Equitable Fee Collection Using Enhanced Impervious Surface Determination in Sioux Falls, SD

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Abstract:

Residents of Sioux Falls, SD, pay their tax burden in many ways. One way is through the storm drainage fee, which is based upon the amount of impervious cover per parcel. The amount of impervious cover is determined by two key variables: land use and parcel area. However, a wide range in impervious cover is seen for the same land use assignments.

To ascertain the amount of impervious cover more realistically, the City merged orthophotography with satellite imagery, resulting in a data set with the higher resolution of the orthophotography but with the spectral coverage of the satellite imagery. These data sets were used as input to determine impervious surface area per parcel via automated feature extraction. The resultant product is used as an additional tool to determine the amount of storm water runoff per parcel, resulting in a fair and balanced storm drainage fee.

Keywords: impervious, feature extraction, orthophotography, satellite imagery, Sioux Falls, South Dakota

Introduction

The City of Sioux Falls has been acquiring hard copy aerial photography of the City and its growth areas since the 1930s and digital high resolution orthophotography and digital elevation models since 1998. Early Geographic Information System (GIS) uses of the digital orthophotography were limited, mainly using it as a background layer on screen and on hard copy map products. There was little analysis performed other than utilizing the imagery to fine tune vector layers. Over time, the uses of the orthophotography have evolved. No longer are the images used solely as an attractive background for non-scientific purposes. Instead, the orthophotography is distributed enterprise wide through various means and is used for high-end spatial analysis.

In the last three decades, the remote sensing community witnessed remarkable improvements in satellite image quality, in terms of spectral and spatial resolution (Hung 2002). The satellite imagery provides information from not only the visible portion of the spectrum, but also the infrared portion, wavelengths not covered by the aerial photography. A resolution merge between the satellite imagery and the aerial photography can result in a data set with the higher resolution of the photography but with the spectral coverage of the satellite imagery.

This paper focuses on the use of high resolution orthophotography, enhanced by infrared data derived from satellite imagery, and the feasibility of using it, in conjunction with feature extraction tools, for determining the location and quantities of impervious areas in the City of Sioux Falls as it relates to the application of a storm drainage fee that is based upon the amount of storm water runoff per parcel.

Region of Study

Sioux Falls, South Dakota is situated in southeast South Dakota at the intersections of Interstates I-29 and I-90 (Figure 1). The elevation of the city ranges from 1262' above sea level in a quarry on the western edge of the city to 1568' on the eastern edge. Clearly, the city is has very little elevation change, and to our benefit, the city greenway is located in the floodplain that surrounds the city.

Figure 1 – Location of Sioux Falls, South Dakota

Impervious Cover and Runoff

A wide range in impervious cover is often seen for the same zoning category (Schueler 1995) and land use assignments, and Sioux Falls is no exception. Schueler (1995) points out that impervious area associated with medium density single family homes can range from 20 percent to nearly 50 percent, depending on the layout of streets and parking. Further, site runoff increases as a result of site impervious cover.

Imperviousness is defined as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape (Schueler 1995). For this study, impervious surfaces will include those features found within a property parcel: rooftops, parking lots, driveways, cement pads, and sidewalks.

An impervious surface is an indicator of a more intensive land use. The infiltration capacity of these areas is lowered to or near zero (Hill, Botsford, and Booth 2003). Water quality is affected by urban pollutant loads which are directly related to watershed imperviousness. Also, impervious surfaces both absorb and reflect heat. In the summer, impervious areas can have local air and ground temperatures that are 10 to 12 degrees warmer than the fields and forests that they replaced (Schueler 1995). The direct hydrological effect of impervious surfaces occurs as a change in the magnitude, velocity, and volume of surface flow, and precipitation that would normally be part of natural infiltration instead falls on and flows over impervious surfaces. The runoff is then channeled and released via storm sewers directly into the receiving stream (Jennings and Jarnagin 2002).

In the City of Sioux Falls, all real property within the city, except property owned by cemetery corporations, is charged an annual Storm Drainage Fee (SDF) for the operation, maintenance, and capital improvements of the storm sewer and drainage system. The fee is based on a Runoff Weighting Factor (RWF), Parcel Area (PA), and a Unit Financial Charge (UFC):

$$SDF = (RWF * PA * UFC)$$

The runoff weighting factor is determined by the type of land use and indicates the relative volume of storm water runoff from a land parcel as a function of the percentage of impervious surface. An example of various runoff weighting factors is shown below in Table 1.

Table 1
Runoff Weighting Factor as Determined by Land Use

Land Use Code	Land Use	Runoff Weighting Factor
12	Duplex	7.50
14	Apartment building (1– 3 stories)	11.25
17	Mobile homes and trailers	11.25
21	Apparel and textiles	17.00
25	Warehouse, indoor storage	17.00
31	Food, agricultural processing, stockyards, rendering	17.00
37	Salvage, junkyard, resource recycling	7.50
41	Bus, railroad yards, terminals, right-of-way	5.00
42	Airport	5.00
43	Auto parking ramps and lots (commercial or public only– not auxiliary parking)	18.75
44	Highway and street right-of-way	5.00
45	Communication (TV, radio, etc.)	17.00
46	Utilities (gas, sewer, water, telephone, etc.)	17.00
48	Military base	17.00
51	Wholesale– food, produce	18.75
55	Extensive retail– new and used car dealers	18.75
56	Extensive retail– recreational vehicles, marine	18.75
61	Food store	18.75
63	Gasoline, auto service station	18.75
65	Clothes and apparel	18.75
73	Nursing homes and hospitals	11.25
74	Colleges and universities, adult education	11.25
76	Day care centers	11.25
83	Theaters	18.75
84	Restaurants, bars, lounges	18.75
85	Hotels, motels, resort lodging	18.75
86	Public parks, golf courses, fairgrounds	1.00
94	Mining and quarrying**	1.00
95	Cemetery	1.00
97	Vacant	1.00
110	Single-family (lot area less than 30,000 square feet)	7.50
111	Single-family (lot area of 30,000– 60,000 square feet)	5.75
116	Estate (lot area greater than 100,000 square feet)	2.50

Alternatively, upon written request from a property owner, a detailed site study can be conducted by the city engineering department to determine the runoff weighting factor (Table 2). The request must be made to the City by April 30th of the year that the fee will be calculated, and the engineering department has until July 1st to analyze the parcel and notify the requestor of the manual storm drainage fee assessment.

Table 2
Runoff Weighting Factor as Determined by Percentage Impervious Area

Percentage Impervious Area	Average Runoff to Rainfall Ratio (Rv*)	Runoff Weighting Factor (Rv × 25)
0	0.04	1
10	0.19	4.75
15	0.26	6.5
20	0.3	7.5
30	0.38	9.5
40	0.45	11.25
50	0.53	13.25
60	0.6	15
70	0.68	17
80	0.75	18.75
90	0.83	20.75
100	0.9	22.5

The parcel area is obtained from the county in which the parcels falls, either the Minnehaha County Department of Equalization or the Lincoln County Assessors Office. The unit financial charge for 2004 – 2008 is shown in Table 3. The unit financial charge is reviewed annually and revised as necessary to keep revenues in balance with anticipated expenditures.

Table 3
Unit Financial Charge

Effective Date	**Unit Financial Charge**
January 1, 2004	0.000354
January 1, 2005	0.000383
January 1, 2006	0.000413
January 1, 2007	0.000446
January 1, 2008	0.000477

Methodology

The methodology used in this project is summarized as follows:

1. Image Preparation and Processing
2. Feature Extraction
3. Storm Drainage Fee Calculation

Image Preparation

High resolution orthophotography acquired April 23, 2004 was utilized (Figure 2). The original resolution of 0.5-ft pixel was maintained.

Figure 2
High Resolution Orthophotography

Color infrared IKONOS imagery acquired May 20, 2002 at a resolution of 4 m was projected to the City of Sioux Falls standard projection schema, UTM projection, Zone 14 North, spheroid GRS1980 (Figure 3).

Figure 3
IKONOS Color Infrared

A resolution merge was performed in ESRI's ArcGIS 9.1 using the Leica Geosystems Image Analysis extension, version 9 (Figure 4). High resolution orthophotography was merged with the IKONOS color infrared image. In the Image Analysis extension, there is no choice of transformation method, and the Brovey Transform is the default. This method resamples lower spatial resolution data (the IKONOS color infrared image) to a higher spatial resolution (in this case, a 1-ft pixel output image was chosen) while retaining spectral information. The Brovey Transform visually increases contrast in the low and high ends of an image's histogram. The resampling itself doesn't do anything to increase contrast, so whatever that transform does to increase contrast, it's unrelated to the resampling itself. This provides contrast in shadows, water, and urban features (Leica Geosystems & GIS Mapping, 2003). The nearest neighbor (zero-order) interpolation method was used to resample the image. The brightness value closest to the pixel specified is assigned to the output pixel (Jensen 1996). This resampling method is preferred by Earth scientists, since it does not alter the pixel brightness values during resampling (Duggin and Robinove 1990).

Figure 4
Resolution Merged Image

Feature Extraction

Our goal is to extract impervious surface. The study area, broken down into property parcels, is thus partitioned into pervious or impervious polygons. We will then be able to calculate the storm drainage fee based upon the actual impervious area, and can compare whether the programmatically derived method, which is the standard, provides a fair and balanced storm drainage fee.

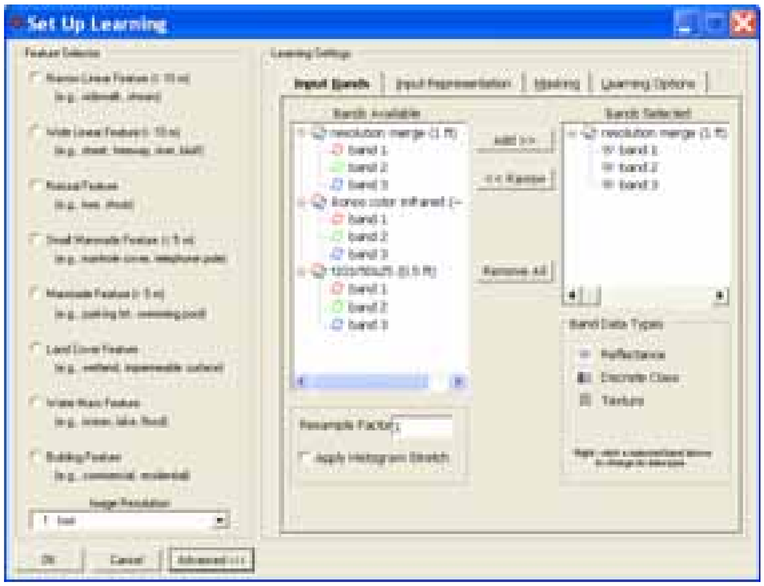
The Feature Extraction extension by Visual Learning Systems for ArcGIS was utilized to perform the extraction. Through trial and error, an extraction scenario was developed to extract the majority of the urban impervious features with the least amount of manual cleanup at the end. Since the City of Sioux Falls acquires orthophotography and planimetric features on a 3-year cycle, and since the City of Sioux Falls maintains a robust enterprise GIS, we were able to utilize numerous existing layers, allowing us to concentrate our efforts on those feature classes that do not already exist.

The existing feature classes that were used include: parcel polygons, building footprints, and roadways. The feature classes that we wanted to extract include: parking lots, driveways, concrete pads, and sidewalks that fall within the parcel polygon.

The steps utilized to extract the parking lots are as follows. All steps use the VLS Feature Extraction extension for ArcGIS. First, a learning feature class was created. This feature class was edited to include different sizes and compositions of parking lots and digitized throughout the area of the image. Using this vector layer as input, a learning scenario was determined. There are four categories of options to choose from. First, the base image was chosen

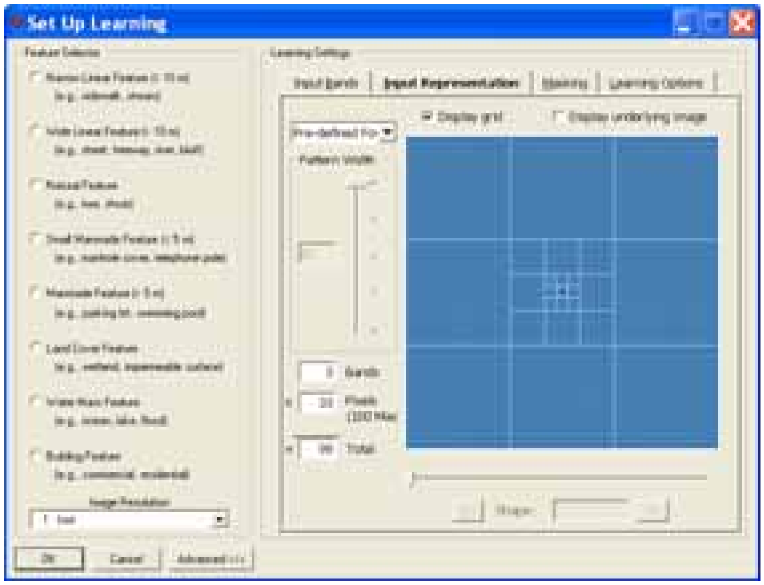
(Figure 5). For this learning scenario, the input image selected was the resolution merged image containing our high resolution orthophotography merged with the color infrared band of an IKONOS image of the same area. All bands were utilized, and the defaults were chosen.

Figure 5
Feature Extraction – Set Up Learning – Input Bands



Through trial and error, an input representation was chosen (Figure 6). The pre-defined foveal vision filter provided the best results for parking lots when using our custom resolution merged image. With a foveal representation, a learning algorithm is given a region of the image with high spatial resolution at the center (where the prediction is being made) and lower spatial resolution away from the center (Visual Learning Systems 2006). This is similar to peripheral vision.

Figure 6
Feature Extraction – Set Up Learning – Input Representation

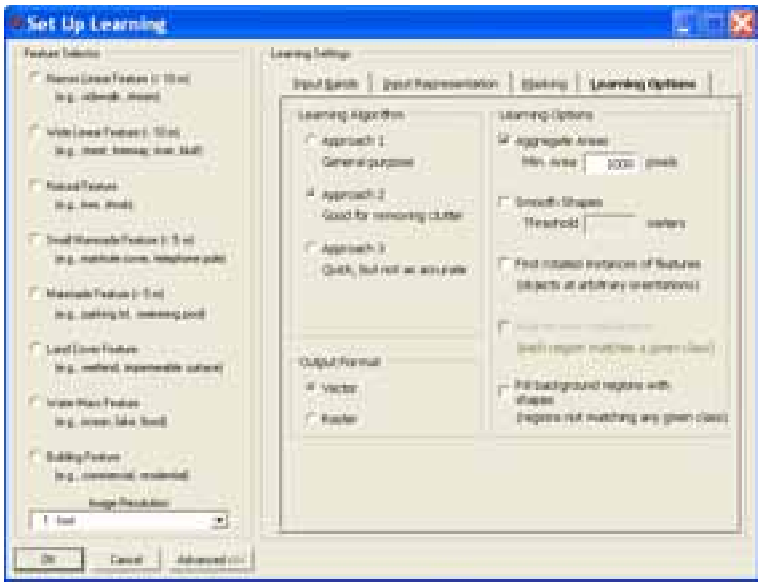


The Masking feature (Figure 7) is a great benefit to the feature extraction process. The software was trained to extract those areas only inside a parcel polygon, but to exclude any buildings or roads that may fall inside those polygons. This provided additional information to the learner, and the results focused exactly in the area of interest.

Figure 7
Feature Extraction – Set Up Learning – Masking

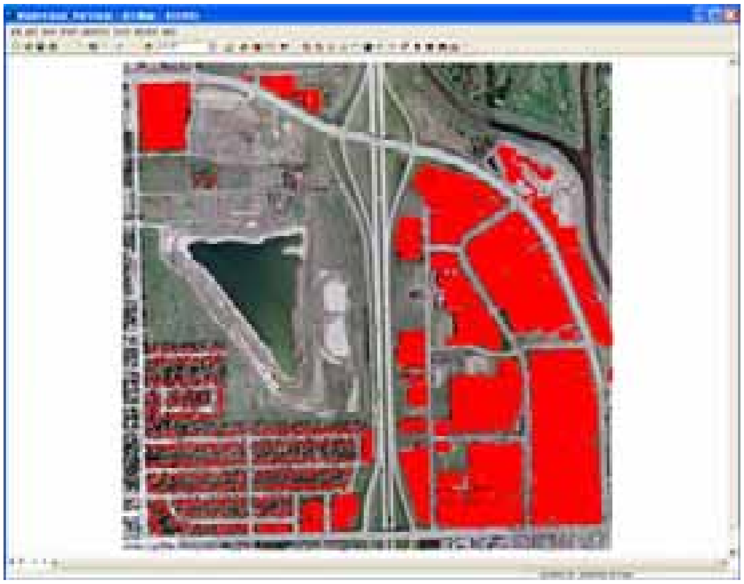
The options chosen for extraction (Figure 8) included utilizing a learning algorithm that removed clutter, and a minimum polygon size of 1000 pixels in area (approximately 30 square feet). This aggregate option could also have been utilized after the extraction using the post-processing tools.

Figure 8
Feature Extraction – Set Up Learning – Learning Options



The final results were impressive (Figure 9). Note that the extraction was run several times in preprocessing to determine which options worked best with the imagery and with the desired features for extraction.   Missed features were digitized and ran through the feature extraction process again and the final feature class was created. Once these results were acceptable, final edits were digitized using ArcGIS.   The above steps were repeated again, with minor enhancements, to extract driveways, concrete pads, patios, and sidewalks that fall within the parcel polygons.

Figure 9
Feature Extraction Derived Features



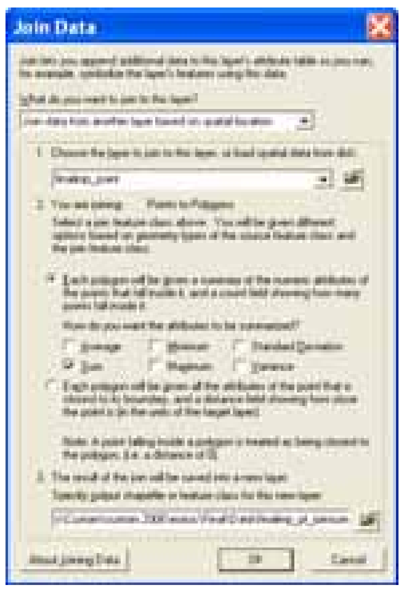
Ultimately the last step of the process involved manual identification, delineation, and separation of spectrally confused features. Manual delineation serves as a simple and effective means of separating out mislabeled features (Sohl et al. 2004), and was used to "clean up" the initial feature extraction product (Figure 10).

Figure 10
Final Impervious Feature Class

Storm Drainage Fee Calculation

Before it could be determined whether manual identification of impervious features was a viable method, the area of pervious and impervious features per parcel had to be determined. First, centroids of all of the impervious feature polygons were identified. Then, a spatial join was performed (Figure 11) by joining the final impervious point layer with the parcel polygons. A summary in the output file of all numeric attributes of the points was also calculated, since many parcels had more than one point.

Figure 11
Spatial Join



The next step involved the creation of an impervious area field, which was created by dividing the impervious feature area by the parcel area. The storm drainage fee was calculated by multiplying the RWF (Runoff Weighting Factor) (see Table 2) by the PA (Parcel Area) by the UFC (Unit Financial Charge), which for 2006 was 0.000413.

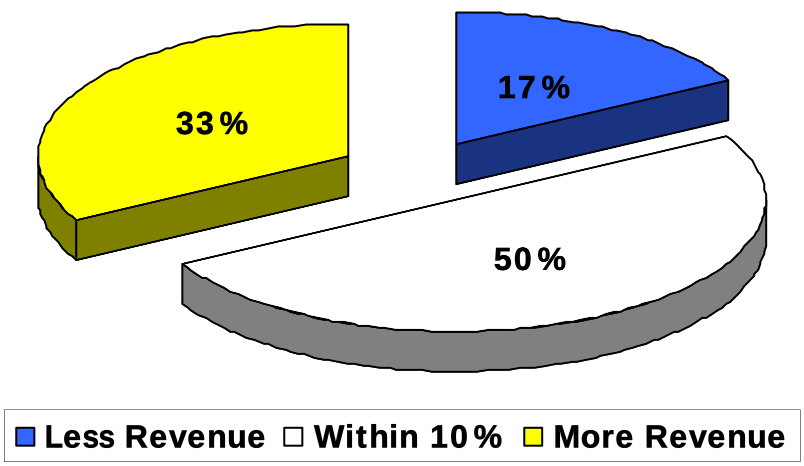
A field was then created that calculated the percentage change from the actual fee that was charged in 2006 and the fee that could be charged using actual impervious area. The formula was as follows:

((impervious area derived sdf - actual sdf assessed) /
(actual sdf assessed) * 100

Assessment

The initial results were somewhat startling (Figure 12). Of the 358 parcels in the study area, 50 percent were within an acceptable 10 percent of the programmatically derived storm drainage fee. But, 17 percent of the parcels had a percentage change of greater than -10 percent. With the method described here, the City of Sioux Falls would receive less revenue from those parcels. 33 percent of the parcels had a percentage change of greater than 10 percent, so with those parcels, the City of Sioux Falls would receive more revenue.

Figure 12
Storm Drainage Fee Percentage Change



The frequency distribution of each method was similar, and the sum of the Storm Drainage Fee of each method was not significant, with a difference of only 0.0014 percent (Figures 13a and 13b).

Figure 13a
Impervious Area Derived SDF Statistics

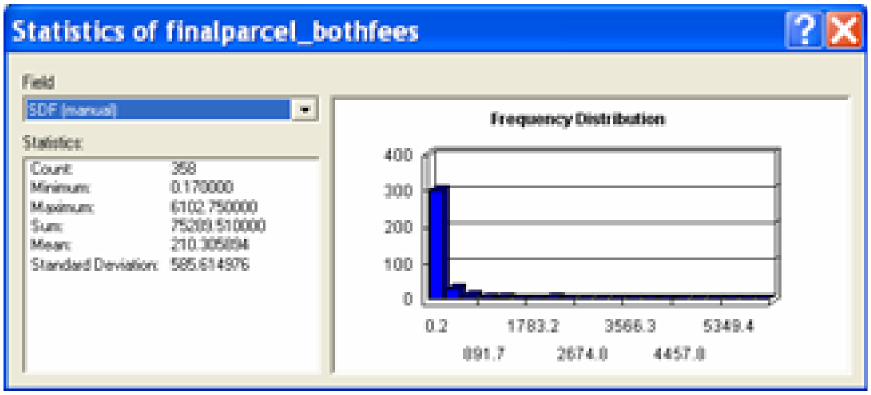
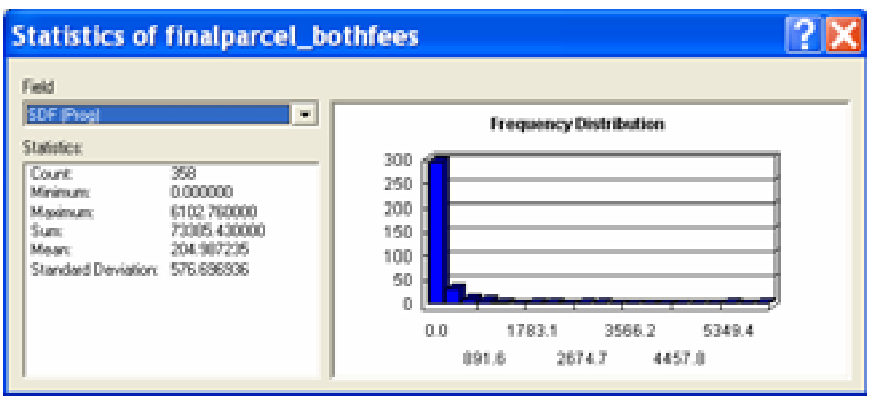


Figure 13b
Programmatically Derived SDF Statistics



Even though the final numbers did not necessarily prove that, as a whole, manually determining the Storm Drainage Fee is a cost effective exercise, by spatially computing this figure, some anomalies in our accounting system were discovered.

For example, the parcel containing The Home Depot (Figure 14) had a percentage change of almost 2000 percent; a curious finding given that the Home Depot has been on that site for a few years. The land use activity code in the accounting system was checked and it was miscoded as Vacant Land (with a Runoff Weighting Factor of 1.0) instead of Neighborhood Commercial Hardware (with a Runoff Weighting Factor of 18.75). For 2006, they were assessed a Storm Drainage Fee of $174.98, when they should have been assessed an amount closer to ~$3500.00.

Figure 14
The Home Depot

Another example on a smaller scale was a residence (Figure 15a). The parcel, outlined in blue (Figure 15b), is much larger than other residential parcels in the neighborhood, and the majority of the parcel is pervious. In 2006, they were billed $68.69, but if they contested that fee and used the method presented here, they would instead be assessed $37.48, a 45 percent reduction.

Figure 15a
Residence

Figure 15b
Residence - Aerial View

There are some commercial properties that can be expected to be at or near 100 percent imperviousness (Figure 16). However, there are some commercial properties that have much more pervious area surrounding their buildings and, for the immediate term, would benefit from the impervious area derived storm drainage fee, like Sturdevant Auto Parts (Figure 17a). The side and back views (Figures 17b and 17c) provide a visual image that the parcel is only 60 percent impervious, and by requesting a manually derived storm drainage fee, they would save 20 percent.

Figure 16
Wal-Mart Supercenter

Figure 17a
Sturdevant Auto Parts

Figure 17b
Sturdevant Auto Parts – Side View

Figure 17c
Sturdevant Auto Parts – Back View

Conclusion

Initial results demonstrate that by merging the spectrally significant IKONOS image with the higher resolution aerial photography creates an outstanding image to utilize for visual and programmatic feature extraction. However, even by adding the additional revenue for individual properties such as The Home Depot, thereby increasing the actual amount of Storm Drainage Fees assessed for 2006, the difference between the two figures are statistically insignificant.

Even with feature extraction tools, the manual editing of single-family parcels was necessary and time consuming. Further, new structures on single-family parcels (garages, sheds) would not add enough impervious area to the parcel to justify the expense of tracking each site (Brown 2002).

Since the feature extraction process is intensive, future research may include the use of flat rates for certain rate classes, thereby reducing the need to extract data from those parcels (e.g., small size parcels such as residential single-family) where it is more difficult to extract features. Since single-family parcels make up the majority of the community, this may simplify the storm drainage fee calculation considerably (Hoag 2004).

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