Center for Land Use and Sustainability
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A Review of Land Cover Data Products for the Delaware River Basin

Final Report 1/19/2020

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Key Findings and Recommendations

The recent release of the 30 meter resolution National Land Cover Data 2016 edition (NLCD 2016) (Yang et al. 2016, MRLC 2019a) has created an immediate need to understand how this new data set compares to the 2011 edition (NLCD 2011) (Homer et al. 2015). At the same time, the 1 meter resolution land cover data produced for the DRWI (UVM SAL 2016) is still underutilized and poorly understood.

This data brief aims to outline the strengths and weaknesses of NLCD 2016, how it compares (quantitatively) to the NLCD 2011 product, and, for sample areas, how it compares to the high resolution land cover data product. Finally, a brief overview will be given of the new 10 meter land cover data products that were developed for the Chesapeake Bay Watershed (CBW) (U.S. Geological Survey 2018) to inform discussions around the potential development of a similar product for the DRB.

Key Findings:

- ➔ At the scale of the entire River Basin, differences in the quantities of land cover classes mapped by the two editions of NLCD can be observed. It is important to note that these differences in land cover estimates are almost entirely due to differences in mapping methods in the two products. This means that the NLCD 2011 edition and NLCD 2016 edition are fundamentally incompatible with each other.
- ➔ These differences vary geographically and are more variable at finer scales.
- ➔ Using the NLCD 2016 edition as a baseline, forests, agriculture, and urban/developed classes comprise the largest changes between 2001 and 2016. When all developed classes are aggregated, urban land increases by almost 7% (+443 km^2 or 109,373 acres) between 2001 and 2016. Over this same time period, forest lands decrease by 1.44%, a loss of 232 km^2 or 57,293 acres, and agriculture declines by 4.74% (-317 km^2 or 78,357 acres).
- ➔ When comparing the 30 meter resolution NLCD categorical land cover product to the 1 meter resolution UVM SAL data set, NLCD consistently estimates a higher proportion of developed land, a lower proportion of forest, and a lower proportion of low vegetation relative to the UVM SAL data. When impervious surface area estimates are compared between the two products, the NLCD consistently *underestimates* relative to the UVM SAL data.
- ➔ Intersecting the UVM SAL data set's low vegetation class with the NLCD shows that *all* NLCD classes are represented in the UVM SAL low vegetation category.
- ➔ The 2013 Phase 6 Land Use Data Sets maximize the resolution gains made by the 1 meter data and the thematic richness of the NLCD. It was developed with a specific application, as input into the Phase 6 Chesapeake Bay Watershed Model, and thus focused on mapping classes with unique nutrient loading characteristics. The 2013 Phase 6 Land Use Data Sets are comprised of thirteen data layers that represent the percentage of land use within each 10 meter pixel for thirteen different land use and land cover classes.

Recommendations

- ➔ The NLCD 2016 edition should be adopted as the new baseline for land cover trends, patterns, and distributions. Due to the incompatibility between the 2011 and 2016 editions, when users adopt the 2016 edition the entire time series should replace the 2011 time series.
- ➔ Because the differences between the 2011 and 2016 editions of the NLCD vary geographically and with scale, users should have a communication strategy to address why "new" numbers are different from "old" numbers.
- ➔ Change analysis using NLCD 2016 should be undertaken with care. Because urban changes will only be captured for 2001, 2006, 2011, 2016, any changes related to urban dynamics will not be captured across all of the seven available dates in the NLCD 2016 edition.
- ➔ The UVM SAL data presents obstacles to adoption, especially for water quality and quantity modeling, due to differences in resolution and land cover categories. While the 2013 Phase 6 Land Use Data Sets in the Chesapeake Bay Watershed offer an example of how to address these challenges, if a similar product is pursued for the DRWI, it should be undertaken with broad stakeholder input so that the end product meets the needs of users.

Acknowledgements

This data brief was funded by the William Penn Foundation in support of the Delaware River Watershed Initiative (DRWI). Drafts of this report were graciously reviewed by members of the DRWI Technical User Group (TUG) and by Peter Claggett, Research Geographer at the U.S. Geological Survey.

1.0 Background and Objectives

The recent release of the 30 meter resolution National Land Cover Data 2016 edition (NLCD 2016) (Yang et al. 2016, MRLC 2019a) has created an immediate need to understand how this new data set compares to the 2011 edition (NLCD 2011) (Homer et al. 2015). NLCD 2016 represents an entirely new data product, where all land cover maps back to 2001 have been reprocessed with improved mapping algorithms. In addition, the temporal database has been expanded, with land cover maps available every 2 - 3 years between 2001-2016. The NLCD 2011 edition only includes 2001, 2006, and 2011. At the same time, the 1 meter resolution land cover data produced for the DRWI (UVM SAL 2016) is still underutilized and poorly understood.

This data brief aims to outline the strengths and weaknesses of NLCD 2016, how it compares (quantitatively) to the NLCD 2011 product, and, for sample areas, how it compares to the high resolution land cover data product. Finally, a brief overview will be given of the new 10 meter land cover data products that were developed for the Chesapeake Bay Watershed (CBW) (U.S. Geological Survey 2018) to inform discussions around the potential development of a similar product for the DRB. Specifically, the following will be presented and discussed:

- An overview of NLCD 2016 will be presented.
- For years that NLCD 2011 and 2016 have in common (2001, 2006, and 2011), basin-wide estimates of land cover and trends will be calculated and compared. Comparisons of quantitative differences for major land cover types (forest, agriculture, urban) will also be made at the scale of HUC 10 watersheds, NHD catchments, and on a pixel-by-pixel basis.
- Land cover trends based on NLCD 2016 will be reported basin-wide.
- For a sample of three counties representing predominantly urban (Montgomery County, PA), agricultural (Berks County, PA), and forested (Monroe County, PA) landscapes, a comparison of NLCD 2016 for the year 2013 and the circa 2013 high resolution land cover will be conducted. This will focus on a comparison of overall quantities of major land cover types, as well as what NLCD land cover types are captured in the "low vegetation" class in the high resolution land cover data. FInally, a comparison of how these two products capture impervious surface area will also be made.
- An overview of the 10 meter land cover data set for the CBW will be given.

2.0 Overview of NLCD 2016

Figure 1: Classes in the NLCD 2016 land cover products. The numerical value corresponds to the numerical code embedded in the raster data.

The NLCD 2016 edition products were released in May 2019 (MRLC 2019) and have a similar "look and feel" as the NLCD 2011 edition products: the class definitions in the land cover maps are consistent and there is a similar suite of products. However, new mapping methods were utilized (Yang et al. 2018) and there are some new products available.

All products in NLCD 2016 have seamless coverage for the continental US (CONUS) and some products are available for Alaska, Hawaii, and/or Puerto Rico. Since the Landsat satellite provides most of the underpinning image data, all products are at a gridded resolution of 30 m x 30 m, so each pixel is 900 m^2 or roughly ¼ acre.

Like the 2011 product, the 2016 land cover data set has 16 land cover classes (Figure 1), but includes a more extensive time series, with land cover maps for 2001, 2003, 2006, 2011, 2013, and 2016. New to NLCD 2016 is a "change index" that indicates land cover changes that occurred at least once between 2001 and 2016 (Figure 2).

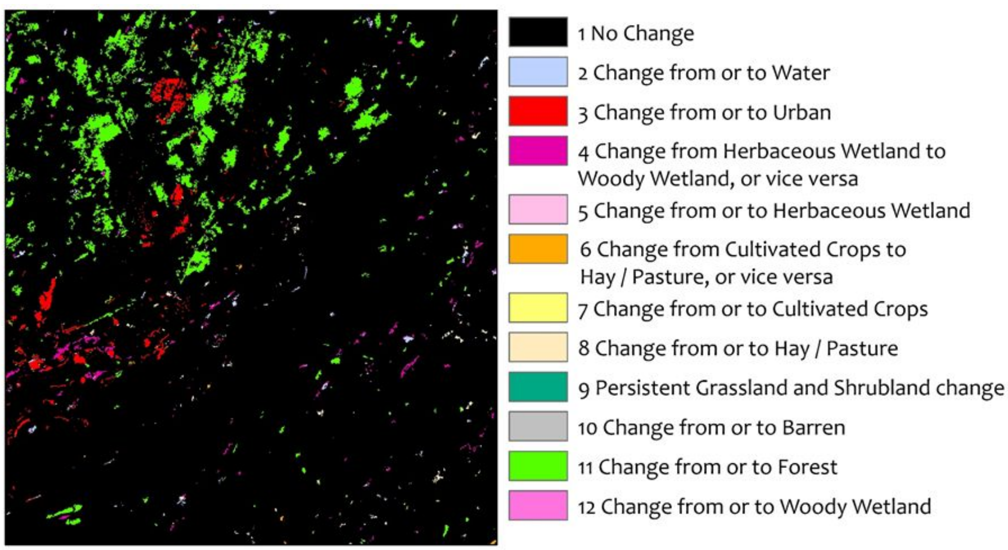

Figure 2: Example of the change index data product. Colors correspond to the type of change that occurred at least once between 2001 and 2016. Numbers correspond to the numerical code embedded in the raster data.

Like NLCD 2011, NLCD 2016 also includes urban imperviousness products that estimate the percentage of developed surface for every 30 meter pixel for four of the seven years of the NLCD land cover product: 2001, 2006, 2011, and 2016. New to NLCD 2016 is a "descriptor layer" that identifies types of roads, core urban areas, and energy production sites for each impervious pixel (Figure 3). Tree canopy products estimating the percentage of tree canopy cover for each 30 meter pixel were also produced again with NLCD 2016 for the years 2011 and 2016.

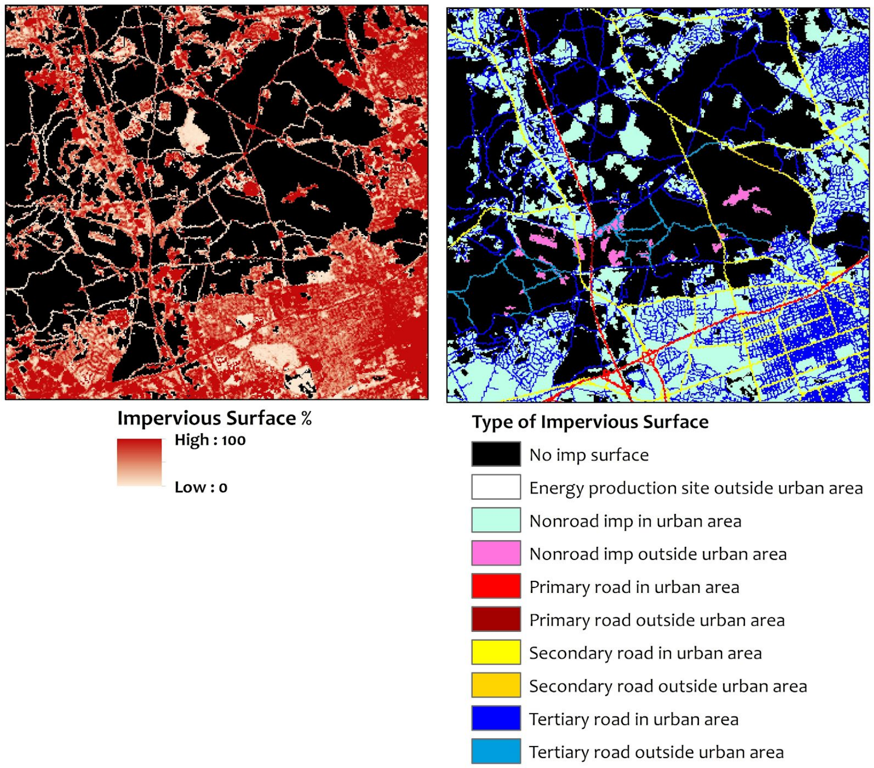

Figure 3: Example of the subpixel impervious surface product (left) and the impervious surface descriptor (right) available with the NLCD 2016 edition.

New products for the western CONUS are a set of shrubland maps for 2016, which estimate the percentage of shrub, herbaceous, bare ground, litter, sagebrush, big sagebrush and annual herbaceous for each 30 meter pixel. There are also maps that estimate of shrub height and sagebrush height.

3.0 Comparing NLCD 2011 and NLCD 2016 Categorical Land Cover Maps

Although the NLCD 2011 and NLCD 2016 land cover maps have the same 16 categories of land cover, because the 2016 edition was created using new mapping algorithms they are fundamentally different. In the example shown in Figure 4, several differences can be observed: pasture/hay (light brown), row crops (yellow), and shrub/scrub (dark brown) often appear “switched” in the two products, as do the different forest classes (shades of green). There are also differences in the extent and location of some of the urban classes, particularly developed open space (light pink).

NLCD 2011 product, year 2011 ***NLCD 2016 product, year 2011***

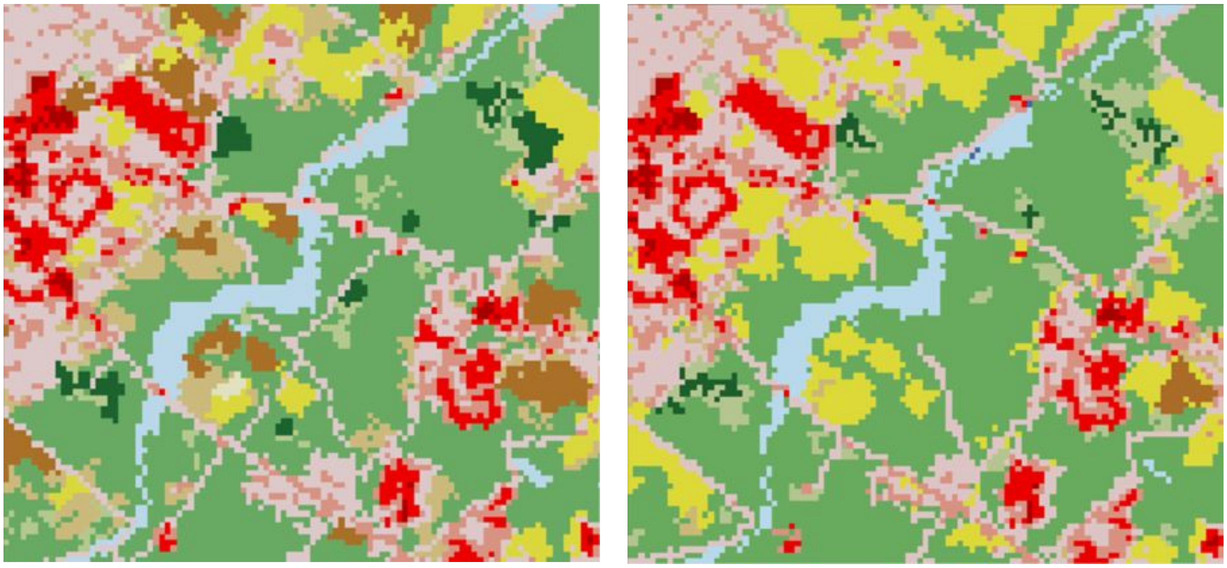

Figure 4: Example of the 2011 (left) and 2016 (right) NLCD data editions for the year 2011.

3.1 Basin-wide Comparison of Land Cover

At the scale of the entire River Basin, differences in the quantities of land cover classes can be observed (Figure 5 and Table 1). For the most dominant land cover type in the basin, deciduous forest, the estimate from the 2016 edition for the year 2011 is more than 900 square kilometers (or 7.16%) lower than the estimate from the 2011 edition. At the same time, the mixed forest class is more than two times higher in the 2016 edition compared to the 2011 edition. This “class swapping” is seen in other classes that are spectrally similar, such as the pasture/hay, cultivated crop, and grassland/herbaceous classes (see section 3.4 for a discussion of “class swapping”). When the forest classes are combined, however, the 2016 edition estimates between 4.00% and 4.31% more forest that the 2011 edition for the 2001-2011 time period. Agriculture classes combined are estimated to be 1.58-2.33% lower in the 2016 edition for this time frame, and urban classes combined are 1.50-2.00% lower. It is important to note that these differences in land cover estimates are almost entirely due to differences in mapping methods in the two products. This means that the NLCD 2011 edition and NLCD 2016 edition are fundamentally incompatible with each other.

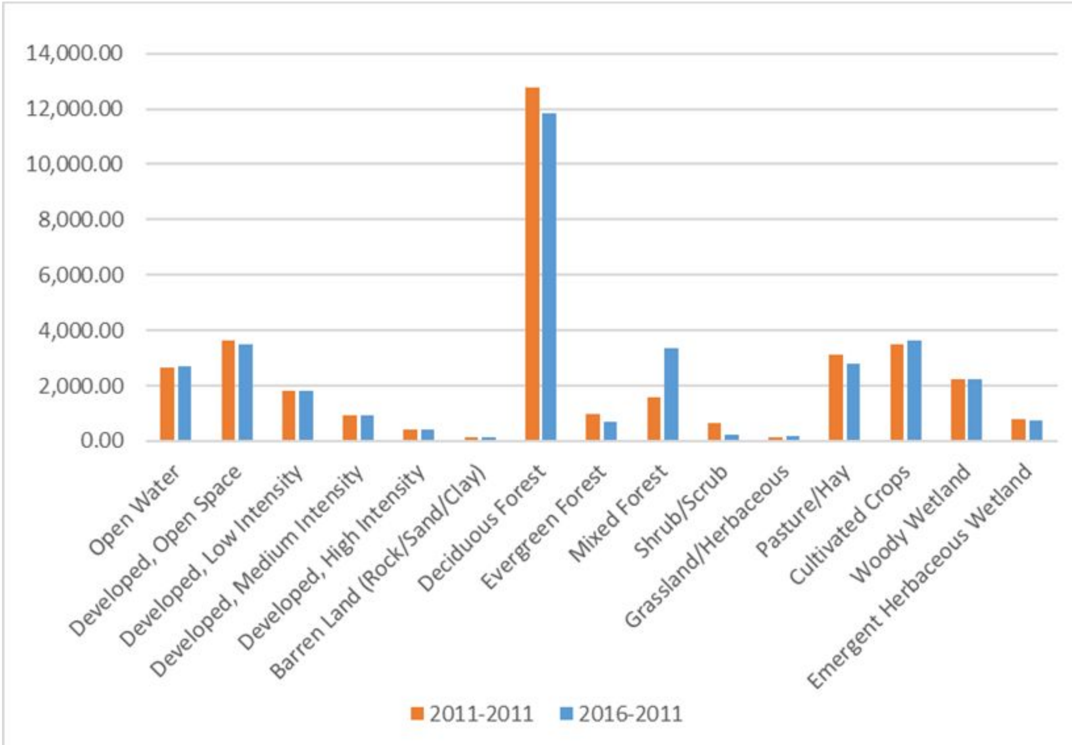

Figure 5: A basin-wide comparison of the area of each land cover class in the 2011 (orange) and 2016 (blue) NLCD editions for the year 2011. Area is in square kilometers.

Table 1: A basin-wide comparison of the area (square kilometers) and percent difference for each land cover class for the 2011 and 2016 NLCD land cover editions for the dates the editions have in common (2001, 2006, and 2011). For percent differences, negative values indicate that the 2016 estimate is lower than the 2011 estimate and positive values indicate the 2016 estimate is higher.

Land cover category	**2011-2001**	**2016-2001**	**% Difference**	**2011-2006**	**2016-2006**	**% Difference**	**2011-2011**	**2016-2011**	**% Difference**
Open Water	2,662.63	2,683.18	0.77	2,664.60	2,677.21	0.47	2,666.79	2,681.73	0.56
Developed, Open Space	3,561.62	3,388.55	-4.86	3,605.15	3,453.85	-4.20	3,634.62	3,499.54	-3.72
Developed, Low Intensity	1,728.79	1,743.68	0.86	1,773.83	1,795.34	1.21	1,807.64	1,833.70	1.44
Developed, Medium Intensity	805.28	828.06	2.83	887.26	900.24	1.46	936.59	943.45	0.73
Developed, High Intensity	377.89	383.56	1.50	409.07	411.19	0.52	430.36	430.61	0.06
Total Developed	**6,473.58**	**6,343.86**	**-2.00**	**6,675.31**	**6,560.61**	**-1.72**	**6,809.20**	**6,707.31**	**-1.50**
Barren Land (Rock/Sand/Clay)	125.35	132.55	5.74	130.86	129.92	-0.72	128.88	128.03	-0.66
Deciduous Forest	12,907.99	12,038.33	-6.74	12,848.81	11,926.33	-7.18	12,763.50	11,851.36	-7.15
Evergreen Forest	966.24	706.59	-26.87	963.12	704.28	-26.88	954.85	701.55	-26.53
Mixed Forest	1,586.07	3,381.68	113.21	1,581.28	3,378.08	113.63	1,572.92	3,374.28	114.52
Total Forest	**15,460.31**	**16,126.59**	**4.31**	**15,393.21**	**16,008.69**	**4.00**	**15,291.26**	**15,927.19**	**4.16**
Shrub/Scrub	612.38	183.16	-70.09	600.22	214.74	-64.22	636.97	222.82	-65.02
Grassland/Herbaceous	123.21	107.40	-12.84	134.86	149.24	10.66	151.36	181.08	19.63
Pasture/Hay	3,195.20	2,945.80	-7.81	3,135.39	2,838.99	-9.45	3,107.35	2,782.79	-10.45
Cultivated Crops	3,603.73	3,745.72	3.94	3,531.29	3,690.70	4.51	3,471.83	3,642.83	4.93
Total Agriculture	**6,798.93**	**6,691.52**	**-1.58**	**6,666.68**	**6,529.68**	**-2.05**	**6,579.19**	**6,425.62**	**-2.33**
Woody Wetland	2,229.98	2,221.92	-0.36	2,222.29	2,216.33	-0.27	2,219.16	2,238.11	0.85
Emergent Herbaceous Wetland	766.33	762.54	-0.49	764.68	766.29	0.21	769.90	740.83	-3.78
Total Wetland	**2,996.31**	**2,984.46**	**-0.40**	**2,986.97**	**2,982.62**	**-0.15**	**2,989.05**	**2,978.94**	**-0.34**

Observing example Basin-wide trends for developed open space and deciduous forest emphasizes the differences between the 2011 and 2016 NLCD editions (Figure 6). For these two example classes, the 2011 edition (orange lines) consistently estimates more area than the 2016 edition (blue lines). While both editions show similar trends - increasing in the case of developed open space and decreasing in the case of deciduous forest - the longer and more detailed time steps available in 2016 are apparent, especially for the forest class. In the case of developed open space, it is notable that the 2016 product does not show any change between 2001 and 2004, 2006 and 2008, or 2011 and 2013. In fact, the other urban classes show no changes for these time periods either (Table 1). This can be explained by the fact that the urban imperviousness product is an input into the mapping process to generate the land cover maps (Yang et al. 2019), and as noted earlier, NLCD 2016 includes urban imperviousness products only for 4 of the 7 dates in the time series: 2001, 2006, 2011, and 2016.

Figure 6: Trends through time as estimated by the NLCD 2011 edition (orange lines) and the NLCD 2016 edition (blue lines) for developed open space (left) and deciduous forest (right).

3.2 HUC 10 Comparison

At the finer scale of HUC 10 watersheds, the two NLCD editions also exhibit geographic differences, as shown in comparisons of the three dominant land cover classes for the DRB, urban, agriculture, and forest (Figures 7 - 9). In the case of urban classes (Figure 7), it is apparent that differences are largely driven by the developed open space category. Moreover, in the northern part of the DRB, the 2016 edition tends to estimate more developed open space than the 2011 edition; the reverse is true in the southern part of the Basin. Interestingly, agriculture (Figure 8), and to a lesser extent forest (Figure 9) exhibits this pattern in reverse. This is likely an indication of the spectral similarity between developed open space, which is largely dominated by managed grass, and the agricultural classes, and differences in the mapping algorithms of the 2011 and 2016 editions. In the case of the forest classes, it is possible that the 2016 edition is better able to discriminate developed open space from forested landscapes that are intermixed with developed land cover.

It is also worth noting the degree of variability between the two products at the HUC 10 scale for the different land classes. For any given watershed, differences in urban classes do not exceed +/- 2.5%, while differences in agricultural or forest classes for individual watersheds can exceed +/- 17%.

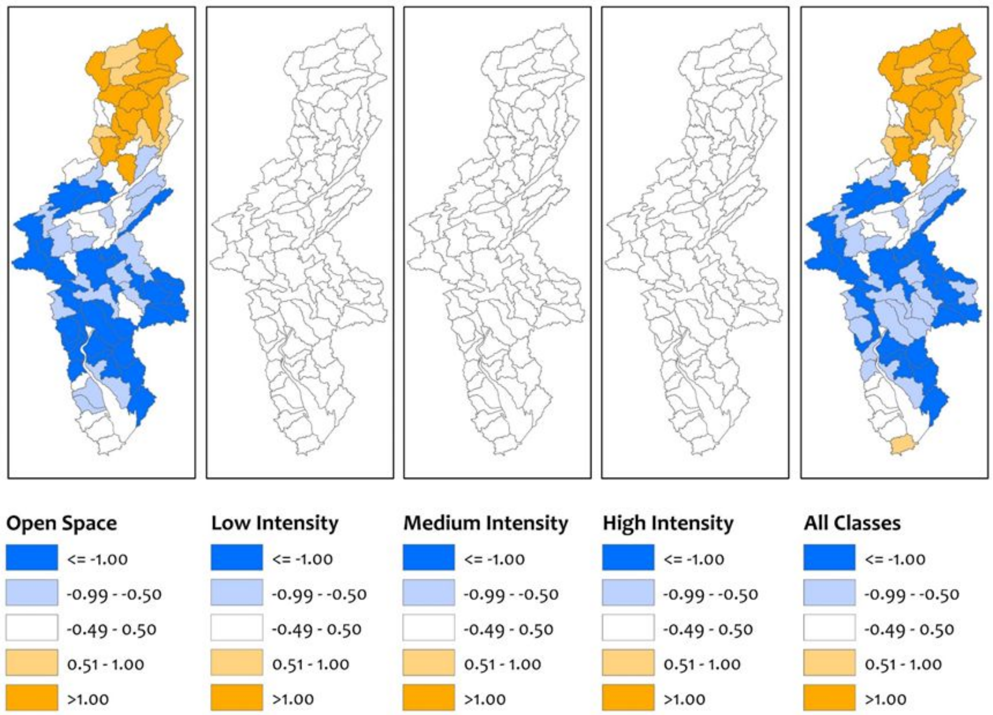

Figure 7: Percent differences between the 2011 and 2016 NLCD editions for each urban class and for all urban classes combined for the year 2011 for HUC 10 watersheds. Shades of orange indicate that NLCD 2016 estimates more relative to NLCD 2011, while shades of blue indicate that NLCD 2011 has higher estimates.

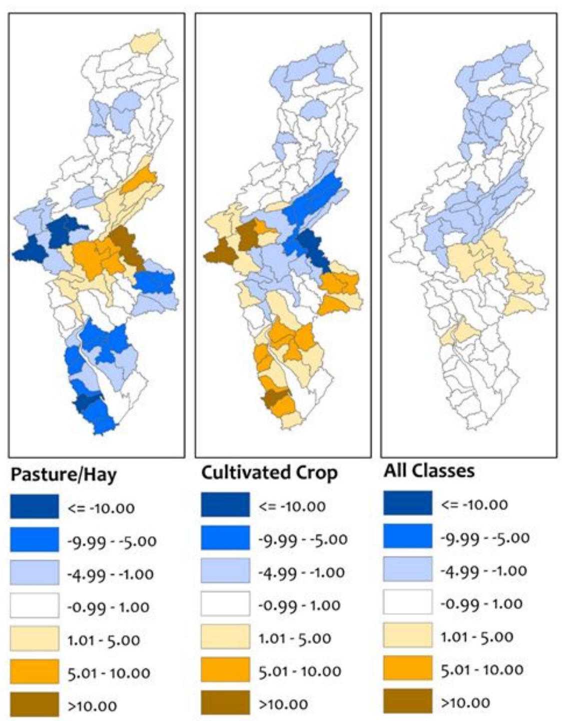

Figure 8: Percent differences between the 2011 and 2016 NLCD editions for each agricultural class and for all agricultural classes combined for the year 2011 for HUC 10 watersheds. Shades of orange indicate that NLCD 2016 estimates more relative to NLCD 2011, while shades of blue indicate that NLCD 2011 has higher estimates.

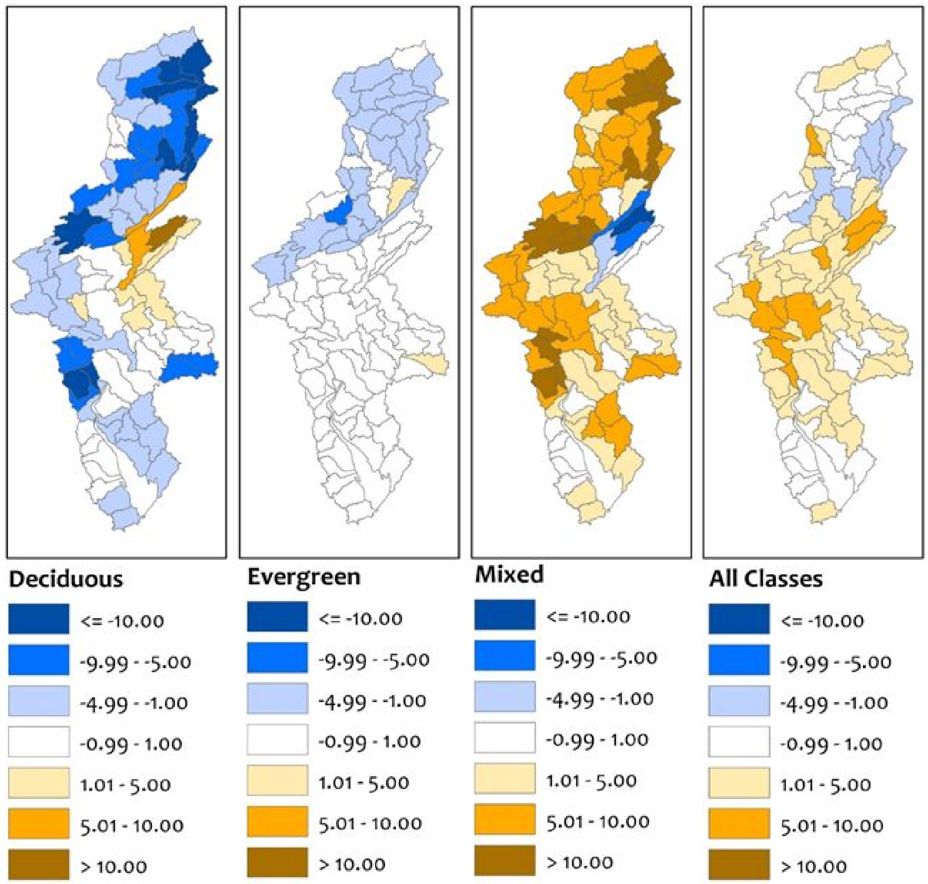

Figure 9: Percent differences between the 2011 and 2016 NLCD editions for each forest class and for all forest classes combined for the year 2011 for HUC 10 watersheds. Shades of orange indicate that NLCD 2016 estimates more relative to NLCD 2011, while shades of blue indicate that NLCD 2011 has higher estimates.

3.3 NHD Catchment Comparison

Variability increases at finer scales. When performing this comparison for much smaller NHD catchments, individual catchments can vary as much as +/- 100% across urban, agricultural, and forest classes (Figures 10 and 11). The aggregated forest class demonstrates the highest variability, with differences exceeding +/- 40% being more common for this class compared to the urban and agricultural classes, where difference exceeding +/- 25% are relatively rare.

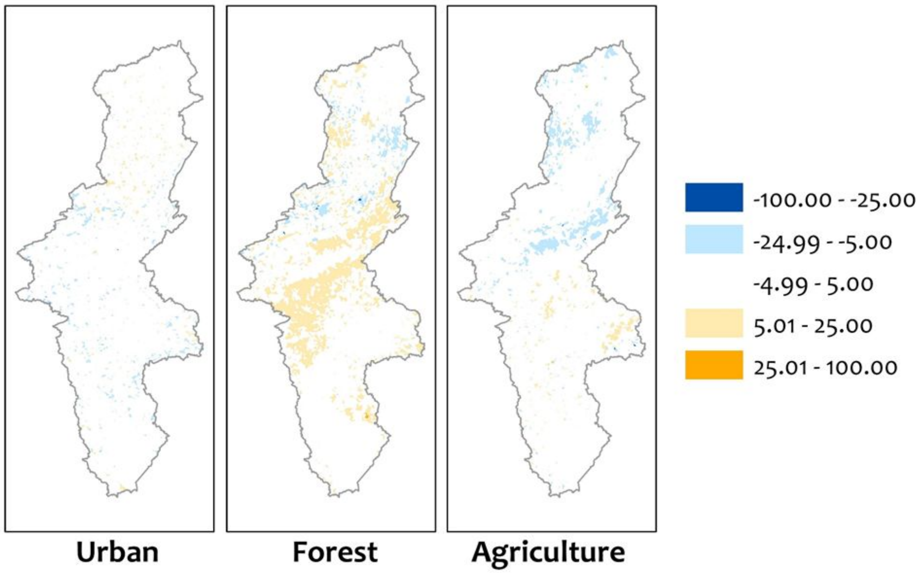

Figure 10: Percent differences between the 2011 and 2016 NLCD editions for aggregated urban, forest, and agricultural classes for the year 2011 for NHD catchments. Shades of orange indicate that NLCD 2016 estimates more relative to NLCD 2011, while shades of blue indicate that NLCD 2011 has higher estimates.

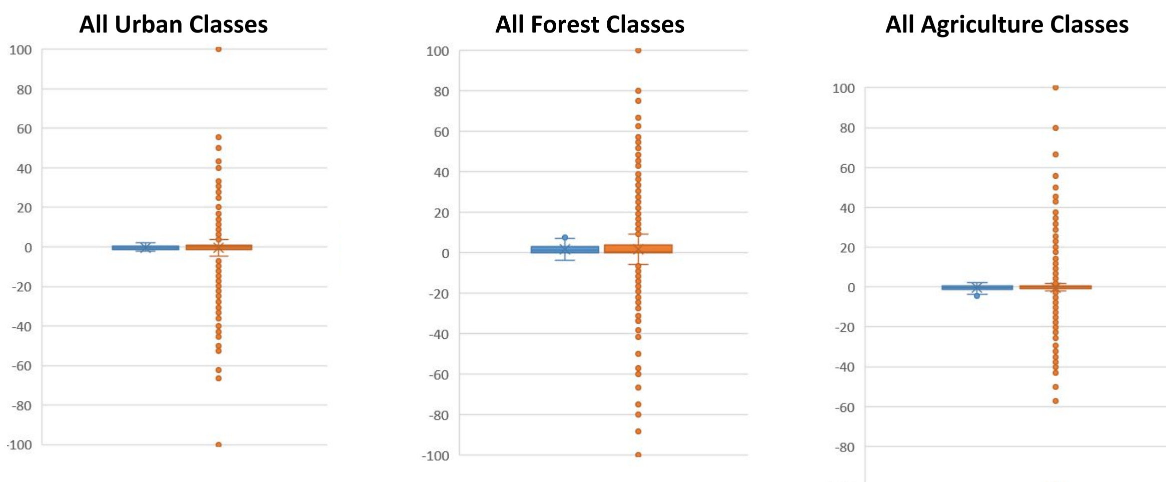

Figure 11: Box plots showing percent differences between the 2011 and 2016 editions for the year 2011 for HUC 10 watersheds (blue) and NHD catchments (orange) for all urban classes combined, all agricultural classes combined, and all forest classes combined.

3.4 Pixel by Pixel Comparison

When the NLCD 2016 and NLCD 2011 editions for the year 2011 are compared on a pixel by pixel basis (Table 2), the classes with the highest agreement are water, where over 96% of the pixels are mapped the same in both editions, and developed high intensity, with an agreement of over 91%. Within the developed classes, developed open space has the lowest agreement between the two editions, with an agreement of 72%. In this case, just over 10% of the pixels mapped as developed open space in the 2011 edition are mapped as deciduous forest in the 2016 editions. Other areas of confusion are in the pasture/hay, mixed forest, row crops, and developed low intensity classes, indicating the spectral similarity of the developed open space class to these other classes.

The class with the lowest agreement is the shrub/scrub class, where the two editions agree across just 18% of the pixels in this category. The highest rates of confusion here are with deciduous forest and mixed forest. Within the grassland/herbaceous, pasture/hay, and row crops classes, there is strong evidence for "class swapping" between spectrally similar classes. For example, overall agreement in the grassland/herbaceous class is 28%, and 22% of the pixels mapped as this class in the 2011 edition are mapped as pasture/hay in the 2016 edition. Similar patterns of class swapping are observed in the three forest classes.

	Water	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed High Intensity	Barren	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub/ Scrub	Grassland/ Herbaceous	Pasture/ Hay	Row Crops	Woody Wetlands	Emergent Herbaceous Wetlands
Water	96.37	0.12	0.05	0.03	0.01	0.29	0.81	0.10	0.32	0.01	0.41	0.07	0.04	0.32	1.07
Developed Open Space	0.18	71.92	3.03	0.42	0.03	0.09	10.10	0.45	3.80	0.33	0.19	4.19	3.40	1.70	0.19
Developed Low Intensity	0.11	6.02	86.67	3.06	0.23	0.14	0.87	0.05	0.36	0.07	0.08	0.95	1.09	0.20	0.11
Developed Medium Intensity	0.08	1.52	6.12	88.06	3.03	0.23	0.21	0.00	0.04	0.02	0.11	0.20	0.30	0.06	0.03
Developed High Intensity	0.06	0.18	1.04	6.63	91.29	0.36	0.04	0.00	0.01	0.01	0.20	0.07	0.10	0.01	0.01
Barren	9.16	1.47	1.37	1.21	0.46	66.07	6.61	0.54	0.87	0.61	4.70	1.50	3.82	0.61	0.99
Deciduous Forest	0.10	3.12	0.20	0.03	0.00	0.09	79.75	0.53	13.37	0.45	0.42	0.80	0.45	0.65	0.04
Evergreen Forest	0.38	2.22	0.17	0.02	0.00	0.11	8.04	46.08	37.48	0.25	0.34	0.61	0.15	4.09	0.07
Mixed Forest	0.28	2.74	0.14	0.02	0.00	0.06	27.82	8.56	57.45	0.17	0.22	0.65	0.20	1.64	0.04
Shrub/ Scrub	0.17	4.86	0.75	0.13	0.02	0.22	32.47	3.31	17.33	18.25	2.04	12.15	6.55	1.61	0.15
Grassland/ Herbaceous	0.63	3.95	1.23	0.41	0.07	1.24	18.27	1.28	3.85	3.47	28.44	21.99	12.62	1.66	0.89
Pasture/ Hay	0.04	3.83	0.64	0.10	0.02	0.03	9.11	0.12	2.12	0.41	0.65	55.64	26.90	0.33	0.08
Row Crops	0.10	2.96	0.89	0.20	0.05	0.21	3.08	0.11	1.00	0.28	0.43	18.04	71.70	0.82	0.15
Woody Wetlands	0.98	1.46	0.19	0.04	0.01	0.03	5.12	0.35	1.53	0.08	0.08	0.74	1.37	84.88	3.14
Emergent Herbaceous Wetlands	5.37	0.32	0.16	0.06	0.01	0.05	0.64	0.02	0.13	0.03	0.11	0.96	1.59	10.50	80.04

Table 2: A confusion matrix comparing the agreement, on a pixel by pixel basis, between the NLCD 2011 edition (rows) and the NLCD 2016 edition (columns) for the year 2011. Grey cells indicate agreement between the two maps.

4.0 Land Cover Trends in the DRB According to NLCD 2016

Overall land cover trends in the DRB (Table 3) show that forests, agriculture, and urban/developed classes comprise the largest changes; urban land cover increases and agriculture and forest decrease. When all developed classes are aggregated, urban land increases by almost 7% (+443 km^2 or 109,373 acres) between 2001 and 2016. Over this same time period, forest lands decrease by 1.44%, a loss of 232 km^2 or 57,293 acres, and agriculture declines by 4.74% (-317 km^2 or 78,357 acres) (Tables 4-6). These trends are consistent over the time period - urban land consistently increases and forest and agriculture consistently decrease - although the rates of change vary. In the case of urban land, that there is no change observed between 2001 and 2004, 2008 and 2008, and 2011 and 2013 is due to the NLCD 2016 mapping protocol as noted above in section 3.1.

Table 3: Area in square kilometers of land cover types in the Delaware River Basin as estimated in the NLCD 2016 edition for all available dates between 2001 and 2016.

Land cover category	2001	2004	2006	2008	2011	2013	2016
Open Water	2,683.18	2,684.27	2,677.21	2,680.40	2,681.73	2,687.13	2,674.61
Developed, Open Space	3,388.55	3,388.55	3,453.85	3,453.85	3,499.54	3,499.54	3,501.01
Developed, Low Intensity	1,743.68	1,743.68	1,795.34	1,795.34	1,833.70	1,833.70	1,863.75
Developed, Medium Intensity	828.06	828.06	900.24	900.24	943.45	943.45	977.70
Developed, High Intensity	383.56	383.56	411.19	411.19	430.61	430.61	444.02
Total Developed	**6,343.86**	**6,343.86**	**6,560.61**	**6,560.61**	**6,707.31**	**6,707.31**	**6,786.48**
Barren Land (Rock/Sand/Clay)	132.55	133.05	129.92	129.29	128.03	126.71	126.78
Deciduous Forest	12,038.33	12,034.04	11,926.33	11,904.28	11,851.36	11,849.24	11,814.00
Evergreen Forest	706.59	707.29	704.28	704.25	701.55	705.50	702.38
Mixed Forest	3,381.68	3,382.96	3,378.08	3,376.42	3,374.28	3,379.15	3,378.35
Total Forest	**16,126.59**	**16,124.29**	**16,008.69**	**15,984.95**	**15,927.19**	**15,933.90**	**15,894.73**
Shrub/Scrub	183.16	190.33	214.74	215.89	222.82	236.24	244.31
Grassland/Herbaceous	107.40	148.16	149.24	177.93	181.08	159.57	169.26
Pasture/Hay	2,945.80	2,890.00	2,838.99	2,829.85	2,782.79	2,785.12	2,753.71
Cultivated Crops	3,745.72	3,756.18	3,690.70	3,693.00	3,642.83	3,644.87	3,620.70
Total Agriculture	**6,691.52**	**6,646.18**	**6,529.68**	**6,522.85**	**6,425.62**	**6,429.99**	**6,374.42**
Woody Wetland	2,221.92	2,218.67	2,216.33	2,232.83	2,238.11	2,260.09	2,262.19
Emergent Herbaceous Wetland	762.54	763.91	766.29	747.95	740.83	711.78	719.93
Total Wetland	**2,984.46**	**2,982.57**	**2,982.62**	**2,980.79**	**2,978.94**	**2,971.88**	**2,982.12**

Tables 4-6: Trends in aggregated urban, forest, and agriculture lands, 2001-2016 in square kilometers, acres, and percent change between each date. Total changes between 2001 and 2016 are also given.

Table 4: Developed lands

Developed	SqKm	Acres	% Change
2001	6,344	1,567,599	
2004	6,344	1,567,599	-
2006	6,561	1,621,160	3.42
2008	6,561	1,621,160	-
2011	6,707	1,657,409	2.24
2013	6,707	1,657,409	-
2016	6,786	1,676,972	1.18
Total change	***443***	***109,373***	***6.98***

Table 5: Forest lands

Forest	SqKm	Acres	% Change
2001	16,127	3,984,961	
2004	16,124	3,984,392	-0.01
2006	16,009	3,955,827	-0.72
2008	15,985	3,949,960	-0.15
2011	15,927	3,935,687	-0.36
2013	15,934	3,937,347	0.04
2016	15,895	3,927,668	-0.25
Total change	***-232***	***-57,293***	***-1.44***

Table 6: Agriculture lands

Agriculture	SqKm	Acres	% Change
2001	6,692	1,653,508	
2004	6,646	1,642,304	-0.68
2006	6,530	1,613,517	-1.75
2008	6,523	1,611,829	-0.10
2011	6,426	1,587,803	-1.49
2013	6,430	1,588,881	0.07
2016	6,374	1,575,150	-0.86
Total change	***-317***	***-78,358***	***-4.74***

5.0 Comparison of NLCD 2016 and the UVM SAL High Resolution Data

5.1 Categorical Land Cover Comparison

In 2016, the University of Vermont Spatial Analysis Lab (UVM SAL) released high resolution (1 meter) land cover data for the Delaware River Basin (UVM SAL 2016) (Figure 12). Based on high resolution aerial imagery, informed by LiDar, parcel data, and other ancillary data, this data set has opened up new opportunities for conservation planning (i.e. better identification of riparian buffer status and needs) and urban forest applications. At the same time, this data set presents some challenges for broad adoption within the Delaware River Watershed Initiative (Jantz et al. 2017).

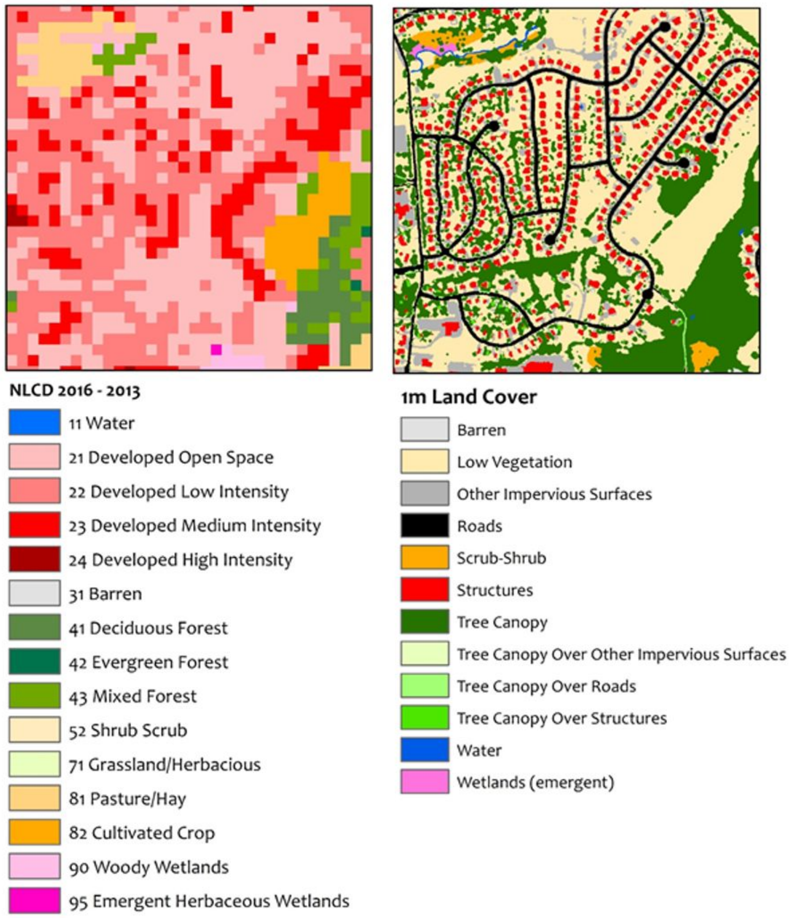

Figure 12: NLCD 2016 for the year 2013 (left) and the UVM SAL circa 2013 (right).

For example, the land classification system in the UVM SAL product differs from the NLCD classification. As seen in Figure 12, the UVM SAL product represents the built environment as structures, roads/railroads, and other paved surfaces, while NLCD has developed open space and low, medium, and high intensity development. From the perspective of water quality modeling, the “low vegetation” class in the UVM product represents lawns, pasture, row crops, and other land covers, all of which have different impacts on water resources (Jantz et al. 2017). Further, due to differences in the resolution (30 m in NLCD and 1 m in UVM SAL), estimates of the area of a number of land cover types (e.g. forest cover) will differ between the NLCD and the UVM SAL product.

With a resolution 900 times more detailed, the UVM SAL data is also a significantly larger data set. The 30 meter resolution of the NLCD products represents an estimated 40.6 million cells in the DRB, while the 1 meter UVM SAL data has an estimated 36.5 billion cells. In terms of file size, as an example, the NLCD land cover data for the year 2013 for Berks County, PA occupies 1.15 MB of disk space, while the UVM SAL is over 300 times larger, occupying 350 MB.

To quantify some of these differences, a comparison of NLCD 2016 for the year 2013 and the circa 2013 UVM SAL data for a sample of three counties representing predominantly urban (Montgomery County, PA), agricultural (Berks County, PA), and forested (Monroe County, PA) landscapes was conducted. This will focus on a comparison of overall quantities, or footprint, of major land cover types, as well as what NLCD land cover types are captured in the "low vegetation" class in the high resolution land cover data.

In order to compare these two data sets, a common classification scheme was defined (Figure 13) where similar land cover types were collapsed in both datasets into a common class. For example, all of the developed classes in NLCD were combined into a single developed class, while any of the impervious surface classes (roads, structures, etc.) in the UVM SAL dataset were combined into a single developed class.

NLCD	Common Class	High Resolution
Water	Water	Water
Developed, Open Space Developed, Low Intensity Developed, Medium Intensity Developed, High Intensity	Developed	Roads Structures Other Impervious Surfaces Tree Canopy Over Structures Tree Canopy Over Other Impervious Surfaces Tree Canopy Over Roads
Barren Land	Barren	Barren
Forest, Deciduous Forest, Evergreen Forest, Mixed Wetlands, Woody	Forest	Tree Canopy
Shrub/Scrub	Scrub/Shrub	Scrub/Shrub
Grassland/Herbaceous Agriculture, Pasture/Hay Agriculture, Cultivated Crops	Low vegetation	Low Vegetation
Wetlands, Herbaceous	Wetlands, Emergent	Wetlands (emergent)

Figure 13: The common classification scheme developed to allow for a comparison of NLCD and UVM SAL data sets.

For each county, the proportion of land cover types was summarized from each data set and then compared (Figures 14-16). Even though the counties differ in terms of dominant land cover patterns (i.e. forest, low vegetation, developed), there are some common patterns. NLCD consistently estimates a higher proportion of developed land, a lower proportion of forest, and a lower proportion of low vegetation relative to the UVM SAL data. This is especially evident in Montgomery County, PA, which is the most urbanized county of the three sample counties.

These differences can be attributed to the different resolutions of the two data products (30 m vs. 1 m). The higher resolution of the UVM SAL data can resolve smaller features of the built environment (i.e. individual building footprints are delineated), yards and open spaces (mapped as low vegetation), and small stands of trees. At the 30 m resolution, the NLCD would map this mix of features as developed open space or developed low intensity, resulting in a much larger developed footprint and a smaller footprint of low vegetation and forest cover. These differences are highlighted visually in Figure 12.

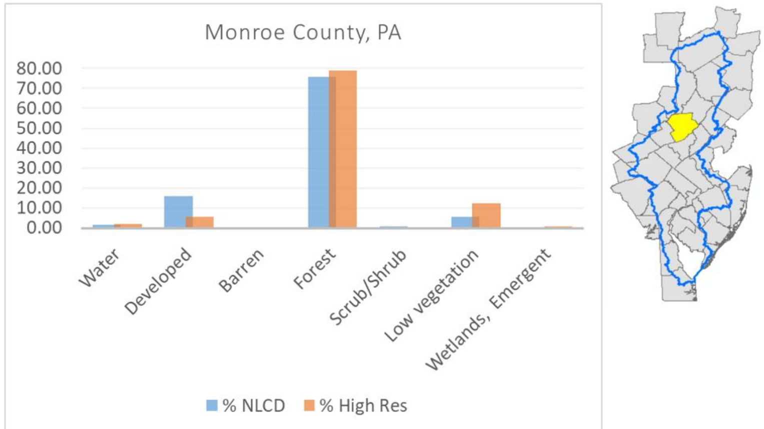

Figure 14: Land cover proportions in Monroe County, PA as estimated from the NLCD 2016 edition for the year 2013 and the UVM SAL high resolution data set.

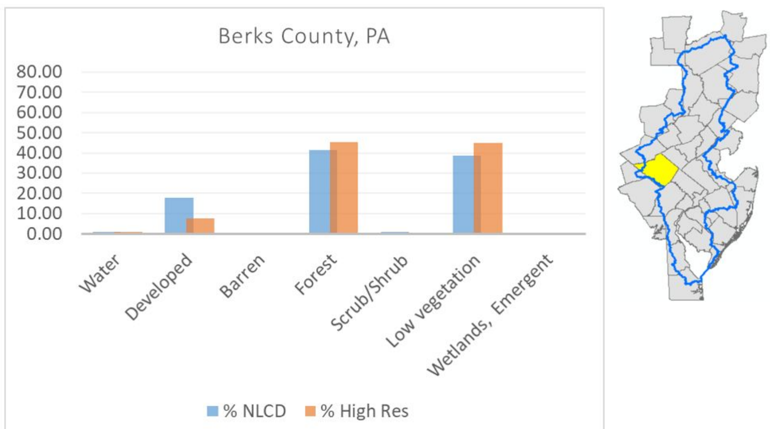

Figure 15: Land cover proportions in Berks County, PA as estimated from the NLCD 2016 edition for the year 2013 and the UVM SAL high resolution data set.

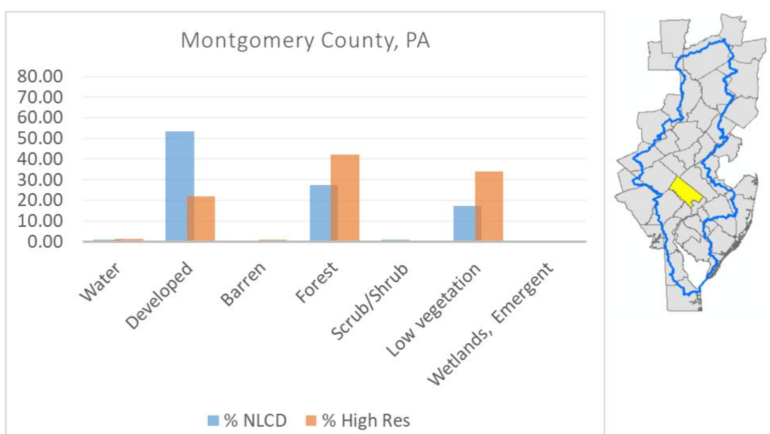

Figure 16: Land cover proportions in Montgomery County, PA as estimated from the NLCD 2016 edition for the year 2013 and the UVM SAL high resolution data set.

5.2 The UVM SAL "Low Vegetation" Class Compared to NLCD

Intersecting the UVM SAL data set's low vegetation class with the NLCD shows a large mix of NLCD classes (Figure 17). In all counties, *all* NLCD classes are represented in the UVM SAL low vegetation category. The proportion of NLCD land covers varies based on the land cover characteristics of the county: in Montgomery County, half of the NLCD land cover types represented in the UVM SAL low vegetation class are developed categories, primarily developed open space and developed low intensity; in Berks County, nearly three quarters are cultivated crops and pasture/hay; and in Monroe County, roughly a third are forest with another third represented by developed open space and developed low intensity.

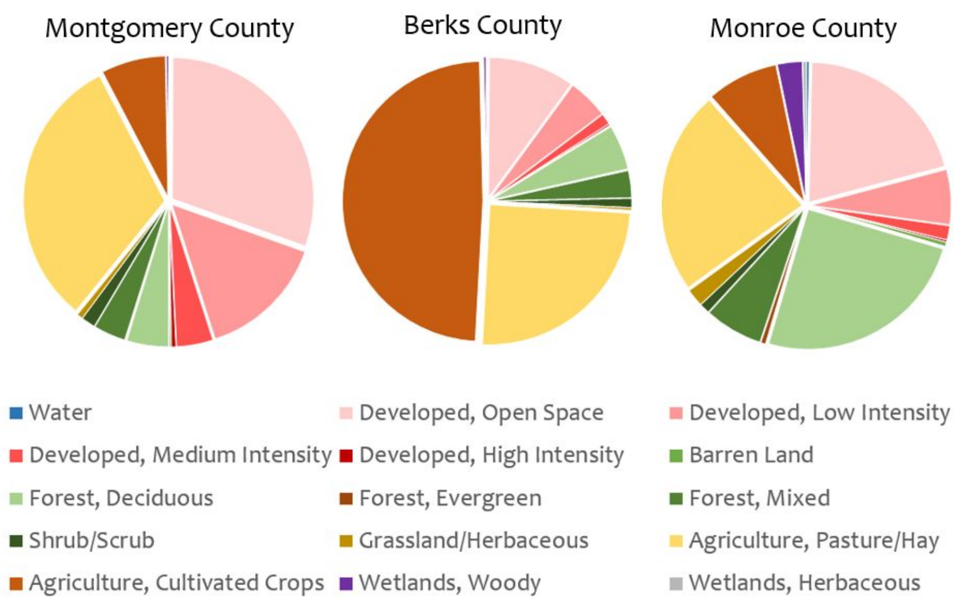

Figure 17: Land cover types in the NLCD dataset that are captured in the low vegetation class of the UVM SAL dataset for Montgomery County, PA (urbanized), Berks County, PA (agriculture and forest), and Monroe County, PA (forested).

When considering how to incorporate the UVM SAL data into the modeling systems of the DRWI, especially water quality and quantity models, the fact that the low vegetation class can be comprised of such a wide range of land cover and land use types is problematic, especially in the middle and lower regions of the Basin where there will be a higher proportion of this class. While this does not negate the other benefits of the high resolution land cover product, if there is a need for higher resolution data in modeling applications, additional processing of the UVM SAL data will be necessary.

5.3 Impervious Surface Area Comparison

The above analysis focused on the footprint of each land cover class between the NLCD 2016 edition categorical land cover data set and the UVM SAL data. However, because the NLCD also includes sub-pixel estimates of impervious surface area (ISA) (Figure 3), a comparison of overall impervious surface estimates between these two products can also be made (Figure 18). To make this comparison, the total area of impervious surface from the 1 meter UVM SAL data, as represented by the "developed" classes in this data set (Figure 12), was summed for each of the three sample counties. Then, the total impervious area from the NLCD subpixel impervious surface product was estimated by multiplying the proportion of ISA in each pixel by 900 m^2 and then summing this area for each county.

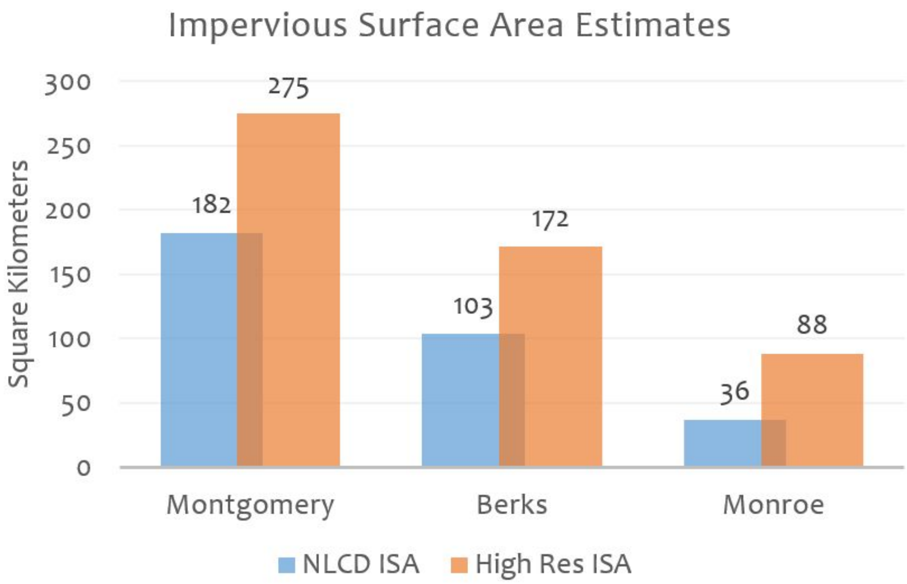

Figure 18: A comparison of the impervious surface area estimates (in square kilometers) in the three sample counties from the NLCD 2016 edition subpixel impervious surface product (blue) and the UVM SAL high resolution data (orange). The date for the NLCD data is 2011.

As seen in Figure 18, when ISA estimates are compared between the two products, the NLCD consistently *underestimates* relative to the UVM SAL data. This is likely due to the fact that the high resolution data is better able to capture all impervious features, especially smaller features and features under tree cover. While the NLCD estimates a larger footprint relative to the UVM SAL data for classes that are comprised of impervious surfaces (Figures 14-16), it underestimates the impervious surface area.

6.0 The Chesapeake Bay 10 Meter Hybrid Land Use Product

Facing similar challenges with land cover data products, the U.S. Geological Survey, overseen by the Chesapeake Bay Program's Land Use Workgroup, created a 10 meter product for the Chesapeake Bay Program's Phase 6 Chesapeake Bay Watershed Model (U.S. Geological Survey 2018). This dataset is derived from a 1 meter land cover data product that is similar to the UVM SAL product that was developed for the DRB. Using ancillary data, such as land parcels, terrain, the National Agricultural Statistics Service (NASS) cropland layer, and multi-scale filtered impervious non-road to identify "rural" areas, the 2013 Phase 6 Land Use Data Sets are comprised of thirteen data layers that represent the percentage of land use within each 10 meter pixel for thirteen different land use and land cover classes (Table 7 and Figures 19 and 20).

Table 7: Land use/land cover classes included in the 2013 Phase 6 Land Use Data Sets. Each class is represented in a separate layer, and each layer represents the percent cover within 10 m x 10 m pixels.

Water
Impervious Roads
Impervious Non-Roads
Turf Grass
Tree Canopy over Impervious Surfaces
Tree Canopy over Turf Grass
Forest
Mixed Open
Cropland
Pasture/Hay
Floodplain Wetlands
Tidal Wetlands
Other Wetlands

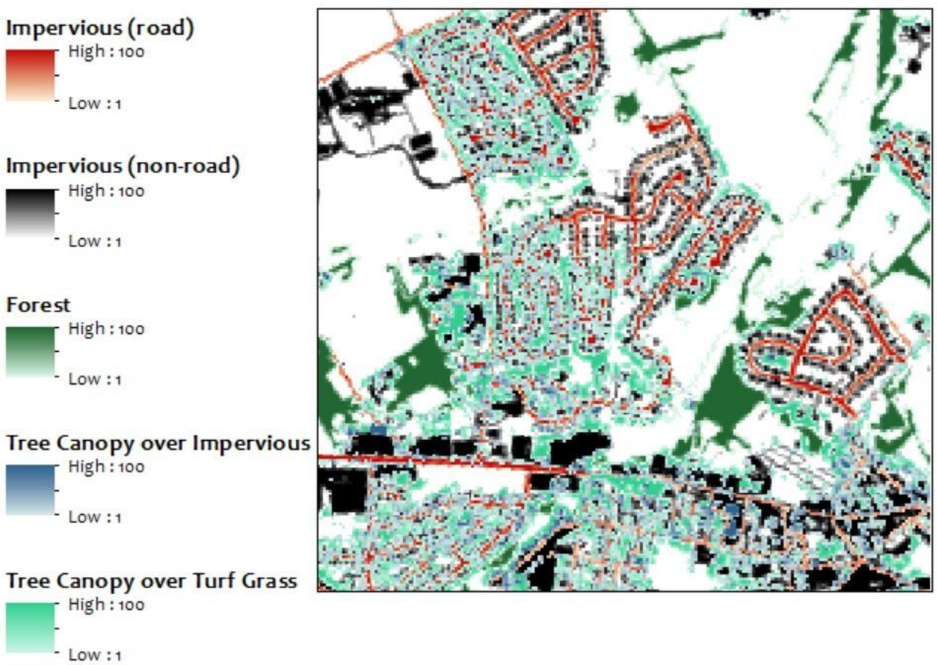

Figure 19: An example of the Phase 6 Land Use Data Sets, showing the two impervious surface layers, the two tree canopy layers, and the forest layer.

The 2013 Phase 6 Land Use Data Sets maximize the resolution gains made by the 1 meter data and the thematic richness of the NLCD (Figure 20). It was developed with a specific application, as input into the Phase 6 Chesapeake Bay Watershed Model, and thus focused on mapping classes with unique nutrient loading characteristics. In pursuing this goal, some areas could not be categorically defined at 1-meter resolution. For example, junkyards and highway rights-of-way are herbaceous yet heavily compacted. Therefore, they perform hydrologically somewhat like impervious cover and somewhat like turf grass. At 10-meter resolution, these fractional classes could be accurately split into their respective categorical classes. One convenience of these data, beside their reduced file size, is that the cell contents represent both percentages and areas (because there are 100 1-meter cells in a 10-meter cell) (Peter Claggett, personal communication).

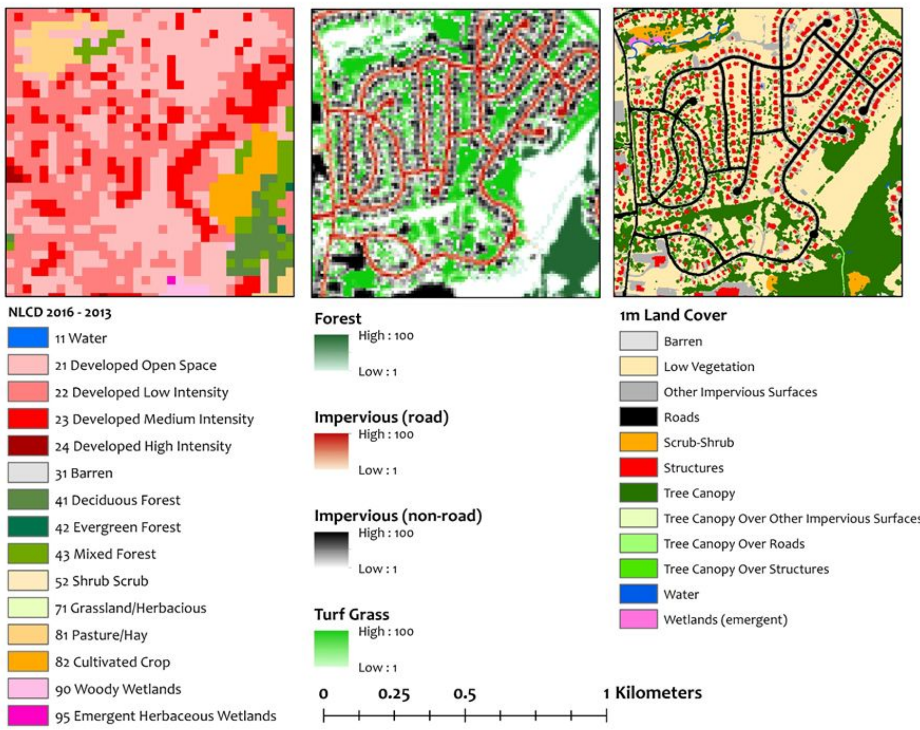

Figure 20: A comparison of the NLCD 2016 edition for the year 2013 (30 meter resolution), a subset of the 2013 Phase 6 Land Use Data Sets (10 meter resolution), and the UVM SAL 2013 data (1 meter resolution) illustrating the differences in spatial resolution and land use/land cover classes available in each data set.

7.0 Conclusions and Recommendations

7.1 NLCD 2016 versus NLCD 2011

The NLCD 2011 is now a legacy product; it is no longer available for download and no longer supported by the Multi-Resolution Land Characteristics Consortium (MRLC). This implies that adoption of the NLCD 2016 product for the DRWI is required. The NLCD 2016 edition should be adopted as the new baseline for land cover trends, patterns, and distributions. It should be emphasized that the NLCD 2011 and NLCD 2016 editions are not compatible, so when users adopt the 2016 edition the entire time series should replace the 2011 time series.

The benefits of the 2016 edition include the ability to analyze changes on finer time steps (2001, 2003, 2006, 2011, 2013, 2016), although urban changes will only be captured for 2001, 2006, 2011, 2016. This fact should not be underestimated in terms of how it will affect land change analysis: the additional time steps area only useful in areas with minimal urbanization. For example, changes in forest cover over all seven dates will not be meaningful if such areas are subject to urbanization pressures, although they will show non-urban change, such as rotational timber harvesting, mining, or natural transitions.

The differences between NLCD 2011 and NLCD 2016 are most noticeable at local scales. They vary geographically across the DRB but not consistently, varying by land cover class. Because of these differences, and the need to adopt the 2016 data product, users should have a communication strategy to address why “new” numbers are different from “old” numbers.

7.2 NLCD versus UVM SAL 1 meter data

The 1 meter UVM SAL land cover data set is potentially transformative as a conservation planning tool. However, challenges to widespread adoption have been noted in Jantz et al. (2017), and some of those issues are highlighted here. For users that are accustomed to the NLCD data products, the UVM SAL land cover classification differs. Differences between NLCD and UVM SAL in the amount or distribution of land use/land cover and impervious surface estimates will also be encountered, which may cause confusion for some users. For some users, including water quality and quantity modelers, the lack of land use information captured in the low vegetation class is especially problematic.

7.3 Options for an Alternative Product

The 10 meter resolution 2013 Phase 6 Land Use Data Sets are introduced and summarized here as a potential alternative product that blends the strengths of a 1 meter land cover product and the 30 meter NLCD. This particular data set was developed for a very specific purpose, as input into the Phase 6 Chesapeake Bay Watershed Model. Comprised of thirteen different data layers where land cover is represented as a continuous variable, it may be ultimately somewhat cumbersome as a conservation planning tool. If a hybrid product is pursued for the DRWI, it should be undertaken with broad stakeholder input so that the end product meets the needs of users.

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