
A COMPARISON OF IMPERVIOUSNESS DERIVED FROM A DETAILED LAND COVER DATASET (DLCD) VERSUS THE NATIONAL LAND COVER DATASET (NLCD) AT TWO TIME PERIODS

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ABSTRACT

To address accuracy concerns of the National Land Cover Dataset (NLCD), this case study compares impervious surface from the NLCD to a Detailed Land Cover Dataset (DLCD) for the Town of Blacksburg, Virginia over two time periods (2005/2006 and 2011) at spatial aggregation scales (fine to coarse) and scopes (site-specific to area-extent). When comparing the total impervious surface area, the NLCD overestimated the DLCD by appreciable amounts (12-27%) for the entire town and across all specified land use zones for both time periods examined. A binary pixel-wise accuracy assessment of impervious surface revealed that the NLCD performed well for all scopes except for the single family land use zone (user accuracy <40%). The spatial aggregation of pixels to 90-m led to improved agreement between the two datasets. Using the DLCD as a reference, an empirical normalization equation was successfully applied to the NLCD to further reduce overestimation and data skewness.

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GENERAL AUDIENCE ABSTRACT

To address accuracy concerns of the National Land Cover Dataset (NLCD), this case study compares impervious surface conditions from the NLCD to a Detailed Land Cover Dataset (DLCD) for the Town of Blacksburg, Virginia over two time periods (2005/06 and 2011) at various spatial scales and scopes. When comparing the total impervious surface area, the NLCD overestimated the DLCD by appreciable amounts for the entire town and across all specified land use zones for both time periods examined. A comparison at the pixel level revealed the NLCD performed well for all scopes except for the single family residential land use zone. Although there was improved agreement between the datasets at coarser resolutions, data skewness was still apparent. By using the DLCD as a ground truth reference, a mathematical correction equation was applied to the NLCD to better align it with the DLCD. Reflected through this assessment, inaccuracies within the NLCD need to be further studied to assist local and regional governments to more correctly depict land cover conditions for applications such as land use planning and stormwater management.

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1 INTRODUCTION

1.1 BACKGROUND

Imperviousness is an important indicator of urbanization trends, and can be evaluated through the use of land cover data which is typically generated from remotely sensed imagery at a variety of spatial scales and scopes. Land cover data is used for a wide range of applications, such as monitoring hydrology (Shuster et al. 2005), ecological trends (Arnold et al. 1996), population distribution (Wu and Murray 2007), pollutant contamination (Shields et al. 2008), and local climate change (Yuan and Bauer 2007). In the US, the Multi-Resolution Land Characteristics (MRLC) Consortium (<http://www.mrlc.gov/>) generates a National Land Cover Dataset (NLCD) at 30-m spatial resolution using Landsat satellite imagery. Currently, national-scale land cover data exists for 1992, 2001, 2006, and most recently 2011. This dataset includes three layers: percent impervious surface, thematic land cover, and percent tree canopy. For this study, the percent impervious surface is utilized and is presented as pixels rather than polygons. Detailed land cover datasets are also developed by some local governments, universities, and research institutions from the digitization of high spatial resolution aerial imagery; this data is beneficial for local applications such as land use planning, watershed management, stormwater infrastructure design, and water quality regulations (Civco and Hurd 1997).

1.2 PROBLEM STATEMENT

The accuracies of the NLCD impervious surface maps are location dependent and frequently do not correctly portray the heterogeneity of local geographic surface conditions, especially in urban environments (Homer et al. 2004). When developing the training data for image classification, the MRLC approach could easily under- or over- estimate land cover classification if the reference data points used were not representative of the area in question (Mannel et al.

2006). To validate accuracy concerns of the NLCD, locally developed, high spatial resolution impervious surface maps are needed. Due to cost issues, this high resolution data is not typically developed and such accuracy assessments have not been routinely conducted (Wickham et al. 2013). Additionally, there may be a temporal discrepancy between NLCD and locally developed, high-resolution land cover data. Although NLCD is now released every five years, locally developed land cover data may not have a standard schedule for updating, or may utilize older data that would not reflect the current land cover distribution.

The NLCD and high resolution impervious surface maps for approximately the same year need to be compared at multiple aggregation scales (fine to coarse) and scopes (site-specific to area-extent). Pending the availability of data, a time series comparison should be conducted to illustrate the changing ground surface conditions. At coarser or spatially aggregated scales, the total amount of impervious cover could be compared for a specific watershed or user-defined administrative boundary (e.g., county, town). The total impervious surface within a given watershed is an important indicator for watershed planning and management (Arnold et al. 1996). If the total amount of impervious cover from the NLCD aligns well with the locally developed high resolution impervious map, local government officials may simply use NLCD-based impervious surface datasets to guide some of their management tasks. In cases where larger disparities exist, caution should be exercised in the use of NLCD impervious surface maps for local applications.

At a site-specific or pixel level, the difference between NLCD and locally developed impervious surface maps could be assessed through a cross-validation procedure, which would include an error matrix, overall accuracy, and kappa statistics (Congalton 1991). Specifically, at 30-m spatial resolution, initial NLCD percent impervious surface and locally developed maps may

be converted to a 2-class (i.e., impervious or non-impervious pixel) land cover map using a threshold value of 50% proportional cover. An error matrix, overall accuracy, and class-specific accuracy can then be used to summarize the agreement and disagreement between the two binary maps. Alternatively, proportional impervious surface from two data sources can be directly compared at any user-defined spatial scale (e.g., 30-m, 90-m). Accuracy statistics such as R^2 and root-mean-square error (RMSE) are then reported for comparison of such continuous measures (Wu and Murray 2003; Shao et al. 2011). A review of recent remote sensing literature indicates that few researchers have thoroughly evaluated the accuracy of NLCD percent impervious surface maps using high resolution impervious surface maps as reference. Assuming that the locally developed high resolution impervious surface map has higher accuracy, there is also a need for developing a method to correct the NLCD impervious surface map and potentially improve its usability for local applications.

Independent of the above comparison method and statistical measures, impervious surface map users may also be interested in how these map products differ across different land use zones. Among specified land uses (e.g., single family subdivisions, multi-family complexes, and non-residential properties), the amount and spatial distribution of impervious surface differ substantially. Consequently, the accuracy of the NLCD impervious surface map may vary accordingly. Therefore, understanding the effects of the discrepancy between land cover data and the relationships derived from land cover and land use are important to help land use planners and stormwater researchers make full use of NLCD products in their local and regional applications.

1.3 GOAL & OBJECTIVES

This comprehensive study is to provide a comparative analysis of impervious cover for two time periods (2005/2006 and 2011) of a locally developed, Detailed Land Cover Dataset (DLCD) versus the National Land Cover Dataset (NLCD) for the Town of Blacksburg, located in southwest Virginia. It is a primary goal of this project to perform a case study accuracy assessment of the NLCD in an effort to assist local and regional governments to more accurately depict land cover conditions for applications such as land use planning, watershed management, stormwater infrastructure design, and water quality regulations. The following list outlines the major objectives set forth for this project:

1. Expand upon prior research to perform a comparison of DLCD and NLCD impervious surface maps over two time periods at multiple spatial aggregation scales for the entire town and across various land use zones: single family subdivisions, multi-family complexes, and non-residential properties.
2. Evaluate the NLCD and DLCD time series data to track chronological changes of impervious surface conditions for the entire town and for each specified land use zone.
3. Determine an empirical normalization method to correct the inaccuracies of the NLCD impervious surface map using the DLCD impervious surface map as a reference. Improve the discrepancies with respect to land use zones. Identify a correction factor range that will create a best-fit scenario for correcting NLCD values to verified ground truth datasets and be applicable to a similar geographical area.

2 LITERATURE REVIEW

There is very little published information assessing the accuracy of NLCD impervious surface maps compared to locally developed, detailed land cover datasets. At such a high resolution, the NLCD impervious surface maps have also not been thoroughly compared at a variety of spatial scales and scopes. Most literature on NLCD impervious surface map accuracy discuss the biased (un-representative) methods of data procurement and the comparison against reference data sources at resolutions of 1-2 meters. A review of the NLCD and DLCD accuracies is summarized below, along with land statistics and projections for the Town of Blacksburg.

2.1 NLCD ACCURACY

There are typically two categories of change detection measurements, pixel-based similar to the NLCD or feature-based as the DLCD was digitized. Pixel-based changes are detected by selecting a threshold of the classes from training data on a pixel-to-pixel basis. This approach suffers from (1) unavoidable misclassification errors caused by dependence on spectral dimensionality, (2) the mixture of classes represented within pixels, and (3) being unable to differentiate between changes in imaging condition (i.e., surface moisture and shadowing) (Wang et al. 2005). The accuracies of the NLCD impervious surface maps are location dependent and frequently do not correctly portray the heterogeneity of local geographic surface conditions, especially in urban environments (Homer et al. 2004). Other important factors that influence NLCD accuracy are: the selection of spectral bands, the radiometric sensitivity of the data, the spatial resolving powers of the sensors, and the subsequent processing of the data. (Townshend et al. 1992).

The MRLC reported accuracy statistics mainly rely on cross-validated estimates of the NLCD versus high resolution imagery (e.g., 1 to 2-m resolution) from sources such as the National

Agricultural Imagery Program (NAIP). Specifically, the training data for image classification are randomly divided into two sets. One set is used for the training of image classification (approximately 1500 pixels per NLCD mapping zone), and the remaining set is held out to evaluate the classification performance. Another issue that has been reported is the lack of NAIP; this caused nearly 10% of the sample pixels in 2001 and 3% in 2006 to not have reference data. The overall accuracies of 2001 and 2006 NLCD impervious surface maps were 79% and 78%, respectively. Most error occurred in the pixels classified as herbaceous vegetation and open space, accounting for approximately 26% of the reported classification error (Wickham et al. 2013).

As a result of known errors, NLCD map products are useful for regional or national projects and are not recommended for projects less than 10 mi² (Vogelmann et al. 2001). When developing the training data for image classification, the MRLC approach could easily under- or over- estimate land cover classification if the reference data points used were not representative of the area in question (Mannel et al. 2006). Because impervious surfaces often cover small parcels of land and their total spatial extent is relatively small, the data registration accuracy requirement is significantly high. Any increase in data mis-registration will cause greater overestimates of positive and negative changes in land cover impervious surface (Townshend et al. 1992).

2.2 DLCD ACCURACY

The other category of change detection measurements, feature-based, extracts features from imagery by visual interpretation and manual digitization of features or, by direct ground-based observations and correction of derived features on a vector basis (Wang et al. 2005). The Town of Blacksburg DLCD was based on data releases (2005, 2009, 2011, and 2013) of high spatial resolution aerial imagery (orthophotography) from the Virginia Base Mapping Program (VBMP) via the Virginia Geographic Information Network (VGIN). This detailed land cover dataset was

created in conjunction with the Blacksburg Stormwater Project for purposes of stormwater modeling and other research uses. To create this dataset, land cover boundaries were delineated in ArcGIS. Within the delineated boundaries, a point was inserted and coded based on the land cover type. The delineated boundaries and points were converted to land cover polygons using the “Features to Polygon” tool in ArcGIS. The resulting GIS shapefile consisted of delineated polygons which were classified as a type of impervious or non-impervious land cover class. Careful digitizing and quality control led to a reliable digitized dataset describing each rooftop, driveway, sidewalk, stand of trees at a fine spatial detail (e.g., 1-ft resolution).

2.3 LAND STATISTICS & PROJECTIONS FOR THE TOWN OF BLACKSBURG

The Town of Blacksburg, approximately 51.5 km² (19.89 mi²), is located within Montgomery County in southwestern Virginia. The downtown district, as well as the campus of Virginia Tech, are located in the center of the Town and have served as the centroid of growth and development. Over the past decade, a shift has been taking place to expand upon the urban downtown environment and develop in the more rural areas of Town. Due to the presence of a large university, Blacksburg is already more urbanized compared to its surrounding communities. The land use composition is mostly divided among residential, commercial/office/industrial, public assembly, institutional/community, and agricultural. The 2010 census population of Blacksburg was 42,620 with an additional student population of approximately 28,000.

From 2000 to 2010, the population in Town grew from 39,573 to 42,620. Due to a mandate in the Code of Virginia, high growth localities must designate ‘Urban Development Areas’ (UDA) in their comprehensive plan, which are areas of reasonably compact development that can accommodate 10 to 20 years of projected growth. Population projections reveal that the Town will grow in size to 45,148 by 2020 and to 48,162 by 2030. Based on these numbers, the total acreage

of UDA designated to handle the anticipated growth and development needs of the Town are 156 to 342 acres by years 2020 and 2030, respectively. As outlined in Figure 2-1, the Town of Blacksburg's UDA includes the existing mixed use areas and the hospital corridor area because of its proximity to the proposed Montgomery County UDA to be designated on US 460 Business between the Towns of Blacksburg and Christiansburg (Town of Blacksburg 2012).

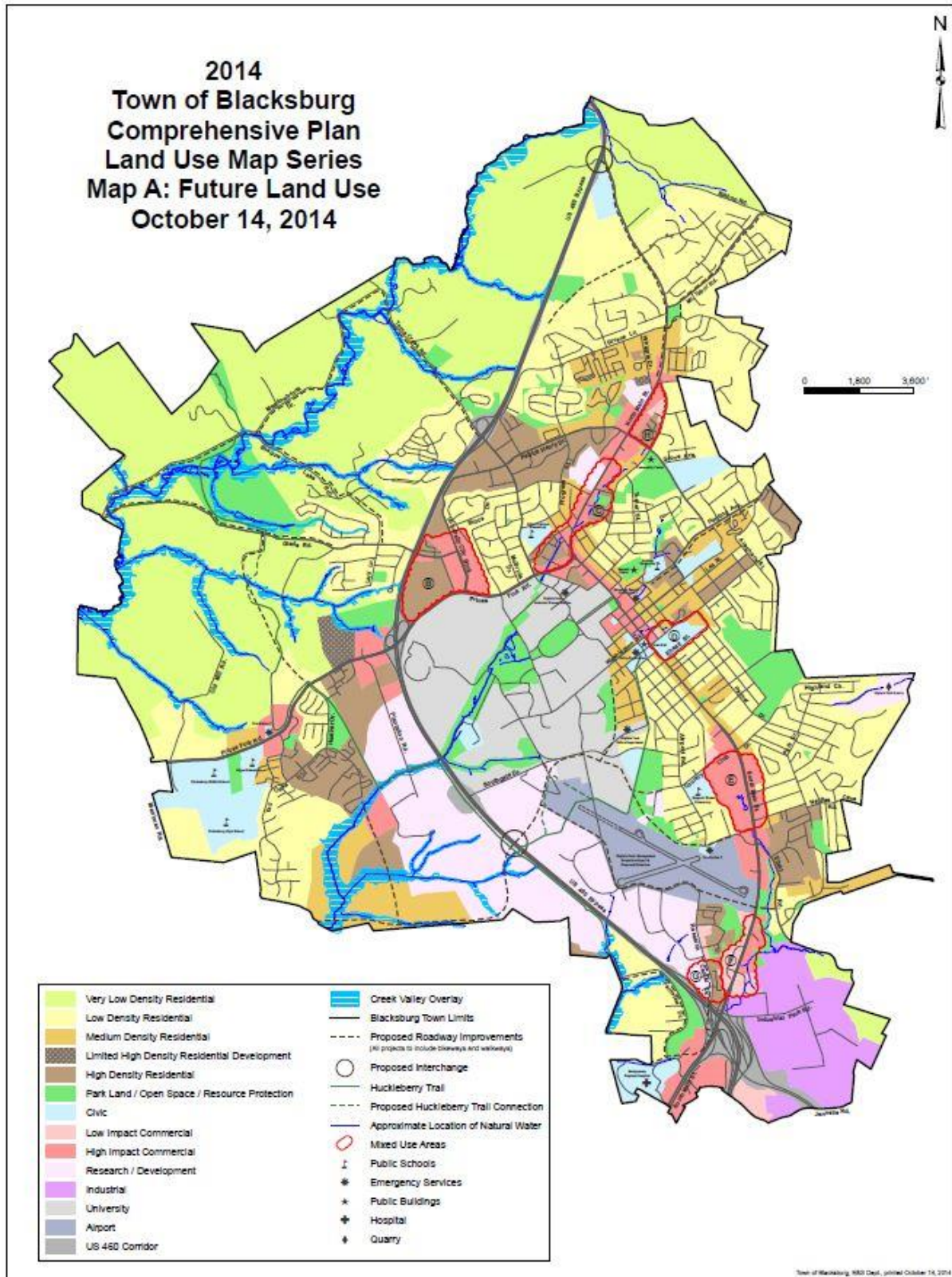


Figure 2-1: Town of Blacksburg Comprehensive Plan Future Land Use Map (Town of Blacksburg 2014)

3 IMPERVIOUS COMPARISON OF NLCD VERSUS A DETAILED DATASET OVER TIME

3.1 INTRODUCTION

Imperviousness is an important indicator of urbanization trends, and can be evaluated through the use of land cover data which is typically generated from remotely sensed imagery at a variety of spatial scales and scope. Land cover data is used for a wide range of applications, such as monitoring hydrology (Shuster et al. 2005), ecological trends (Arnold et al. 1996), population distribution (Wu and Murray 2007), pollutant contamination (Shields et al. 2008), and local climate change (Yuan and Bauer 2007). In the US, the Multi-Resolution Land Characteristics (MRLC) Consortium (<http://www.mrlc.gov/>) generates a National Land Cover Dataset (NLCD) at 30-m spatial resolution using Landsat satellite imagery. Currently, national-scale land cover data exists for 1992, 2001, 2006, and most recently 2011. This dataset includes three layers: percent impervious surface, thematic land cover, and percent tree canopy. For this study, the percent impervious surface is utilized and is presented as pixels rather than polygons. Detailed land cover datasets are also developed by some local governments, universities, and research institutions from the digitization of high spatial resolution aerial imagery; this data is beneficial for local applications such as land use planning, watershed management, stormwater infrastructure design, and water quality regulations (Civco and Hurd 1997).

The accuracies of the NLCD impervious surface maps are location dependent and frequently do not correctly portray the heterogeneity of local geographic surface conditions, especially in urban environments (Homer et al. 2004). Other important factors that influence NLCD accuracy are: the selection of spectral bands, the radiometric sensitivity of the data, the spatial resolving powers of the sensors, and the subsequent processing of the data. (Townshend et al. 1992). The MRLC reported accuracy statistics mainly rely on cross-validated estimates of the NLCD versus

high resolution imagery (e.g., 1 to 2-m resolution) from sources such as the National Agricultural Imagery Program (NAIP). Specifically, the training data for image classification are randomly divided into two sets. One set is used for the training of image classification (approximately 1500 pixels per NLCD mapping zone), and the remaining set is held out to evaluate the classification performance. The overall accuracies of 2001 and 2006 NLCD impervious surface maps were 79% and 78%, respectively. Most error occurred in the pixels classified as herbaceous vegetation and open space (Wickham et al. 2013). As a result of known errors, NLCD map products are useful for regional or national projects and are not recommended for projects less than 10 mi² (Vogelmann et al. 2001). When developing the training data for image classification, the MRLC approach could easily under- or over- estimate land cover classification if the reference data points used were not representative of the area in question (Mannel et al. 2006). Because impervious surfaces often cover small parcels of land and their total spatial extent is relatively small, the data registration accuracy requirement is significantly high. Increases in data mis-registration will cause more classification error and greater overestimates of positive and negative changes in land cover impervious surface (Townshend et al, 1992).

To validate accuracy concerns of the NLCD, locally developed high spatial resolution impervious surface maps are needed. Due to cost issues, this high resolution data is not typically developed and such accuracy assessments have not been routinely conducted (Wickham et al. 2013). Additionally, there may be a temporal discrepancy between NLCD and locally developed, high-resolution land cover data. Although NLCD is now released every five years, locally developed land cover data may not have a standard schedule for updating, or may utilize older data that would not reflect the current land cover distribution.

The NLCD and high resolution impervious surface maps for approximately the same year need to be compared at multiple aggregation scales (fine to coarse) and scopes (site-specific to area-extent). Pending the availability of data, a time series comparison should be conducted to illustrate the changing ground surface conditions. At coarser or spatially aggregated scales, the total amount of impervious cover could be compared for a specific watershed or user-defined administrative boundary (e.g., county, town). The total impervious surface within a given watershed is an important indicator for watershed planning and management (Arnold et al. 1996). If the total amount of impervious cover from the NLCD aligns well with the locally developed, high resolution impervious map, local government officials may simply use NLCD-based impervious surface datasets to guide some of their management tasks. In cases where larger disparities exist, caution should be exercised in the use of NLCD impervious surface maps for local applications.

At a site-specific or pixel level, the difference between NLCD and locally developed impervious surface maps could be assessed through a cross-validation procedure, which would include an error matrix, overall accuracy, and kappa statistics (Congalton 1991). Specifically, at 30-m spatial resolution, initial NLCD percent impervious surface and locally developed maps may be converted to a 2-class (i.e., impervious or non-impervious pixel) land cover map using a threshold value of 50% proportional cover. An error matrix, overall accuracy, and class-specific accuracy can then be used to summarize the agreement and disagreement between the two binary maps. Alternatively, proportional impervious surface from two data sources can be directly compared at any user-defined spatial scale (e.g., 30-m, 90-m). Accuracy statistics such as R^2 and root-mean-square error (RMSE) are then reported for comparison of such continuous measures (Wu and Murray 2003; Shao et al. 2011). A review of recent remote sensing literature indicates

that few researchers have thoroughly evaluated the accuracy of NLCD percent impervious surface maps using high resolution impervious surface maps as reference. Assuming that the locally developed, high resolution impervious surface map has higher accuracy, there is also a need for developing a method to correct the NLCD impervious surface map and potentially improve its usability for local applications.

Independent of the above comparison method and statistical measures, impervious surface map users may also be interested in how these map products differ across various land use zones. Among specified land uses (e.g., single family subdivisions, multi-family complexes, and non-residential properties), the amount and spatial distribution of impervious surface differ substantially. Consequently, the accuracy of the NLCD impervious surface map may vary accordingly. Few published studies have researched the accuracy and spatial distribution of NLCD and locally digitized impervious surface maps compared to land use categories. Therefore, understanding the effects of the discrepancy between land cover data and the relationships derived from land cover and land use are important to help land use planners and stormwater researchers make full use of NLCD products in their local and regional applications.

The overall purpose of this study was to thoroughly compare impervious surface area derived from a Detailed Land Cover Dataset (DLCD) and National Land Cover Dataset (NLCD) over two separate time periods (2005/2006 and 2011), and explore the relationship between land cover conditions and land use zones. The comparative analyses were performed at multiple spatial aggregation scales from site-specific to area extent and across different land use zones. An empirical normalization method was developed with the intent to correct NLCD impervious surface maps to better correlate with DLCD, reduce discrepancies with respect to different land use zones, and potentially apply to similar geographical areas.

3.2 STUDY AREA

The Town of Blacksburg, approximately 51.5 km² (19.89 mi²), is located within Montgomery County in southwestern Virginia. The downtown district, as well as the campus of Virginia Tech, are located in the center of the Town and have served as the centroid of growth and development. Over the past decade, a shift has been taking place to expand upon the urban downtown environment and develop in the more rural areas of Town. Due to the presence of a large university, Blacksburg is already more urbanized compared to its surrounding communities. The land use composition is mostly divided among residential, commercial/office/industrial, public assembly, institutional/community, and agricultural. The 2010 census population of Blacksburg was 42,620 with an additional student population of approximately 28,000.

3.3 METHODS

3.3.1 Data Development

The datasets used in this study were a 2005 and 2011 Detailed Land Cover Dataset (DLCD) and the 2006 and 2011 National Land Cover Dataset (NLCD). The digitization of the DLCD for the Town of Blacksburg was based on data releases (2005, 2009, 2011, and 2013) of high spatial resolution aerial imagery (orthophotography) from the Virginia Base Mapping Program (VBMP) via the Virginia Geographic Information Network (VGIN). The DLCD specifies 11 land cover classes illustrated in Table 3-1, which are divided into two categories: impervious cover and non-impervious cover. The resulting GIS shapefile consists of delineated polygons which were classified as a type of impervious or non-impervious land cover matching the general descriptions for each class. Careful digitizing and quality control led to a reliable digitized dataset describing each rooftop, driveway, sidewalk, stand of trees at a fine spatial detail (e.g., 1-ft resolution).

Table 3-1: Detailed Land Cover Dataset (DLCD) Categories

<u>Impervious Cover</u>	<u>Non-Impervious Cover</u>
Sidewalk	Open Space (Lawn)
Road/Parking	Light Forest/Tree Canopy
Buildings	Dense Forest
Other Asphalt/Concrete Areas	Brush/Bush
Gravel	Light Brush/Bare Soil/Mulch
	Bare Soil

The 2006 and 2011 NLCD percent impervious surface maps were acquired from the Multi-Resolution Land Characteristics Consortium (<http://www.mrlc.gov/>). The land cover product operates on a five year cycle; NLCD 2006 was released in 2011 as an update of NLCD 2001 (Xian and Homer 2010) and corrected some issues present with the previous land cover data. The fractional impervious surface maps were generated as 30-m pixels using classification and regression tree analysis techniques (Homer et al. 2004).

Other useful sources of data include: Town of Blacksburg corporate boundary; Town of Blacksburg Zoning and Comprehensive Plan for information about zoning and future growth outlook; and Town of Blacksburg Comprehensive land use shapefile and Montgomery County parcel shapefile to divide data into their respective land use zones.

3.3.2 Comparison of Total Impervious Surface Area

The first analyses compared the DLCD and NLCD impervious surface area across the entire town for 2005/2006 and then for 2011. Figure 3-1 shows a sample area of the Town to illustrate the distribution of impervious surface conditions for the 2011 DLCD and NLCD. Within the DLCD, five specific digitized land cover classes (sidewalk, road/parking, buildings, gravel, and other asphalt/concrete areas) were re-grouped as a single impervious surface class. Total impervious surface area was then calculated and compared to the summarized value for NLCD percent impervious data.

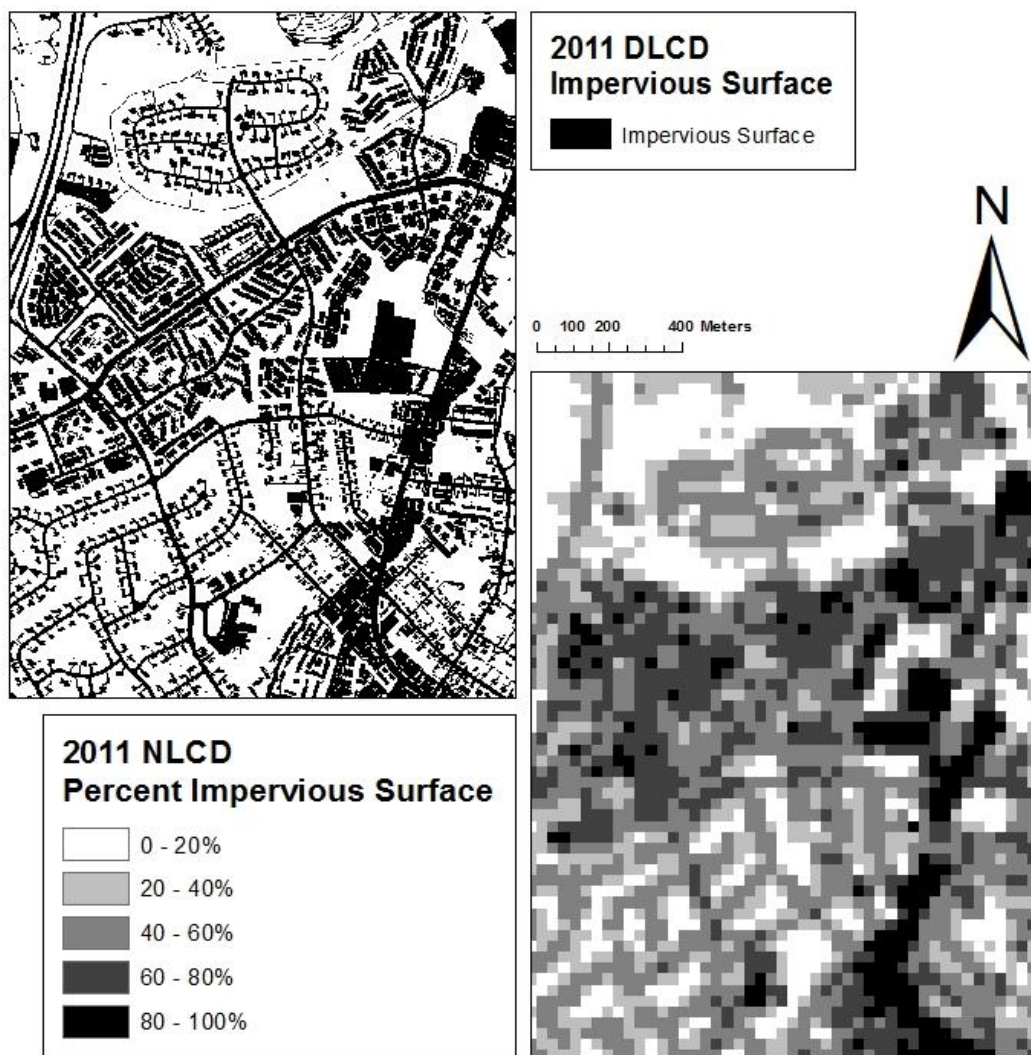


Figure 3-1: Sample Area of the Town of Blacksburg 2011 Detailed Land Cover Dataset (Left) and 2011 National Land Cover Dataset (Right)

To further understand the impervious surface area distribution and differences between the NLCD and DLCD, the total impervious surface area was calculated and compared for three land use zones: single family area, multi-family area, and non-residential area (Figure 3-2). For data comparison purposes, the 2005/2006 analyses featured land use zones classified through 2005; whereas, the 2011 analyses included land use zones classified through 2011. The single family residential land use area includes 70 single family subdivisions ranging in median development year from 1913 to 2011. The multi-family area includes 117 multi-family complexes ranging in median development year from 1930 to 2011. This multi-family area consists of apartments, condominiums, duplexes, and townhomes. The non-residential area includes 512 non-residential properties ranging in development year from 1800 to 2011. Within non-residential areas, specific land uses include commercial, office, industrial, public assembly, and institutional. Additionally, a comparison was conducted between the two comparative years of data for DLCD and NLCD to determine the percentage of growth and development for the town and across the three land use zones.

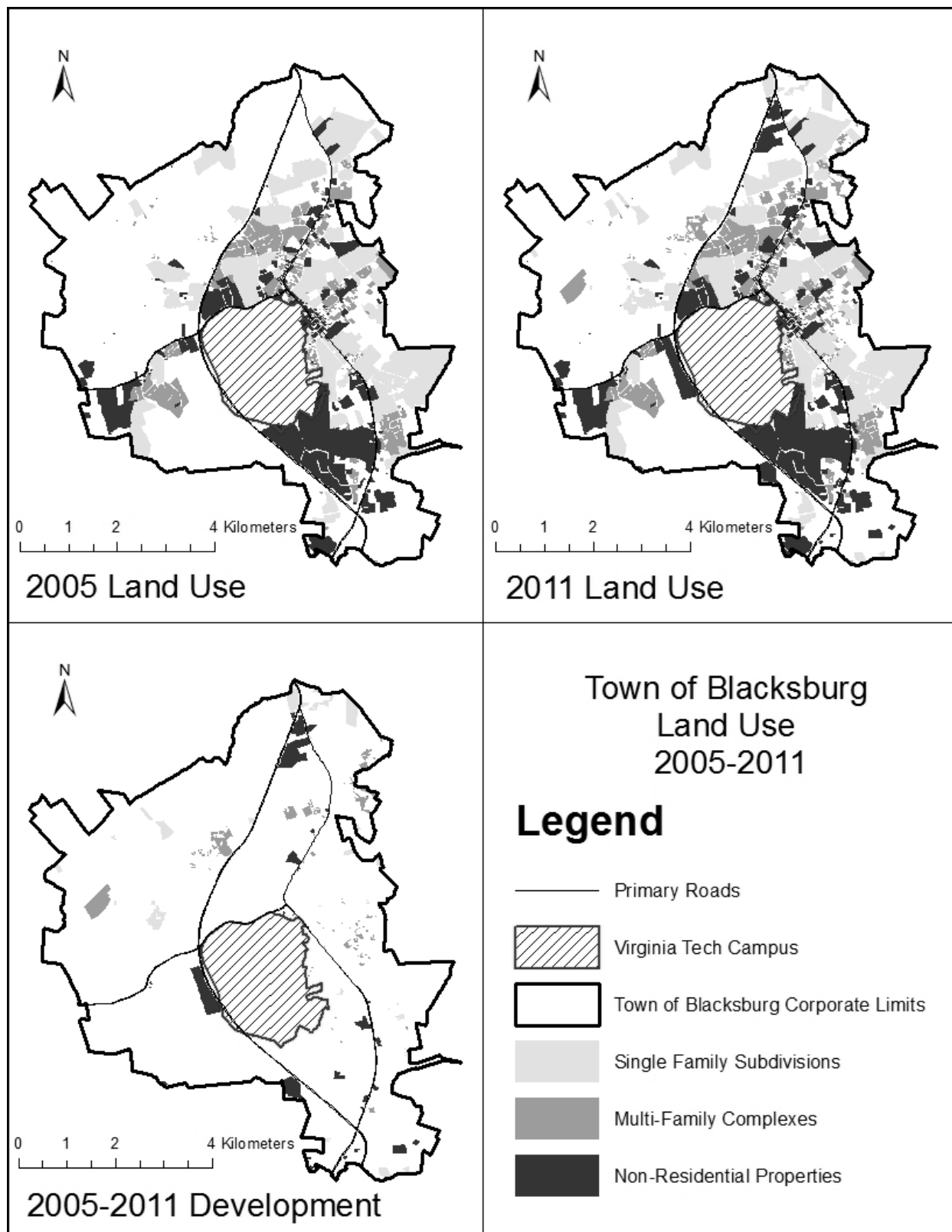


Figure 3-2: Distribution of Single Family Subdivisions, Multi-Family Complexes, and Non-Residential Properties in the Town of Blacksburg, Virginia from 2005 to 2011

3.3.3 Pixel-Level Comparison for NLCD and DLCD

When comparing the impervious surface total area, there is a lack of spatial differentiation between impervious pixel locations. Two maps with the same amount of total impervious surface may have very different spatial distribution of impervious pixel locations (Foody 2002). A pixel-level comparison was conducted using the DLCD and NLCD as inputs for 2005/2006 and 2011. For DLCD, all the digitized impervious polygons were converted to raster format at 2-ft resolution first and then degraded to 30-m resolution to spatially correspond to the NLCD data, providing a “fractional map” for impervious cover. A threshold value of 50% was used to convert the fractional map to a binary map with impervious (code = 1) and non-impervious (code = 0) classes. Similarly, the 50% threshold value was used to convert the NLCD percent impervious surface map to a binary map with two classes. The impervious/non-impervious binary maps were then compared to generate an error matrix, overall accuracy, and class-specific accuracy. These error statistics were computed at a town wide scale and across the three land use categories zones. Because the DLCD is being used as a reference or the observed data values, the DLCD is termed as the producer, and the NLCD-predicted data is termed as the user.

3.3.4 Direct Comparison of Percent Impervious Surface Maps

The percent impervious surface measure within each 30-m NLCD pixel can also be directly compared with the DLCD-derived “fractional map”. The difference between DLCD and NLCD impervious surface maps for 2005/2006 and 2011 were quantified using R^2 and root-mean-square error (RMSE) statistics. RMSE is calculated using Equation 1,

$$RMSE = \sqrt{\frac{\sum_1^n (NLCD_i - DLCD_i)^2}{n}} \quad (1)$$

where $NLCD_i$ and $DLCD_i$ are percent impervious surface estimates for pixel location i from two datasets, respectively, and n is the total number of pixels selected for comparison.

Although the aerial imagery used for DLCD has been co-registered to the NLCD data, the registration error also introduces uncertainties in comparing two data sources. Song (2004; 2005) indicated that the direct comparison of percent land cover at a 30-m spatial scale may not be appropriate considering mis-registration between the two datasets. To reduce the impacts from spatial mis-registration, both the DLCD and NLCD impervious surface maps were further degraded to 90-m for impervious surface comparison. At both aggregation scales, the DLCD was considered as the reference or ground truth impervious surface, as it was directly interpreted from high-resolution aerial photos.

3.3.5 Correction of NLCD Percent Impervious Map using DLCD as Reference

Comparison of the DLCD and NLCD percent impervious surface maps reveals patterns of error distributions for NLCD data. For example, the NLCD map may systematically under- or over- estimate impervious surface area compared to the DLCD. It is also possible to see the skew of the NLCD data points compared to the DLCD: an underestimate of high values and an overestimate of small values. Therefore, a statistical model or a data normalization method is needed to correct the NLCD map to better match the DLCD map. For example, if the NLCD map appeared to underestimate high impervious percent values and overestimate low impervious percent values, the following min-max normalization equation (Equation 2) could be used to correct the initial NLCD percent impervious surface to ensure that data covers the entire range from 0 to 1 (Duda et al. 2012),

$$nlcd_corr = \frac{imp_i - imp_{min}}{imp_{max} - imp_{min}} \quad (2)$$

where imp_i is the initial percent impervious surface values for the NLCD pixels, and imp_{max} and imp_{min} are user-defined empirical minimum and maximum percent impervious values used for data normalization. It is not important to normalize NLCD data for areas where DLCD are

available. However, the normalization coefficients (imp_{max} and imp_{min}) could be applied to areas where DLCD are not available and the corrected NLCD percent map thus may be used as a surrogate for certain local and regional applications. This equation was utilized to determine a correction for the NLCD impervious surface map, using the DLCD as a reference for the 2005/2006 and 2011 datasets.

3.4 RESULTS & DISCUSSION

3.4.1 Comparison of Total Impervious Surface Area

Table 3-2 summarizes the DLCD and NLCD total impervious surface areas from 2005/2006 to 2011 for the entire town and across different land use zones. The impervious areas increased in all categories in both datasets during the 5 to 6 year period, some as much as 18%. As estimated by the DLCD, the town wide total impervious surface area increased 14.8%, such that 15.6% of the total land area in 2011 was impervious. Single family subdivisions increased the most (14.4%), followed by non-residential properties (12.7%) and multi-family complexes (11.3%).

Table 3-2: DLCD and NLCD Total Impervious Surface Areas from 2005/2006 to 2011 for the Town of Blacksburg and across Different Land Use Zones

	Town Wide	Single Family	Multi-Family	Non-Residential
DLCD 05 11 (km ²) (% Change)	7.00 8.03 (+14.8)	1.72 1.97 (+14.4)	1.29 1.43 (+11.3)	1.71 1.92 (+12.7)
NLCD 06 11 (km ²) (% Change)	7.94 9.24 (+16.4)	2.18 2.21 (+1.3)	1.54 1.73 (+12.2)	1.91 2.26 (+18.0)
DLCD vs NLCD % Difference 05-06 11	+13.4 +15.0	+26.6 +12.0	+19.6 +20.5	+12.1 +17.4

As estimated by the NCLD during the 5 year period, the town wide total impervious surface area increased 16.4%, such that 17.9% of the total land area in 2011 was impervious (2.3% higher than the DLCD estimate). Non-residential properties increased the most (18.0%), followed by multi-family complexes (12.2%) and single family subdivisions (1.3%).

The DLCD and the NLCD datasets for both comparative time periods show interesting results. In all cases for both years, the NLCD estimates were more than 12% higher, reaching 26.6% higher for the single family land use in the 2005-06 comparison. Town wide, the NLCD overestimated by 13.4% in 2006 and 15.0% in 2011. Likewise, multi-family and non-residential land uses had appreciable overestimates from the NLCD as compared to the DLCD.

Since DLCD was locally developed through reliable digitizing at a high positional accuracy, the total impervious surface estimates from DLCD were considered more accurate than the NLCD data. Both datasets show a significant increase in total impervious surface area during the study timeframe (2005-2011), which occurred before and during the recent economic recession. For all of the areas studied, the NLCD showed a larger percent increase in impervious surface conditions, except for the single family land use zone which was already being over-predicted in 2006. Since this was only a six year time span, the expansion of total impervious area was significant for the Town and validates the trends of development in less urbanized areas of the Town. For land use planners and stormwater researchers who try to use NLCD products in their local applications, total impervious surface areas derived from NLCD may need to be adjusted to a lower value.

3.4.2 Pixel-Level Comparison for NLCD and DLCD

Table 3-3 shows 2006 and 2011 NLCD accuracy statistics at a 30-m pixel scale. Each of the NLCD and DLCD pixels were labeled as impervious or non-impervious class based on a threshold value of 50% land cover proportion. The overlay of such NLCD- and DLCD-derived binary maps led to the development of a standard error matrix and corresponding accuracy statistics.

Table 3-3: Pixel-Level (Binary) Accuracy Assessment for 2006 and 2011 NLCD using 2005 and 2011 DLCD as Reference at 30-m Spatial Resolution

Pixel-Level Accuracy Assessment	User (NLCD-Derived) (% Correct)		Producer (DLCD) (% Correct)		Overall Accuracy (%)	
	2006	2011	2005	2011	2005/2006	2011
Town Wide						
Impervious	80.8	81.6	67.7	64.9	94.6	93.4
Non-Impervious	96.0	94.8	98.0	97.8		
Single Family						
Impervious	38.9	28.8	31.1	34.1	95.8	95.0
Non-Impervious	97.5	97.7	98.2	97.1		
Multi-Family						
Impervious	89.3	93.4	72.7	74.3	75.9	81.1
Non-Impervious	59.8	69.4	82.4	91.7		
Non-Residential						
Impervious	76.1	87.3	83.9	80.5	89.2	91.2
Non-Impervious	94.3	92.6	90.9	95.4		

For the town wide pixel-level comparison, the 2006 NLCD map had 94.6% overall accuracy using the DLCD map as reference or the ‘ground truth’. In other words, when the predicted values of impervious surface (NLCD) were related to the observed values of impervious surface (DLCD) for the same spatial area extent, the NLCD map was over 90% accurate. The user (NLCD-derived) and producer (DLCD) accuracy for non-impervious surface were 96.0% and 98.0%; whereas, the user accuracy for impervious surface was 80.8%. The 2011 NLCD map had 93.4% overall accuracy using the DLCD map as reference. Similarly, the user and producer accuracy for non-impervious surface were 94.8% and 97.8%, while the user accuracy for impervious surface was 81.6%. It should be noted that the high overall accuracy for this comparison is mainly attributed to the non-impervious class agreement at this aggregation of scale.

Within the three land use types, overall accuracy for the NLCD map ranged from 75.9% to 95.8%. The single family residential (SFR) land use had the worst class-specific accuracy for impervious surface. For the 2006 and 2011 NLCD maps, the user accuracies were 38.9% and

28.8%. At a 30-m scale, the DLCD and NLCD are not registering smaller areas of impervious surface, which is leading to an unrepresentative depiction of the overall accuracy for the SFR land use. Also, the majority of the NLCD-predicted impervious surface pixels were actual non-impervious surface pixels based on the DLCD. For the multi-family and non-residential land uses, the class-specific accuracies of the 2006 and 2011 NLCD-derived impervious maps increased to approximately 90% and 80%, respectively; both of which can be considered acceptable for local land cover and land use studies.

The lower class-specific user accuracy for SFR land use was expected, as individual houses and parking spaces in this land use are more spatially dispersed and often mixed with vegetation cover (include tree canopy and shade). Detection of impervious surface in the SFR zone thus would be more challenging compared to the multi-family and non-residential land use zones where impervious surfaces are in a more aggregated nature (Shao et al., 2015). Accuracy statistics for different land use zones suggested that the users should apply caution if they plan to use the NLCD percent impervious surface product for the SFR land use zone. On the other hand, the accuracies of NLCD for the multi-family and non-residential land use zones performed the best in this analysis and are considered more reasonable for use in local applications.

3.4.3 Direct Comparison of Percent Impervious Surface Maps

Figures 3-3 and 4 illustrate a direct comparison of town wide percent impervious surfaces of the NLCD and DLCD for 2005/2006 and 2011 time frames at 30-m and 90-m pixel resolution. For visual clarity, the following illustrations represent a 25% sampling of the 30-m NLCD pixels. The R^2 and RMSE values are summarized and shown in Table 3-4. Generally, both scales show an over-prediction of impervious surface by the NLCD, although the NLCD product slightly

underestimated the percent impervious surface for pixels with very high density values (i.e., >90%).

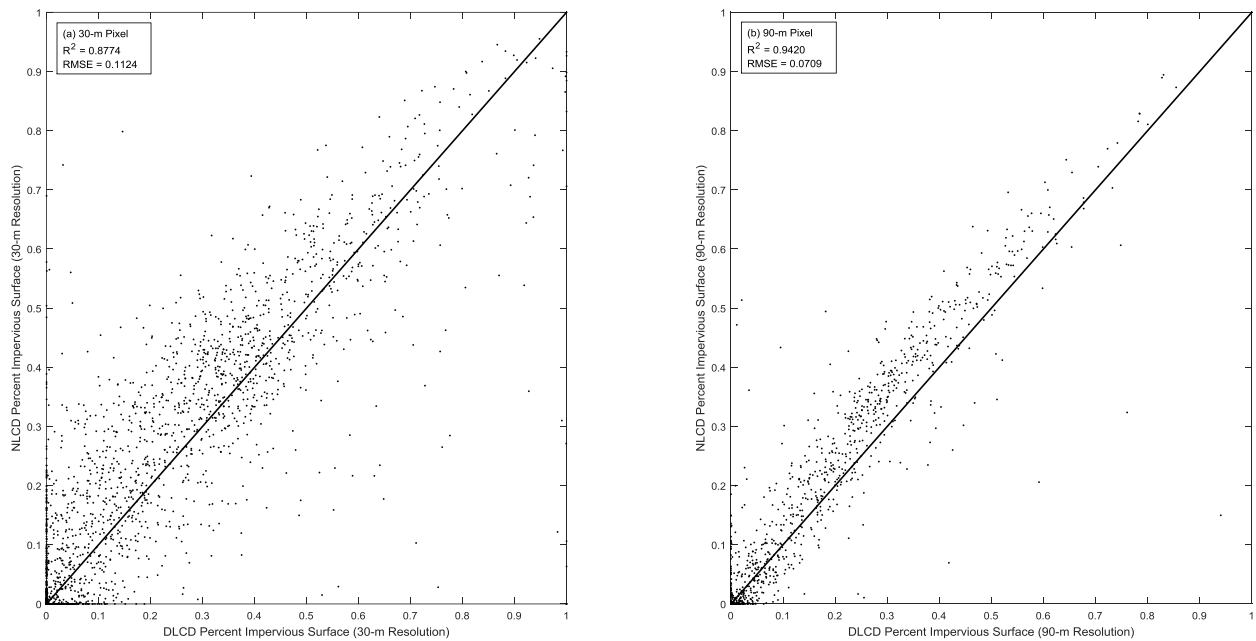


Figure 3-3: Town Wide Comparison of Percent Impervious Surface Area for 2005 DLCD and 2006 NLCD at 30-m and 90-m Spatial Resolution

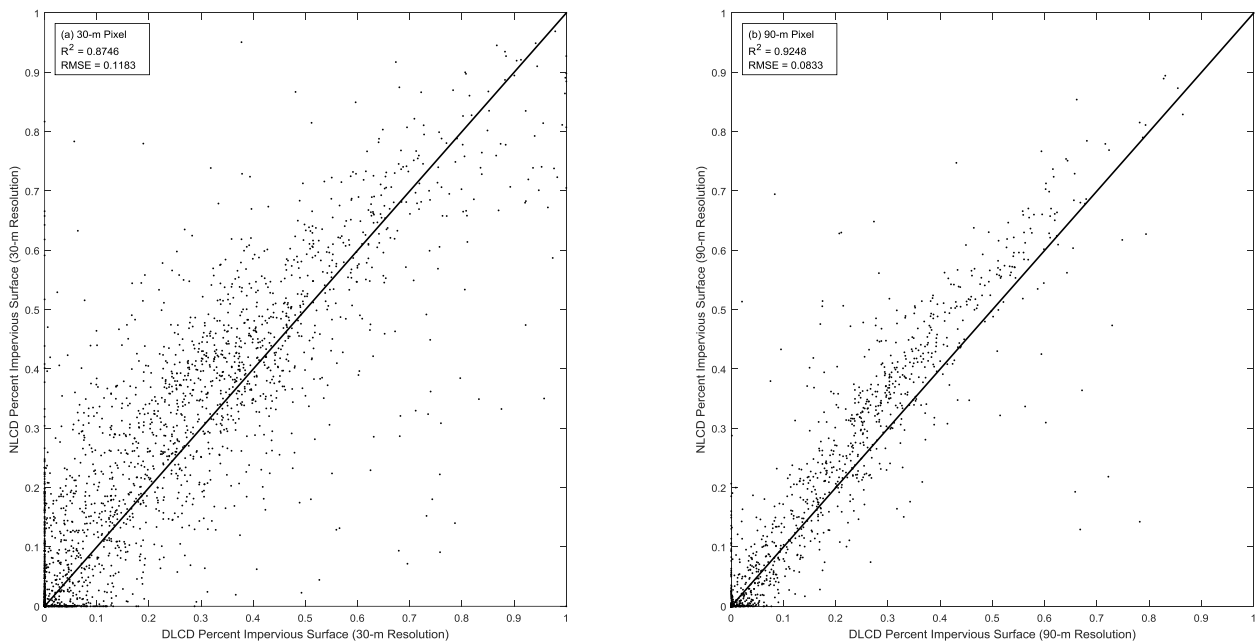


Figure 3-4: Town Wide Comparison of Percent Impervious Surface Area for 2011 DLCD and 2011 NLCD at 30-m and 90-m Spatial Resolution

At the 30-m pixel scale, large point scattering was observed. A pixel with 30% of impervious surface based on the DLCD may have as high as 80% of impervious surface based on NLCD estimation. An R^2 value of 0.877 and an RMSE value of 0.112 suggests some inconsistency between the 2005 DLCD and 2006 NLCD percent impervious surface estimates. Similar results were observed for the 2011 comparison.

At the 90-m spatial scale, point scattering was substantially reduced. R^2 increased to 0.942 and the RMSE value decreased to 0.071 for the 2005 DLCD and 2006 NLCD comparison. Similar results were observed for the 2011 comparison. Previous studies suggested that the improved accuracy statistics can be attributed to reduction of spatial mis-registration (Song 2005; Wu and Murray 2007). It also needs to be noted that prediction errors may be smoothed out by spatial aggregation. Nevertheless, the over-estimation of impervious surface still needs to be highlighted, especially for pixels with relatively low impervious surface densities (e.g., 0-40%).

Figure 3-5 compares the DLCD and NLCD percent impervious surfaces for 2005/2006 and 2011 at 30-m spatial scale for the three land use zones. The R^2 and RMSE values are also summarized and shown in Table 3-4 accordingly. The three land use zones had very different ranges of impervious surface density values. For the SFR zone, the majority of pixels had less than 60% impervious surface area. For most pixels in the multi-family zone, the percent impervious surface area ranged from 30% to 80%, while pixels were scattered across the entire spectrum for the non-residential land use zone.

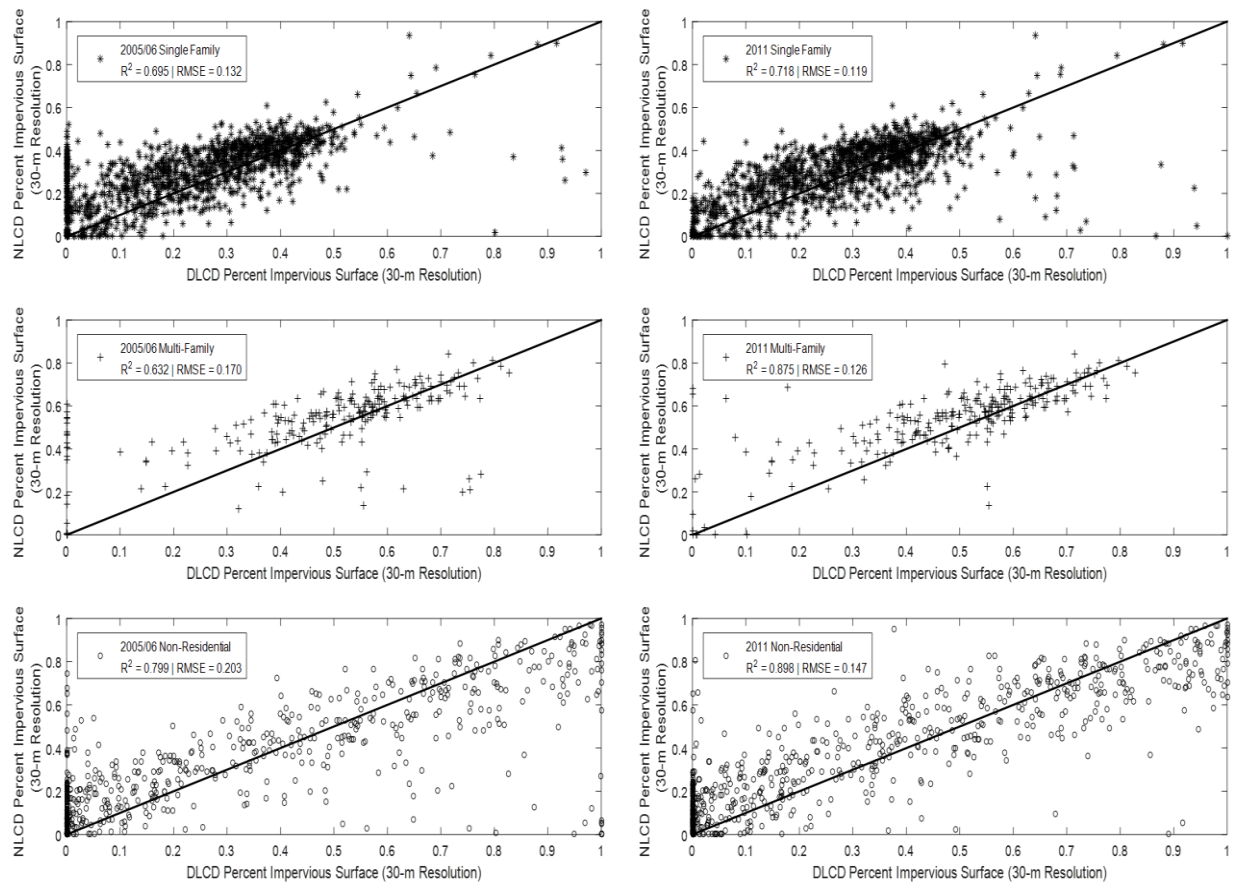


Figure 3-5: Comparison of 2005/06 and 2011 DLCD and NLCD Percent Impervious Surface Areas for Three Different Land Use Zones: Single Family, Multi-Family, and Non-Residential at 30-m Spatial Resolution

At a 30-m spatial scale, the R^2 value was 0.695 and 0.632 for the SFR and multi-family zones for the 2005 DLCD and 2006 NLCD comparison. These values were lower than the R^2 values for the non-residential (0.799) and town wide (0.877) analyses, suggesting inconsistency across different land use categories. For the 2011 comparison, the single family, multi-family, and non-residential R^2 values increased to 0.718, 0.875, and 0.898. With the town wide value remaining relatively high, the 2011 data comparison seems to have a better correlation. At the 90-m spatial scale, the variation of R^2 values improved for the town wide and non-residential comparison.

Table 3-4: Summary of R² and RMSE Values for DLCD and NLCD Direct Comparison of Percent Impervious Surface Area from 2005/2006 and 2011

2005 DLCD & 2006 NLCD	30-m Pixel		90-m Pixel	
	R ²	RMSE	R ²	RMSE
Town Wide	0.877	0.112	0.942	0.071
Single Family	0.695	0.132	0.559	0.110
Multi-Family	0.632	0.170	N/A	N/A
Non-Residential	0.799	0.203	0.783	0.139
2011 DLCD & 2011 NLCD	30-m Pixel		90-m Pixel	
	R ²	RMSE	R ²	RMSE
Town Wide	0.875	0.118	0.925	0.083
Single Family	0.718	0.119	0.365	0.104
Multi-Family	0.875	0.126	N/A	N/A
Non-Residential	0.898	0.147	0.952	0.080

3.4.4 Correction of NLCD Percent Impervious Map using DLCD as Reference

Total area and detailed pixel-wise comparisons suggested that the NLCD generally overestimated the percent impervious surface area, especially for pixels with low impervious surface values (Figures 3- 3-5). There was also a slight under-estimation of percent impervious surface for pixels with high impervious surface values (e.g., > 90%). Such data skewness needs to be corrected to give users confidence in using NLCD percent impervious surface maps for a local application where DLCD may not be available. Using trial and error data comparison at a 90-m pixel scale with the R² and RMSE statistics, the empirical min-max normalization equation was tested using imp_{max} (1.0) and imp_{min} (0.05) as user-defined normalization coefficients. The following graphic illustrates how the NLCD percent impervious pixel values were corrected using this equation (Figure 3-6).

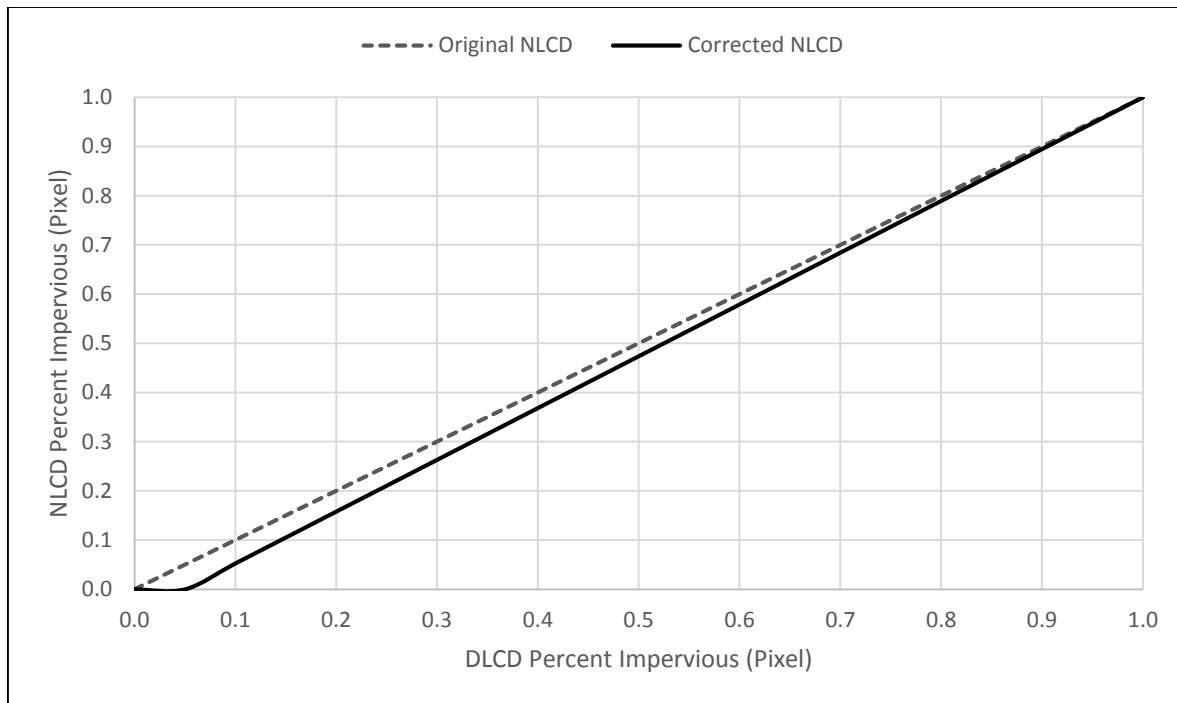


Figure 3-6: Data Correction Method using an Empirical Min-Max Normalization Equation

After applying the correction, NLCD percent impervious pixels that had negative values were forced to 0 since negative percent impervious has no practical meaning. The lower percent impervious pixel values were reduced the most at 5%, while the data transformation converged to a 1:1 relationship at 100% impervious.

Figures 3-7 and 8 compare the uncorrected/corrected 2006 NLCD values and the 2005 DLCD data at 30-m and 90-m resolution. For visual clarity, the following illustrations represent a 25% sampling of the 30-m NLCD pixels. The R^2 value remained constant or slightly increased, and the RMSE was slightly reduced after the correction for both comparisons was made. These results were re-affirmed with the 2011 data analysis (Figures 3-9 and 10). As shown in Figures 3-7-10, the correction method reduced the overestimation of NLCD percent impervious surface estimates.

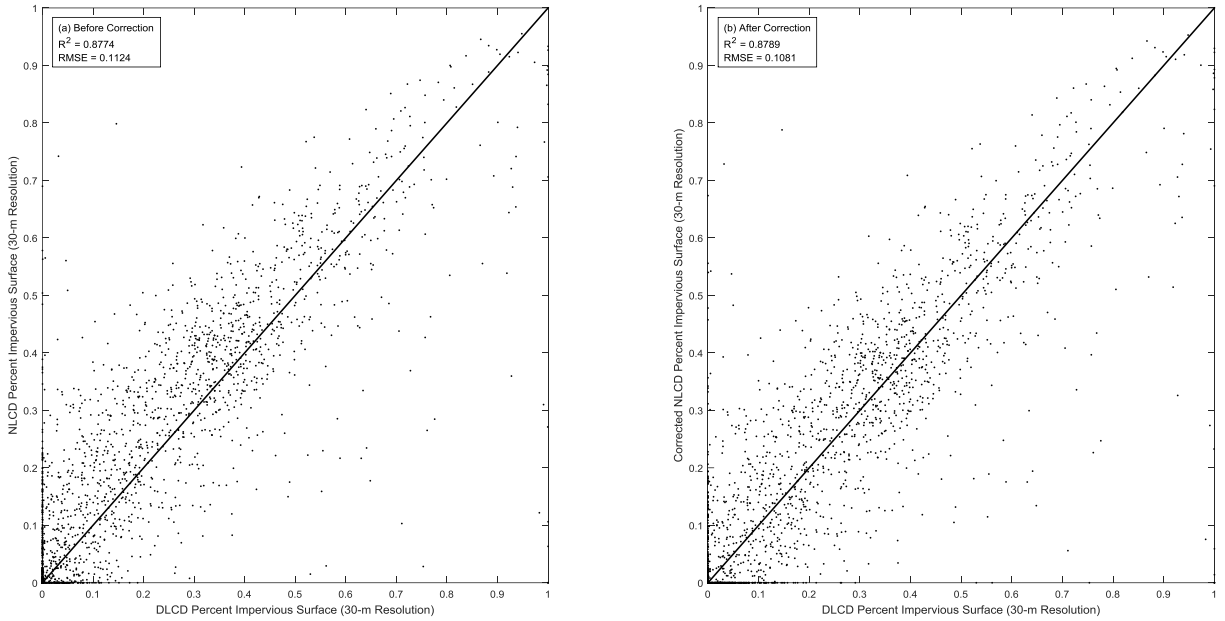


Figure 3-7: 2006 NLCD Data Correction at 30-m Spatial Resolution: (a) 2005 DLCD Percent Impervious Surface Values vs Original 2006 NLCD Percent Impervious Surface Values; (b) 2005 DLCD Percent Impervious Surface Values vs Corrected 2006 NLCD Percent Impervious Surface Values

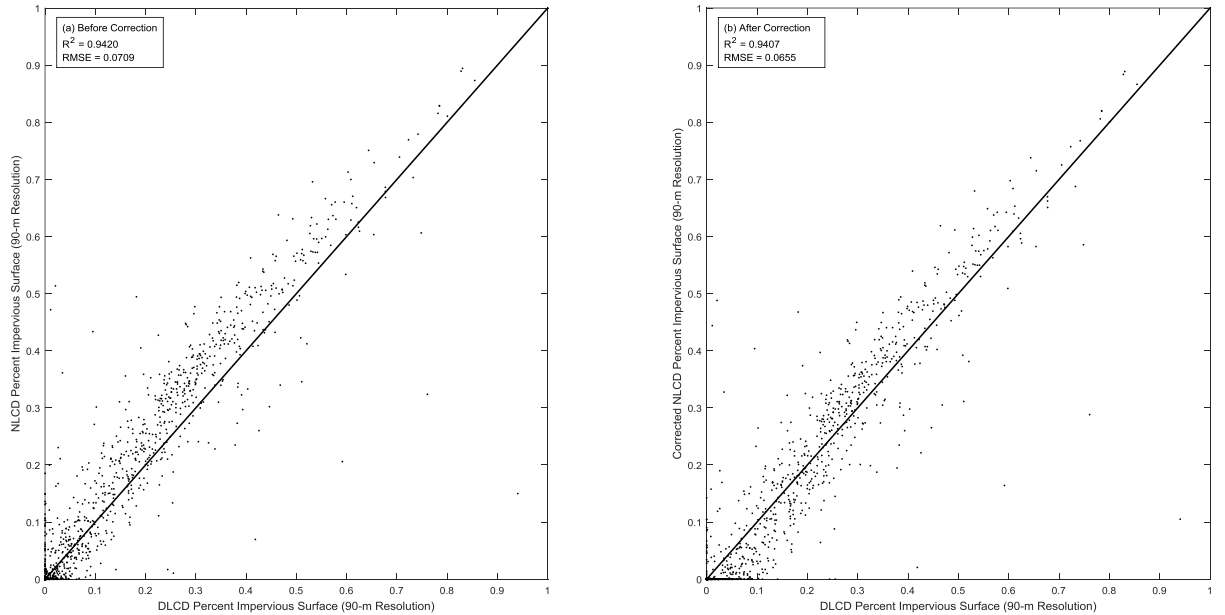


Figure 3-8: 2006 NLCD Data Correction at 90-m Spatial Resolution: (a) 2005 DLCD Percent Impervious Surface Values vs Original 2006 NLCD Percent Impervious Surface Values; (b) 2005 DLCD Percent Impervious Surface Values vs Corrected 2006 NLCD Percent Impervious Surface Values

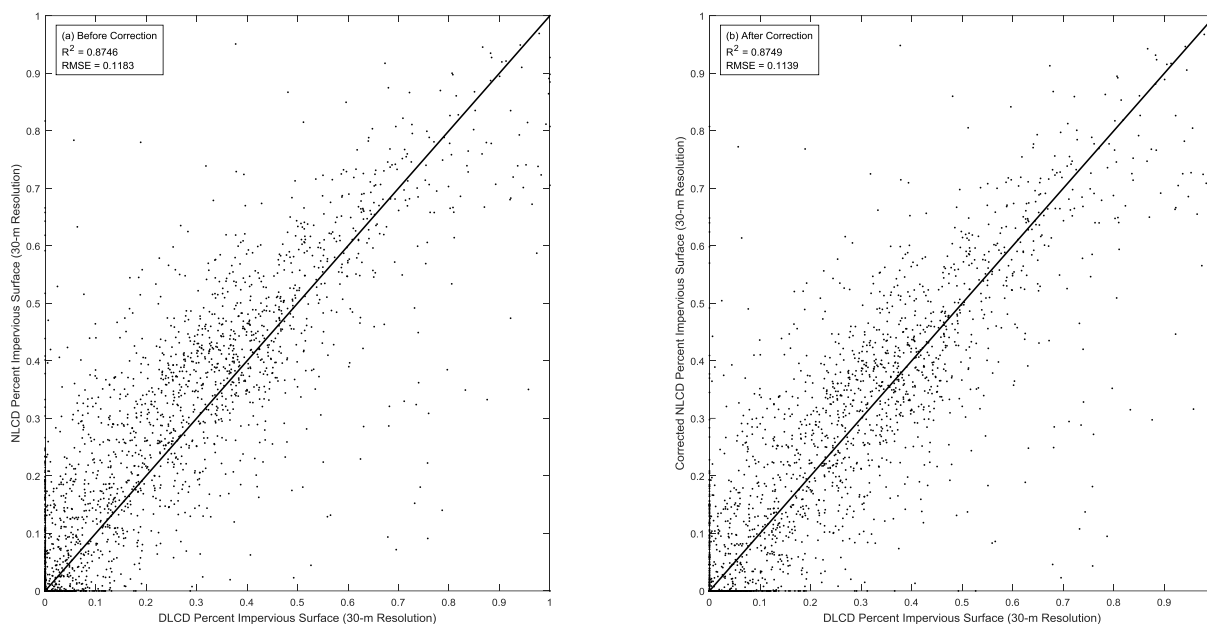


Figure 3-9: 2011 NLCD Data Correction at 30-m Spatial Resolution: (a) 2011 DLCD Percent Impervious Surface Values vs Original 2011 NLCD Percent Impervious Surface Values; (b) 2011 DLCD Percent Impervious Surface Values vs Corrected 2011 NLCD Percent Impervious Surface Values

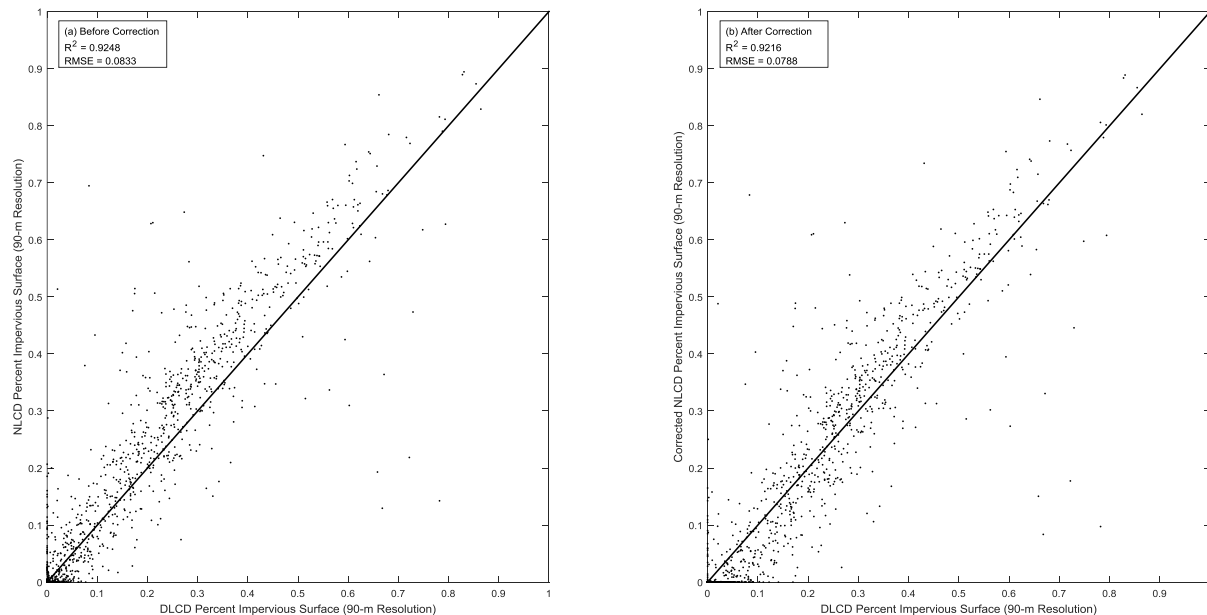


Figure 3-10: 2011 NLCD Data Correction at 90-m Spatial Resolution: (a) 2011 DLCD Percent Impervious Surface Values vs Original 2011 NLCD Percent Impervious Surface Values; (b) 2011 DLCD Percent Impervious Surface Values vs Corrected 2011 NLCD Percent Impervious Surface Values

This data fit was designed specifically for the Town of Blacksburg; more studies need to be conducted in similar geographical areas to affirm patterns in NLCD bias before using a common correction method for local and regional application. Based on the amount and spatial distribution of impervious surface, the user-defined $\text{imp}_{\min}$ normalization coefficient can be manipulated accordingly (estimated range of 0 to approximately 10%). It is also possible to use a set of pseudo-invariant features (PIF) to guide the selection of normalization coefficients. The users could identify a set of point locations where percent impervious surface areas are known (0 and 1) and stable over time. For these locations, NLCD percent impervious surface estimates can be extracted and compared to the known values. Normalization coefficients can then be determined in a more robust approach.

3.5 CONCLUSION

A thorough comparison of the impervious coverage of the 2005 and 2011 DLCD and the 2006 and 2011 NLCD was performed. For this study area, the NLCD overestimated total impervious surface area by 13.40% (2006) and 14.96% (2011) at a town wide extent. The overestimation varied across three different land use zones: single-family (+26.55% for 2006 and +12.04% for 2011), multi-family (+19.58% for 2006 and +20.53% for 2011), and non-residential area (+12.08% for 2006 and +17.38% for 2011). The binary pixel-wise comparison of the two datasets revealed that NLCD performed reasonably well at the town wide scope and for the multi-family and non-residential land use zones. However, the accuracy of the NLCD-derived impervious map for the single family land use zone was poor (user accuracy < 40%). The direct comparison of percent impervious surface at 30-m spatial scales showed that NLCD estimates had data skewness; underestimated high values and overestimated small values. The spatial aggregation of 30-m pixels to 90-m pixels led to improved agreement between the two datasets; however, the data skewness was still apparent. An empirical normalization equation was applied to correct the NLCD percent impervious map to better match the DLCD. After the adjustment, the overestimation and data skewness of NLCD impervious surface values were reduced. The R^2 value remained constant or slightly increased, and the RMSE decreased slightly. Other non-linear regression data correction techniques, such as a step method or power function, should also be studied in an effort to determine the most accurate adjustment to the NLCD impervious surface pixels. This type of approach has potential to improve the NLCD percent impervious surface map for use in local and regional applications.

4 CONCLUSION

4.1 IMPLICATIONS

A thorough comparison of the impervious coverage of the 2005 and 2011 DLCD and the 2006 and 2011 NLCD was performed. For this study area, the NLCD overestimated total impervious surface area by 13.40% (2006) and 14.96% (2011) at a town wide extent. The overestimation varied across three different land use zones: single-family (+26.55% for 2006 and +12.04% for 2011), multi-family (+19.58% for 2006 and +20.53% for 2011), and non-residential area (+12.08% for 2006 and +17.38% for 2011). The binary pixel-wise comparison of the two datasets revealed that NLCD performed reasonably well at the town wide scope and for the multi-family and non-residential land use zones. However, the accuracy of the NLCD-derived impervious map for the single family land use zone was poor (user accuracy < 40%). The direct comparison of percent impervious surface at 30-m spatial scales showed that NLCD estimates had data skewness; underestimated high values and overestimated small values. The spatial aggregation of 30-m pixels to 90-m pixels led to improved agreement between the two datasets; however, the data skewness was still apparent. An empirical normalization equation was applied to correct the NLCD percent impervious map to better match the DLCD. After the adjustment, the overestimation and data skewness of NLCD impervious surface values were reduced. The R^2 value remained constant or slightly increased, and the RMSE decreased slightly. Other non-linear regression data correction techniques, such as a step method or power function, should also be studied in an effort to determine the most accurate adjustment to the NLCD impervious surface pixels. This type of approach has potential to improve the NLCD percent impervious surface map for use in local and regional applications.

4.2 FUTURE WORK

As the MRLC continues to re-visit and improve their protocol for creating NLCD percent impervious surface maps, there should be an increasing correlation with locally developed, detailed land cover datasets. However, due to the level of spatial mis-registration and coarser methods of data procurement, the high resolution detailed land cover datasets will likely remain the best way to portray changes in land cover and represent percent impervious surface conditions. If the NLCD aligns closely to the DLCD or if there is no existing DLCD for use, local and regional governments will still need to utilize NLCD products. As new releases of the VGIN occur, the Blacksburg DLCD should be updated to reflect these changes and compared against the NLCD for approximately the same time period. As urban growth and development trends continue to take place in more rural areas of the Town, impervious surface conditions are only going to increase. Since the Blacksburg DLCD showed a 15% increase in impervious surface area during an unfavorable time period for development, it is not unreasonable to think that another 15% increase has occurred from 2011 to 2016. This would represent over a 30% increase in impervious surface conditions during the timespan of a decade. With an additional time period added to the analysis, a better relationship can be determined for impervious surface conditions at multiple scales and scopes. This relationship could then be used to modify the NLCD correction method and create a more accurate, representative map of ground surface conditions.

4.3 FINAL WORDS

As this study attempts to assess the accuracy of NLCD impervious surface maps using a DLCD for a specified location, more assessments need to be conducted for a time series of data and within each NLCD mapping zone in an effort to determine why and where the NLCD is performing well and not so well. With increasing amounts of data to work with, the relationship

between NLCD and locally developed, detailed land cover datasets will be better understood. Therefore, local and regional governments will be able to more accurately depict land cover conditions for applications such as land use planning, watershed management, stormwater infrastructure design, and water quality regulations.

REFERENCES

- Arnold Jr, C. L., & Gibbons, C. J. (1996). Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American planning Association*, 62 (2), 243-258.
- Civco, D. L., & Hurd, J. D. (1997). Impervious surface mapping for the state of Connecticut. In *Proceedings of the 1997 ASPRS Annual Conference* (pp. 124-135).
- Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37 (1), 35-46.
- Duda, R.O., Hart, P.E., & Stork, D.G. (2012). *Pattern Classification*. John Wiley & Sons.
- Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, 80 (1), 185-201.
- Homer, C., Huang, C., Yang, L., Wylie, B., & Coan, M. (2004). Development of a 2001 national land-cover database for the United States. *Photogrammetric Engineering & Remote Sensing*, 70 (7), 829-840.
- Mannel, S., Price, M., & Hua, D. (2006). A method to obtain large quantities of reference data. *International Journal of Remote Sensing*, 27 (3), 623-627.
- Shao, Y., Li, G. L., Guenther, E., & Campbell, J. B. (2015). Evaluation of Topographic Correction on Subpixel Impervious Cover Mapping With CBERS-2B Data.
- Shao, Y., Taff, G. N., & Walsh, S. J. (2011). Comparison of early stopping criteria for neural-network-based subpixel classification. *Geoscience and Remote Sensing Letters, IEEE*, 8 (1), 113-117.
- Shields, C. A., Band, L. E., Law, N., Groffman, P. M., Kaushal, S. S., Savvas, K., Fisher, G. T., & Belt, K. T. (2008). Streamflow distribution of non-point source nitrogen export from urban-rural catchments in the Chesapeake Bay watershed. *Water Resources Research*, 44 (9).
- Shuster, W., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D. (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*, 2 (4), 263-275.
- Song, C. (2004). Cross-sensor calibration between Ikonos and Landsat ETM+ for spectral mixture analysis. *Geoscience and Remote Sensing Letters, IEEE*, 1 (4), 272-276.
- Song, C. (2005). Spectral mixture analysis for subpixel vegetation fractions in the urban environment: How to incorporate endmember variability? *Remote Sensing of Environment*, 95 (2), 248-263.
- Town of Blacksburg (2012). Section A-Demographics and Land Use Statistics. *Town of Blacksburg Administrative Manual*.
- Town of Blacksburg (2014). Land Use Map Series Map A: Future Land Use. *Town of Blacksburg Comprehensive Plan*.
- Townshend, J. R. G., Justice, C. O., Gurney, C., & McManus, James. (1992). The Impact of Misregistration on Change Detection. *Transactions on Geoscience and Remote Sensing, IEEE*, 30 (5), 1054-1060.

- Vogelmann, J. E., Howard, S. M., Yang, L., Larson, C. R., Wylie, B. K., & Van Driel, N. (2001). Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. *Photogrammetric Engineering and Remote Sensing*, 67 (6).
- Wickham, J. D., Stehman, S. V., Gass, L., Dewitz, J., Fry, J. A., & Wade, T. G. (2013). Accuracy assessment of NLCD 2006 land cover and impervious surface. *Remote Sensing of Environment*, 130, 294-304.
- Wu, C., & Murray, A. T. (2003). Estimating impervious surface distribution by spectral mixture analysis. *Remote Sensing of Environment*, 84 (4), 493-505.
- Wu, C., & Murray, A. T. (2007). Population estimation using Landsat enhanced thematic mapper imagery. *Geographical Analysis*, 39 (1), 26-43.
- Xian, G., & Homer, C. (2010). Updating the 2001 National Land Cover Database impervious surface products to 2006 using Landsat imagery change detection methods. *Remote Sensing of Environment*, 114 (8), 1676-1686.
- Yuan, F., & Bauer, M. E. (2007). Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote Sensing of Environment*, 106 (3), 375-386.

APPENDICES

APPENDIX A: Land Use Categories & Descriptions

When using GIS to classify the land use zones in this study: single family subdivisions, multi-family complexes, and non-residential properties, the following tiered classification system was utilized. Residential properties were split between single family detached units classified as single family subdivisions and duplexes, rental units, villas, townhomes, manufactured housing- mobile home parks, Greek housing, apartment complexes, and condos classified as multi-family complexes. Low density was classified separately from medium/high density residential units. Non-residential properties included the following land use zones: commercial/office/industrial, public assembly, and institutional/community.

1000

Residential

1100 Single Family

- 1110 Detached Units
- 1120 Duplexes, Rental Units, more than one house
- 1140 Townhouses
- 1150 Manufactured Housing - Mobile Home Parks
- 1160 Greek Housing

Comp Map Class

Low Density
Residential
Medium Density
Residential
Medium Density
Residential
High Density
Residential
Medium Density
Residential

1200 Multifamily

- 1210 Apartment Complexes, Multiple Stories
- 1220 Condos

High Density
Residential
High Density
Residential

2000

Commercial / Office / Industrial

2100 Office

- 2110 Standard Offices
- 2120 Bank
- 2130 Research Office Parks - CRC

Professional Office
Professional Office
Research & Dev. /
Light Industry

2200 Commercial

- 2210 Drive Thru / Fast Food Restaurant
- 2220 Standard Restaurant
- 2230 Retail Sales
- 2260 Farmer's Market
- 2270 Gas Stations

Commercial
Commercial
Commercial
Commercial
Commercial

		2280 Auto Repair - Garages / Bays	Commercial
		2290 Hotels, Motels, Bed & Breakfast	Commercial
	2300 Mixed Use	2310 Mixed Use Commercial & Residential	Mixed Use
		2320 Mixed Use Office & Residential	Mixed Use
		2330 Mixed Use Commercial & Office & Residential	Mixed Use
	2400 Mixed Use	2410 Mixed Use Commercial & Office	Mixed Use
	2500 Shopping Center	2510 Large Shopping Complexes	Commercial
	2600 Industrial	2610 Light Industry - Office / Heavy Equipment	Research & Dev. / Light Industry
		2620 Heavy Industry - Manufacturing	Industrial
	2700 Storage	2710 Mini Warehouse Storage	Commercial
3000 Public Assembly	3200 Indoor Recreation	3210 Aquatic Center	Civic
	3500 Churches	3510 Churches, Religious Institutions	Civic
		3520 Church with Residential	Civic
	3600 Government Admin	3610 Town Hall, BMC, Old Town Hall	Civic
	3800 Large Assembly	3810 Community Centers / Reception Halls	Civic
4000 Institutional / Community	4100 Medical Facility	4110 Hospital	Civic
		4120 Medical Offices / Doctor / Dental / Specialty	Civic
		4130 Assisted Living	Civic

4200 School / University	4210 Grade School	Civic
	4220 University	University
	4230 Specialty School / Day Care	Civic
4300 Library	4310 Public Library	Civic
4400 Museums / Art Galleries	4410 Alexander Black House, Armory, Odd Fellows	Civic
4500 Public Safety	4510 Fire / Rescue Station	Civic
	4520 Police Station	Civic
4700 Cemetery	4710 All cemeteries	Civic
4800 Funeral Home	4810 McCoy Funeral Home	Civic

APPENDIX B: MATLAB Script for Data Analyses

Example Script taken from 2005/2006 Data Analyses

Comparison of Total Impervious Surface Area

```
cd('C:\Users\ceecuser\Desktop')
A = imread('05DLCDImpRas1.tif','tiff');
B = imread('nlcd2006proj1.tif','tiff');
AMaskT = imread('05DLCDMaskR1.tif','tiff');
AMaskSF = imread('2005_SF_Ras1.tif','tiff');
AMaskMF = imread('2005_MF_Ras1.tif','tiff');
AMaskNR = imread('2005_NR_Ras1.tif','tiff');
```

```
A(A>=1)=1;
A(A<1)=0;
AMaskT = double(AMaskT);
AMaskT(AMaskT>65000)=0;
AMaskT(AMaskT>=1)=1;
AMaskSF(AMaskSF==255)=0;
AMaskSF(AMaskSF>0)=1;
AMaskMF(AMaskMF>0)=1;
AMaskMF(AMaskMF<0)=0;
AMaskNR(AMaskNR>0)=1;
AMaskNR(AMaskNR<0)=0;
```

```
AT=(A(AMaskT==1));
sum(sum(AT))
ASF=(A(AMaskSF==1));
sum(sum(ASF))
AMF=(A(AMaskMF==1));
sum(sum(AMF))
ANR=(A(AMaskNR==1));
sum(sum(ANR))
```

```
B = double(B);
B = (B/100);
BT = (B(AMaskT==1));
sum(sum(BT))
BSF = (B(AMaskSF==1));
sum(sum(BSF))
BMF = (B(AMaskMF==1));
sum(sum(BMF))
BNR = (B(AMaskNR==1));
sum(sum(BNR))
```

Pixel-Level Comparison for NLCD and DLCD

```
cd('C:\Users\ceecuser\Desktop')
A = imread('05DLCDImpRas1.tif','tiff');
B = imread('nlcd2006proj1.tif','tiff');
AMaskT = imread('05DLCDMaskR1.tif','tiff');
AMaskSF = imread('2005_SF_Ras1.tif','tiff');
AMaskMF = imread('2005_MF_Ras1.tif','tiff');
AMaskNR = imread('2005_NR_Ras1.tif','tiff');

A(A>=1)=1;
A(A<1)=0;
AMaskT = double(AMaskT);
AMaskT(AMaskT>65000)=0;
AMaskT(AMaskT>=1)=1;
AMaskSF(AMaskSF==255)=0;
AMaskSF(AMaskSF>0)=1;
AMaskMF(AMaskMF>0)=1;
AMaskMF(AMaskMF<0)=0;
AMaskNR(AMaskNR>0)=1;
AMaskNR(AMaskNR<0)=0;

A100 = blkproc(A, [100 100], 'mean2');
B100 = blkproc(B, [100 100], 'mean2')/100;
AMaskT100 = blkproc(AMaskT, [100 100], 'mean2');
AMaskSF100 = blkproc(AMaskSF, [100 100], 'mean2');
AMaskMF100 = blkproc(AMaskMF, [100 100], 'mean2');
AMaskNR100 = blkproc(AMaskNR, [100 100], 'mean2');

A100(A100>=0.5)=1;
A100(A100<0.5)=2;
B100(B100>=0.5)=1;
B100(B100<0.5)=2;

DLCDT100 = A100(AMaskT100==1);
NLCDT100 = B100(AMaskT100==1);
tblT100 = crosstab(DLCDT100,NLCDT100);

DLCDSF100 = A100(AMaskSF100==1);
NLCDSF100 = B100(AMaskSF100==1);
tblSF100 = crosstab(DLCDSF100,NLCDSF100);
```

```
DLCDMF100 = A100(AMaskMF100==1);
NLCDMF100 = B100(AMaskMF100==1);
tblMF100 = crosstab(DLCDMF100,NLCDMF100);
```

```
DLCDNR100 = A100(AMaskNR100==1);
NLCDNR100 = B100(AMaskNR100==1);
tblNR100 = crosstab(DLCDNR100,NLCDNR100);
```

Direct Comparison of Percent Impervious Surface Maps

```
%Townwide Comparison of 2005 DLCD & 2006 NLCD Impervious Surface
cd('C:\Users\ceecluser\Desktop')
A = imread('05DLCDImpRas1.tif','tiff');
B = imread('nlcd2006proj1.tif','tiff');
AMaskT = imread('05DLCDMaskR1.tif','tiff');
```

```
A(A>=1)=1;
A(A<1)=0;
AMaskT = double(AMaskT);
AMaskT(AMaskT>65000)=0;
AMaskT(AMaskT>=1)=1;
```

```
A100 = blkproc(A, [100 100], 'mean2');
A300 = blkproc(A, [300 300], 'mean2');
B100 = blkproc(B, [100 100], 'mean2')/100;
B300 = blkproc(B, [300 300], 'mean2')/100;
AMaskT100 = blkproc(AMaskT, [100 100], 'mean2');
AMaskT300 = blkproc(AMaskT, [300 300], 'mean2');
```

```
DLCDT100 = A100(AMaskT100==1);
DLCDT300 = A300(AMaskT300==1);
NLCDT100 = B100(AMaskT100==1);
NLCDT300 = B300(AMaskT300==1);
```

```
subplot(1,2,1)
TMatrix100 = plot(DLCDT100, NLCDT100, 'k.');
refline(1,0);
xlabel('DLCD Percent Impervious Surface (30-m Resolution)');
ylabel('NLCD Percent Impervious Surface (30-m Resolution)');
subplot(1,2,2)
TMatrix300 = plot(DLCDT300, NLCDT300, 'k.');
refline(1,0);
xlabel('DLCD Percent Impervious Surface (90-m Resolution)');
ylabel('NLCD Percent Impervious Surface (90-m Resolution)');
```

%Land Use Comparison of 2005 DLCD & 2006 NLCD Impervious Surface

```
AMaskSF = imread('2005_SF_Ras1.tif','tiff');
```

```
AMaskMF = imread('2005_MF_Ras1.tif','tiff');
```

```
AMaskNR = imread('2005_NR_Ras1.tif','tiff');
```

```
AMaskSF(AMaskSF==255)=0;
```

```
AMaskSF(AMaskSF>0)=1;
```

```
AMaskSF100 = blkproc(AMaskSF, [100 100], 'mean2');
```

```
AMaskSF300 = blkproc(AMaskSF, [300 300], 'mean2');
```

```
AMaskMF(AMaskMF>0)=1;
```

```
AMaskMF(AMaskMF<0)=0;
```

```
AMaskMF100 = blkproc(AMaskMF, [100 100], 'mean2');
```

```
AMaskMF300 = blkproc(AMaskMF, [300 300], 'mean2');
```

```
AMaskNR(AMaskNR>0)=1;
```

```
AMaskNR(AMaskNR<0)=0;
```

```
AMaskNR100 = blkproc(AMaskNR, [100 100], 'mean2');
```

```
AMaskNR300 = blkproc(AMaskNR, [300 300], 'mean2');
```

```
DLCDSF100 = A100(AMaskSF100==1);
```

```
DLCDSF300 = A300(AMaskSF300==1);
```

```
NLCDSF100 = B100(AMaskSF100==1);
```

```
NLCDSF300 = B300(AMaskSF300==1);
```

```
DLCDMF100 = A100(AMaskMF100==1);
```

```
DLCDMF300 = A300(AMaskMF300==1);
```

```
NLCDMF100 = B100(AMaskMF100==1);
```

```
NLCDMF300 = B300(AMaskMF300==1);
```

```
DLCDNR100 = A100(AMaskNR100==1);
```

```
DLCDNR300 = A300(AMaskNR300==1);
```

```
NLCDNR100 = B100(AMaskNR100==1);
```

```
NLCDNR300 = B300(AMaskNR300==1);
```

```
SFMatrix100 = plot(DLCDSF100,NLCDSF100,'k*');
```

```
hold on
```

```
MFMatrix100 = plot(DLCDMF100,NLCDMF100,'k+');
```

```
NRMatrix100 = plot(DLCDNR100,NLCDNR100,'ko');
```

```
refline(1,0);
```

```
xlabel('DLCD Percent Impervious Surface (30-m Resolution)');
```

```
ylabel('NLCD Percent Impervious Surface (30-m Resolution)');
```

```
legend('Single Family', 'Multi-Family', 'Non-Residential', '1:1 Line', 'Location', 'northwest');
```

Correction of NLCD Percent Impervious Surface Map using DLCD as Reference

%Correction of Town-wide NLCD Impervious Surface Map Using DLCD

NLCD_Corr100 = ((NLCDT100-0.05)/(1-0.05));

NLCD_Corr100(NLCD_Corr100<0)=0;

NLCD_Corr300 = ((NLCDT300-0.05)/(1-0.05));

NLCD_Corr300(NLCD_Corr300<0)=0;

subplot(1,2,1)

TMatrix100 = plot(DLCDT100,NLCDT100,'k.');

refline(1,0);

xlabel('DLCD Percent Impervious Surface (30-m Resolution)');

ylabel('NLCD Percent Impervious Surface (30-m Resolution)');

subplot(1,2,2)

TMatrix100Corr = plot(DLCDT100,NLCD_Corr100,'k.');

refline(1,0);

xlabel('DLCD Percent Impervious Surface (30-m Resolution)');

ylabel('Corrected NLCD Percent Impervious Surface (30-m Resolution)');

subplot(1,2,1)

TMatrix300 = plot(DLCDT300,NLCDT300,'k.');

refline(1,0);

xlabel('DLCD Percent Impervious Surface (90-m Resolution)');

ylabel('NLCD Percent Impervious Surface (90-m Resolution)');

subplot(1,2,2)

TMatrix300Corr = plot(DLCDT300,NLCD_Corr300,'k.');

refline(1,0);

xlabel('DLCD Percent Impervious Surface (90-m Resolution)');

ylabel('Corrected NLCD Percent Impervious Surface (90-m Resolution)');