figure 12).

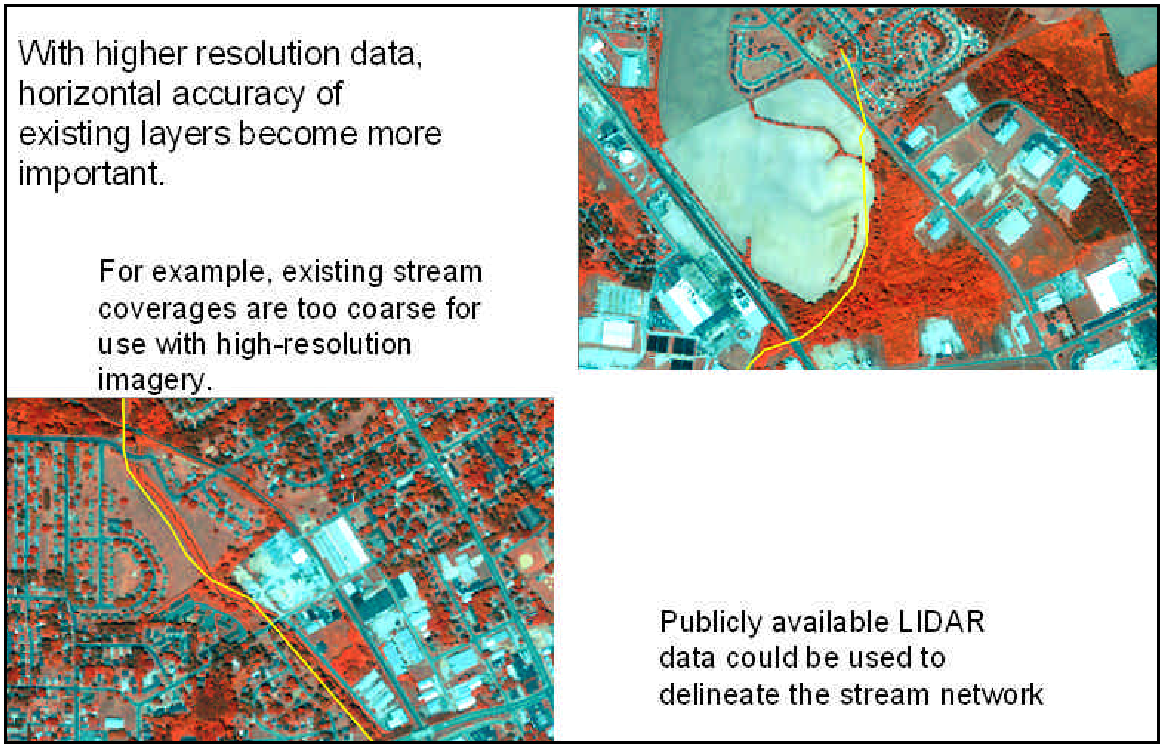

Figure 11. Horizontal accuracy of existing stream coverage is too coarse for use with high resolution imagery.

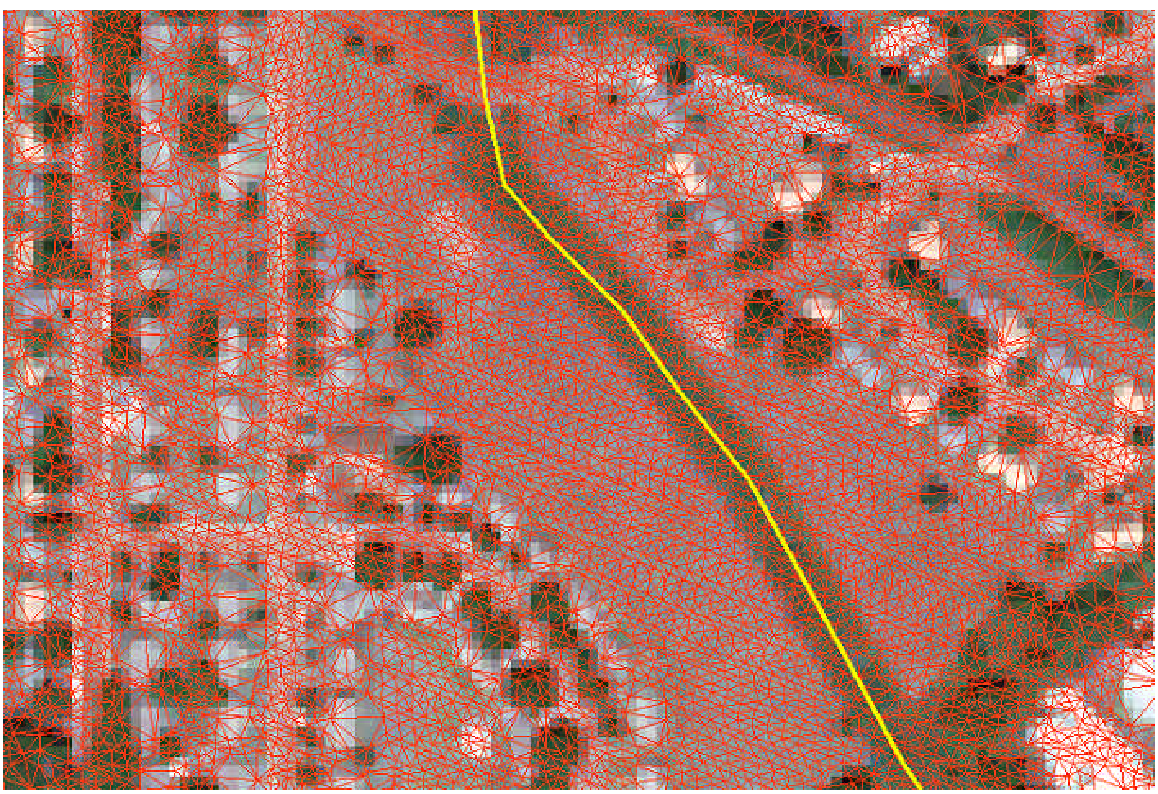

Figure 12. Stream centerline derived from LIDAR originated TIN model.

?? CEO's data fusion technique increased the classification accuracy of impervious classes (Figure 13). However, it also increased the detection of some classes such as small patches of soil or grass within the forested or agricultural areas. This caused lower accuracy results for agricultural and grass classes. Many of these small patches of grass and bare soil are temporal in nature (for example, changes from bare soil to grass in a short period of a time). Because of the time difference between image acquisition and reference data, these small patches may appear as one class in the image and another class in the reference data. Utilization of two-date image data (winter and summer) would be one way to reduce this effect.

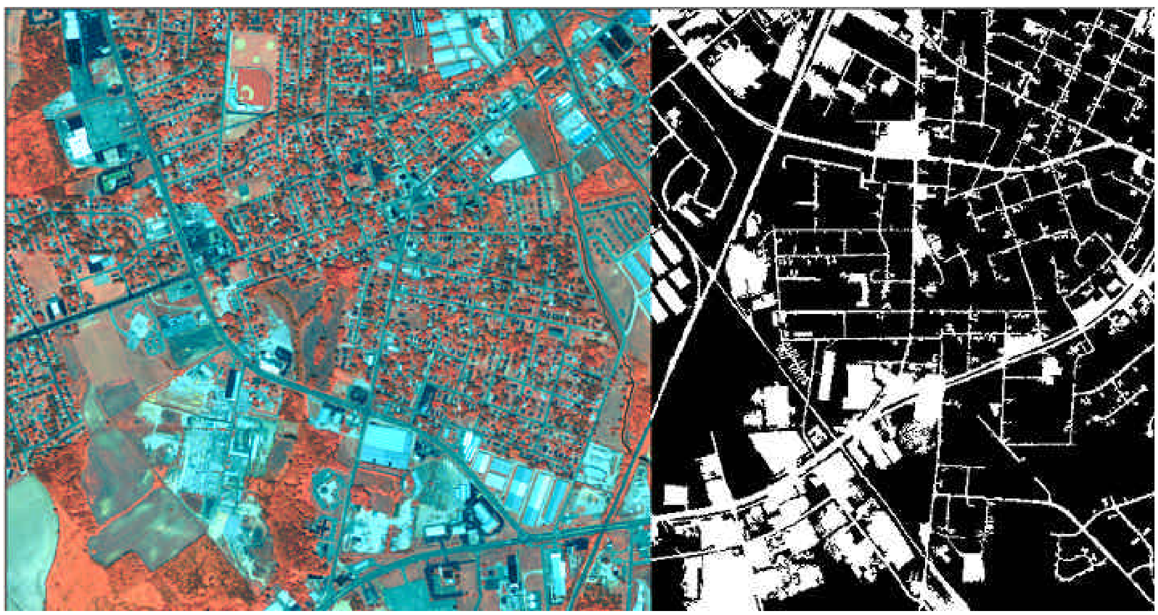

Figure 13. Impervious surfaces can be detected in greater details with increased spatial resolution (Impervious features above extracted from 1-m fused (CEO) IKONOS imagery). This image shows how easily one can delineate (automatically) the impervious surface areas from the IKONOS imagery using the technique we have developed in CEO (patent pending).

?? Most water quality studies focus on stream buffers and land use/land cover (LU/LC) classes within these buffer zones. Usually buffer widths are small for conventional satellite data (i.e., Landsat and SPOT 4 data) to detect LU/LC classes within these buffers (Figure 14 and 15). Thus higher spatial resolution data is essential for successful buffer zone mapping.

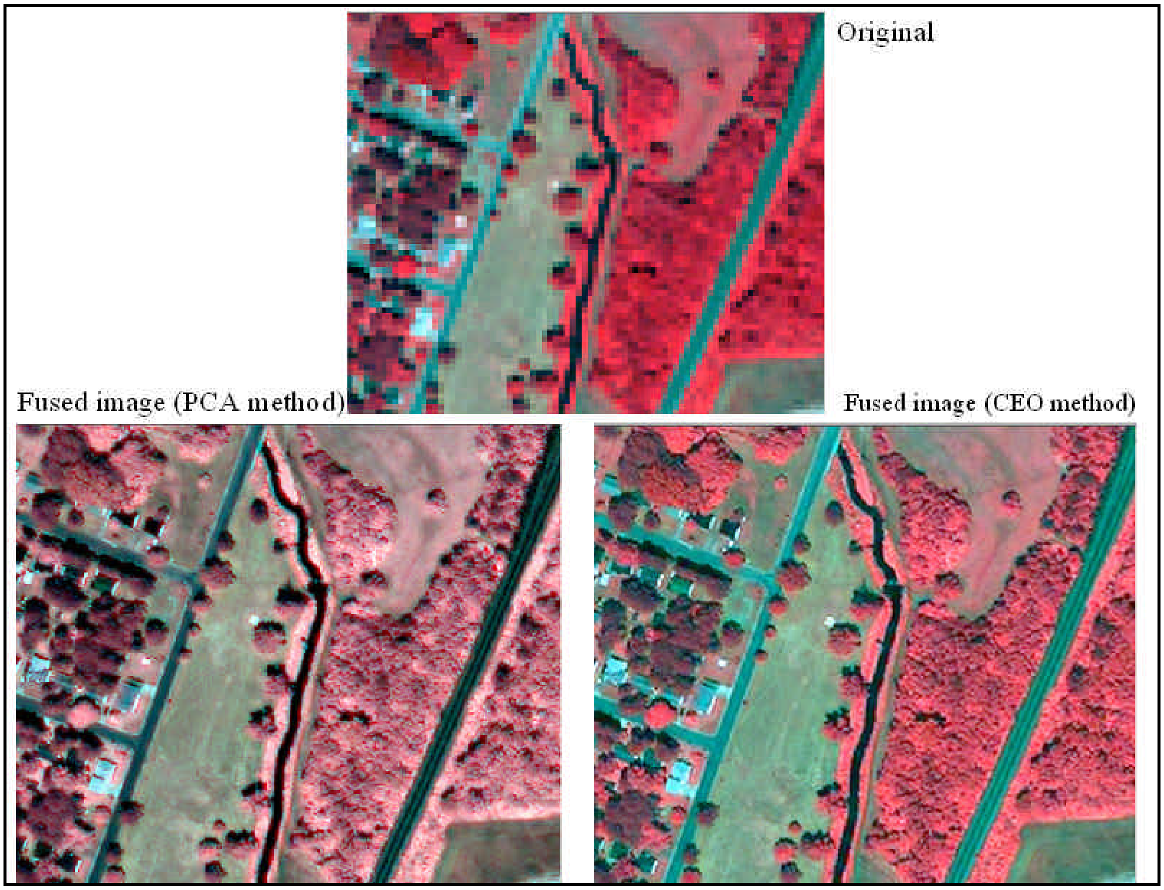

Figure 14. False color composites of original IKONOS 4-meter, IKONOS 1-meter fused with PCA method and IKONOS 1-meter fused with CEO's fusion method. CEO's fusion method preserves the integrity of original data as compared to other methods. Thus, it can be used for classification and modeling purposes. The advantage of integrating great details from 1-m. resolution data into image classification is quite apparent in these images.

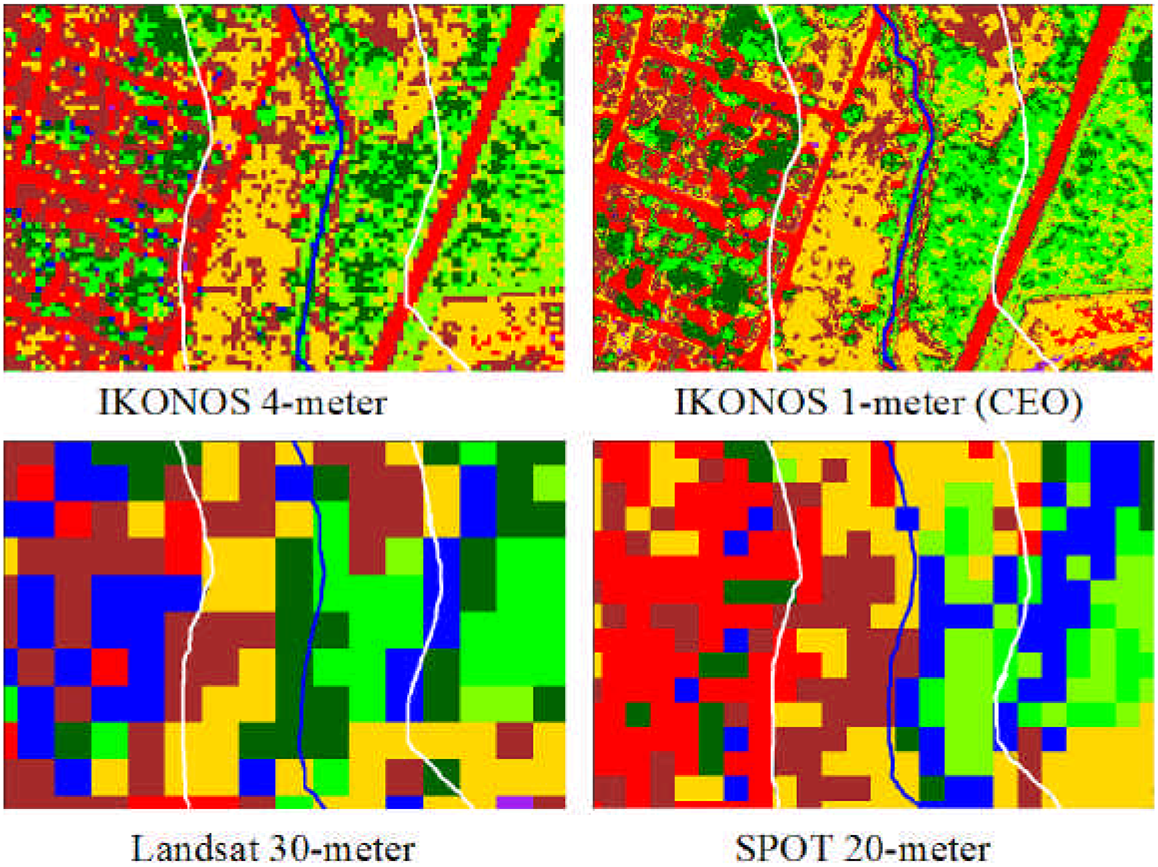

Figure 15. Comparison of thematic maps produced from various data types with different spatial resolutions for stream buffer zone mapping. Stream centerline and 300 ft buffer zones are shown in these images. Effect of spatial resolution in efficient buffer zone mapping is quite apparent in this figure.

7.0 CONCLUSIONS AND RECOMMENDATIONS

To protect water quality and control erosion and associated sedimentation, the best management practices must be applied for the use of land for agriculture, industrial, and urban growth. In order t do so, a detailed, accurate, and repeatable land use and land cover maps of those areas having direct impact on water quality must be prepared. Improving degraded watersheds and streams require accurate and current land use and land cover (LU/LC) data. In this study, IKONOS imagery provided an effective means of obtaining accurate and detailed LU/LC data within the stream buffer zones as well as the difficult to assess areas such as urban watersheds. Extensive field data obtained using GPS and photo interpretation were integrated for the accuracy assessment of LU/LC data and validation. The accuracy of maps produced in this project was very good and satisfactory.

IKONOS was particularly effective at delineating impervious surfaces prevalent in urban areas, which are problematic to map from other low resolution remotely sensed data. However, IKONOS classifications based on single date imagery have some limitations with regard to other LU/LC classes. The delineation of bare and disturbed soils proved problematic. Bare and disturbed soils are a small part of the total proportion of the area within a watershed but these areas play a critical role in water quality and sediment load. Bare and disturbed soils are nearly identical spectrally and are often misclassified with fallow agriculture due to the short temporal cycle and the similarity of spectral signatures. Additionally, grass and open space, which are commonly a significant part of an urban/suburban watershed, are often confused with agriculture. Due to the seasonal nature of agriculture, using multi-date imagery could be effective in distinguishing agriculture from the grass/open space class and from the bare/disturbed soil class. This will also account for the removal of changes due to the short temporal cycle in these classes.

While IKONOS imagery proved to be an effective data source to quantify land use composition within an urban watershed, this analysis of LU/LC only provided a mapping of the watershed land use composition at a single point in time, commensurate with the objective of this project. To completely understand the impact land use has on water quality, it is important to accurately assess the type and position of changes occurring within the watershed. This can be accomplished through change detection using remotely sensed imagery. Currently, most LU/LC change detection studies have used lower resolution imagery. However, lower resolution imagery proved incapable of accurately detecting small-scale or mixed LU/LC classes that fall below the resolution of the imagery but still may be significant contributors of upland sediment load determination. Recommendations for future studies include the use of multi-date IKONOS imagery with multivariate image analysis, and proprietary fusion techniques to access the use of IKONOS in improving LU/LC classifications within an urban watershed, and identify LU/LC changes. Other new high resolution satellite imagery, which offer comparable results to IKONOS and that has recently (2002) become available to the public such as SPOT-5 is recommended as a cheaper and more routinely available alternative source of data for such studies. The SPOT-5 satellite has 10-meter multispectral and 2.5-meter panchromatic imaging capacity. Furthermore, with the advanced data fusion techniques that we have developed at North Carolina State University's Center for Earth Observation (CEO), it is possible to fuse the 10-meter multispectral imagery with the 2.5 meter panchromatic imagery provided by SPOT-5 while preserving the spectral integrity of multispectral data. Conventional fusion techniques that are used commercially for fusing panchromatic and multispectral data permanently alter the spectral characteristics of multispectral data, therefore making this data unfeasible for image classification and modeling. The technique that we have developed at CEO (patent pending) functions to effectively fuse the panchromatic and multispectral data while preserving the spectral integrity of multispectral data and therefore making the image classification for mapping LU/LC change detection and modeling feasible. LIDAR (Light Detection and Ranging) data is also recommended to be incorporated into both image classification and change detection datasets to provide high-resolution mapping of headwater stream networks throughout the watershed, thus providing accurate and detailed connectivity between stream networks and adjacent land use classes. Ancillary data could be used to improve the classification of shadowed areas within the IKONOS imagery. An attractive data type for this purpose is radar data. Radar data is insensitive to time of day, weather conditions, and solar insulation. The Canadian Radarsat can provide eight-meter spatial resolution data that would be helpful for resolving problems in shadow areas. The use of additional historic data to assess LU/LC changes is recommended. In summary, the methods outlined in this paper along with the high resolution IKONAS data have produced a highly detailed and accurate high-resolution land cover classification for the stream buffer zones and the adjacent areas in Hominy Creek watershed. The innovative procedures used have allowed for the improvement of spatial resolution without sacrificing high spectral resolution. We expect this approach to be quite applicable to other watersheds with similarly good results.

References

Anderson, J. R. E. Hardy, J. Roach, and R. Witmer, (1976), *A Land Use and Land Cover classification System for Use with Remote Sensor Data*, Washington, DC: U.S. Geological Survey Professional Paper 964, 28p.

CEO TR 217, (2000). Land Cover classification of the Hominy Creek watershed. Submitted to NC Wetlands restoration project, NC Division of Water Quality. *Center for Earth observation Technical Report Series,* no 217.

Congalton, R., (1991). A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data, *Remote Sensing of Environment*, Vol. 37. ISSN: 0034-4257.

Dai, X. L., and S. Khorram, (1998). The effects of image misregistration on the accuracy of remotely sensed change detection, IEEE *Transactions on Geoscience and Remote Sensing*, vol.36, no.5, pp. 1566-1577, 1998.

EPA, (2003). EPA reach file (rf3).

Jensen, J. R., *Introductory Digital Image Processing, A Remote Sensing Perspective*, Prentice-Hall, Inc., 1996. ISBN 0-13-205840-5

Khorram, S., G.S. Biging, N. R. Chrisman, D.R. Colby, R. G. Congalton, J. E. Dobson, R. L. Ferguson, M.F. Goodchild, J. R. Jensen, and T. H. Mace. (1999). Accuracy Assessment of Remote Sensing-derived Change Detection, Monograph, *America Society of Photogrammetry and Remote Sensing* (ASPRS), 68p.

Space Imaging, (2003). *IKONOS Imagery Products & Product Guide*, Space Imaging, LLC.

USDA, Natural Resources Conservation Service, Conservation Engineering Division, (1986), Urban Hydrology for Small Watersheds, TR-55, Technical Release 55, June 1986

APPENDICES

Appendix A

IKONOS 4-meter multispectral data and final classified image (thematic map) from IKONOS data are presented in attached CD. There is a ReadMe file explaining how to view these files.