Center for Land Use and Sustainability
SHIPPENSBURG UNIVERSITY

DRB2070 Version 2 Baseline & Alternative Scenarios

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Product overview:

DRB2070 Version 2 represents a revised baseline forecast and two new alternative forecasts ("corridors" and "centers") of urban land cover in the Delaware River Basin (DRB), out to 2070. To develop these forecasts, we calibrated the SLEUTH urban growth model[1] for our modeling subregions over the 2001-2006 time period, and validated the model for the 2006-2011 time period. We used the National Land Cover Database (NLCD)[2] urban classes to represent urban land cover as developed or not developed (**Figure 1**).

The data packaged in the ArcMap document is described in **Appendix 1**, and represents forecasts of urban land cover in 2030 and 2070, summarized by National Hydrography Dataset Plus (NHDPlus, version 2.0)[3] catchments, for the baseline scenario and two alternative scenarios.

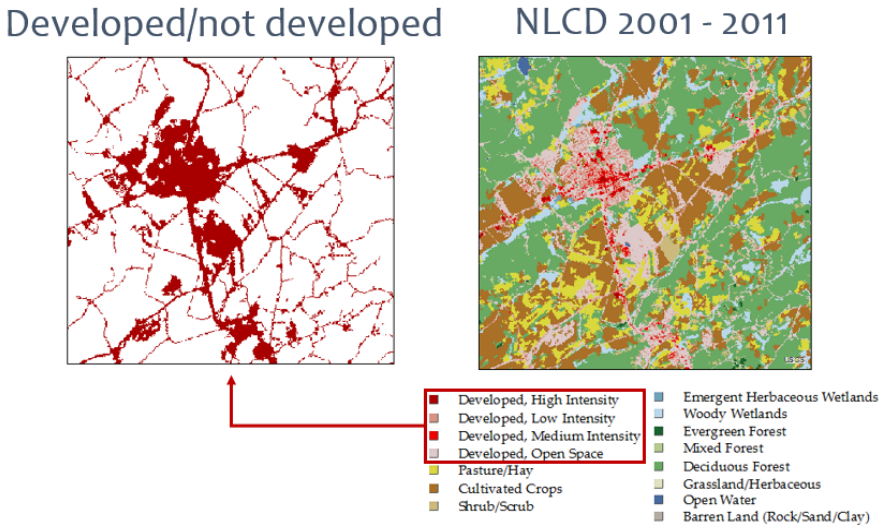

Figure 1: All four NLCD developed classes were consolidated into a single representation to designate developed/non developed as required for SLEUTH input.

[1] The National Center for Geographic Information and Analysis. University of California, Santa Barbara. Project Gigalopolis. http://www.ncgia.ucsb.edu/projects/gig/
[2] U.S. Geological Survey. The National Land Cover Database. https://www.mrlc.gov/
[3] U.S. Geological Survey. National Hydrography Dataset. https://nhd.usgs.gov/

DRB Modeling Subregions:

The Delaware River Basin is a large area, with the following characteristics:

- 43 overlapping counties in 5 states
- 35,000 sq. km (13,500 sq. miles)
- 8.2 million residents [4]
- 3.6 million payroll jobs[5]
- Provides water resources and ecosystem services to more than 15 million people, or 5% of the US population. [6]

We explored trends across all counties in the DRB and Delmarva peninsula to identify patterns in population, employment, and commuter flows, the main drivers of development on which we focus. Because of heterogeneous land cover dynamics across this large region, we subdivided the region into smaller, homogeneous modeling subregions to improve accuracy. We found that commuter flows between counties allowed us to group counties that share similar characteristics into eight different subregions. These subregions were named after the largest city within the region, where growth was focused, and modeled independently: Albany, Allentown, Baltimore- Annapolis, Delaware, Harrisburg, New York Metro, Philadelphia, and Upper-DRB (**Figure 2**).

Before generating forecasts, the demand for new developed land by 2070 was estimated. For the baseline land cover scenario, we calculated the average amount of development per person from 2001-2006 using Daily Human Intensity (DHI), or the sum of population and employment density. Finding the relationship between DHI and urban extent allows us to use population and employment projections to estimate the expected amount of development in 2070 for each subregion.

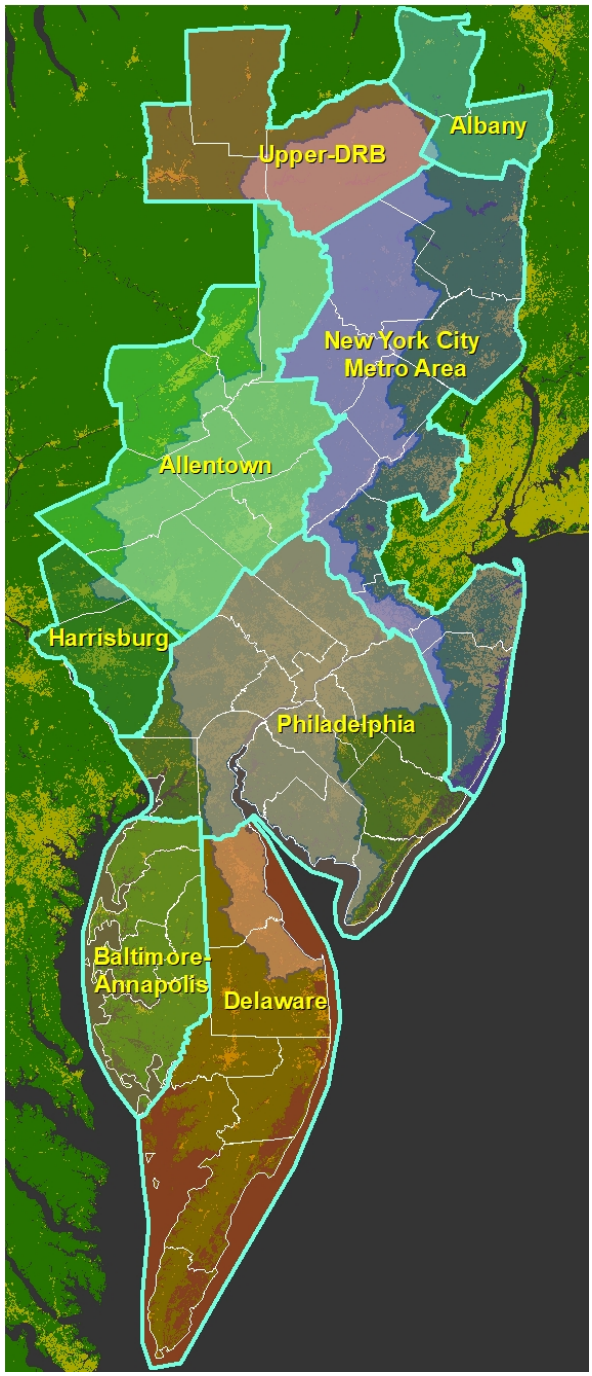

Figure 2: Subregions used to model land cover dynamics in the DRB and Delmarva Peninsula

[4] US Census Bureau. American Community Survey Demographic and Housing Estimates, 2009-2013 American Community Survey 5-year Estimates.
[5] US Census Bureau. Longitudinal Employer-Household Dynamics, 2013.
[6] Delaware River Basin Commission. "Basin Information." http://www.state.nj.us/drbc/basin/. Accessed March 9, 2017.

Modeling Scenarios:

Because of the inherent difficulties in making reliable and accurate *predictions* of future land use changes, scenarios are often used to explore feasible visions, or *forecasts*, of what the future might look like. To develop the baseline and alternative scenarios, we held a series of focus groups throughout the DRB, deployed an on-line widely distributed survey, and held a scenario writing workshop **(Figure 3)**.[7, 8] These stakeholder engagement activities allowed us to identify define key trends and drivers of land use change and to define a reasonable baseline scenarios and two alternative scenarios.

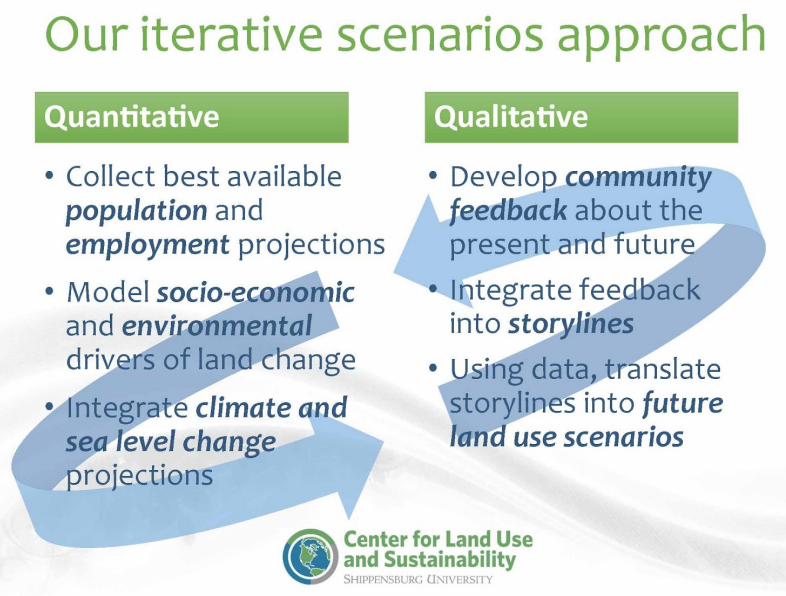

Figure 3: Iterative approach to develop scenarios in the DRB using the best available qualitative and quantitative data.

The Pinchot Institute for Conservation sponsored a customized model for the Poconos-Kittatinny Cluster (PKC), one of eight project areas in the Delaware River Watershed Initiative.[9] The PKC region is unique in that the main drivers of land use change are related to the scenic and recreational resources (i.e. second-home development); population and employment growth in distant metro areas; and broader scale economic trends - drivers that were not adequately captured in the Basin-wide model. Given the more detailed modeling approach and the fact that the PKC scenarios are analogous to the Basin-wide scenarios, PKC2070 version 2.1[10] data within the PKC boundary has replaced the Basin-wide results.

Exclusion/Attraction Layer:

The primary input layer to SLEUTH is the exclusion/attraction layer, a layer that describes areas that are more or less suitable for urban development. The exclusion/attraction layer developed for the DRB baseline scenario is the result of statistical and spatial modeling of accessibility, environmental suitability, employment and population spatial dynamics, and land protection. We then adapted the baseline exclusion/attraction layer to reflect the two alternative scenarios (**Figure 4**).

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[7] Price, A., C. Jantz, S. Drzyzga, A. Yáñez Morillo, D. Minnick, J. Barth, and C. Lucas. (2017). A community-driven approach to developing future land use scenarios at the river basin scale: An example from the Delaware River Basin. US-IALE 2017 Annual Meeting- Baltimore, MD.

[8] Choosing Trajectories: An Aide for Modeling Future Land Use Scenarios in the Delaware River Basin– Created for our DRB2070 Scenario Development Workshop in Media, PA (10/18/16)

[9] Delaware River Watershed Initiative. http://www.drwi.net/poconos-kittatinny-1

[10] PKC2070 Version 2.1 Documentation for baseline and alternative scenarios in the PKC Cluster.

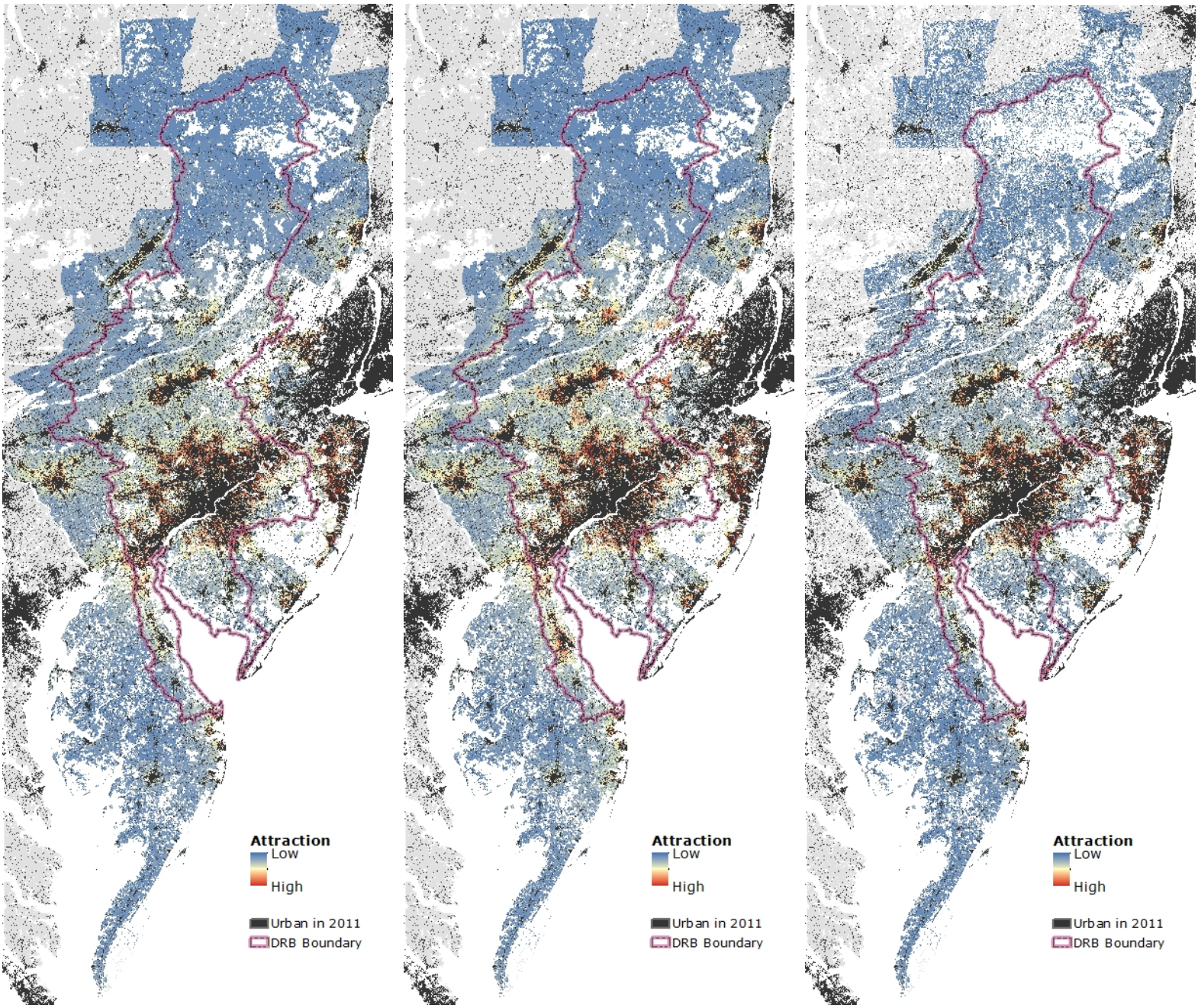

Figure 4: The exclusion/attraction layers used to drive the 2030 and 2070 baseline forecast (left), sprawl and growth along corridors (middle), and conservation and growth in urban centers (right). See the PKC2070 version 2.1 documentation for exclusion/attraction layers specific to that area.

For the baseline and alternative scenarios, trajectories were determined for population growth, regional build-out, regional infrastructure, and conservation efforts. These factors, along with assumptions regarding sea level rise and storm surge, were used to develop individualized exclusion/attraction layers prior to modeling future land cover using SLEUTH.

"Baseline" Land Cover Scenario (revised from DRB2070 version 1.0):

The "baseline" land cover scenario represents recent trends in the Delaware River Basin for population growth, employment, regional build-out, regional infrastructure, and conservation efforts. It also assumes future sea level rise and storm surge. (Corresponding PKC2070 scenario: baseline).

- *Population Growth Trajectory*: We based the population trajectory on state county-level forecasts to 2020 and the EPA Integrated Climate and Land-Use Scenarios (ICLUS[11]) Basecase (BC) population forecast to 2070 (see **Figure 5**). The BC forecast relies on moderate fertility, domestic migration, and net international migration rates, which reflect recent historical rates. Summary statistics for the resulting urban land cover change trajectory are presented for the entire modeling domain (including the Delmarva Peninsula), the 43 counties that intersect the DRB, and the DRB in **Table 1**.

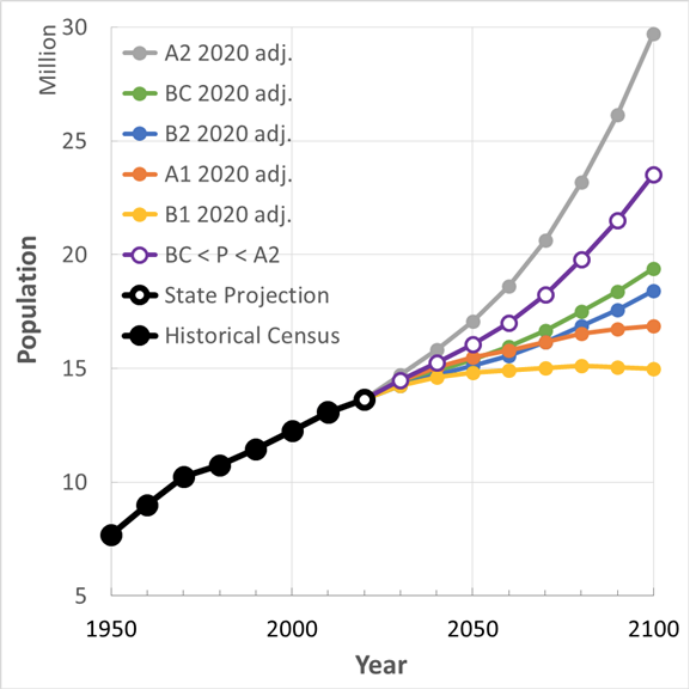

Figure 5: Population projections used to drive the Basin-wide baseline and alternative future scenarios with state projections to the year 2020, and ICLUS scenarios until 2070.

Note: for the corridors scenario, participants wished to see population growth between the BC and A2 estimates produced by the EPA. Our team combined BC and A2 to yield a 2070 population that is 8% larger than "BC 2020 adj." population for the same year.

- *Regional Build-Out Trajectory*: our model considered accessibility to different resources: transportation (e.g. roads and intersections), urban density, and recreational resources (natural areas and water) as positive drivers to attract development. Large-scale development plans were also included, such as the casino in Monticello, New York.
- *Regional Infrastructure Trajectory*: Our model includes current roads and rail. After modeling, an analysis of energy infrastructure (electric and pipeline) will be released.
- *Conservation Efforts*: Non-forested wetlands are fully protected, forested or shrub wetlands have moderate to weak protection and we included protected lands as

[11] Integrated Climate and Land-Use Scenarios, version 1.3.2. County Population Projections. Environmental Protection Agency. https://www.epa.gov/iclus

indicated in the PAD-US data. The Nature Conservancy's secured areas layer was included in our exclusion/attraction layer. The Upper Delaware Scenic & Recreational River Corridor was removed from excluded areas.

- *Sea Level Rise and Storm Surge Risk:* We accounted for a global average of 6 feet (1.8 meters) sea level rise and Category 2 storm surge risk for the basin, and added moderate repulsion of growth (with a gradient depending on depth) in affected areas.

"Corridors" Land Cover Scenario: Climate-induced westward expansion: the new frontier (population growth along corridors)

The "corridors" land cover scenario explores a future with higher than baseline population growth (i.e., more) and increased growth along corridors (i.e., different pattern). (Corresponding PKC2070 scenario: sprawl with low conservation).

- *Population Growth Trajectory:* We based the population trajectory in the DRB state forecasts to 2020 and a combination of the EPA Integrated Climate and Land-Use Scenarios (ICLUS[12]) Basecase (BC) and A2 population forecasts to 2070 (see **Figure 5**). Including the A2 forecast effectively simulates a future with increased population growth and domestic migration along with decreased net international migration. Summary statistics for the resulting urban land cover change trajectory are presented in **Table 1**.
- *Regional Build-Out Trajectory*: our model considered accessibility to different resources: transportation (e.g. roads and intersections), urban density, and recreational resources (natural areas and water) as positive drivers to attract development. Large-scale plans for development were also included, such as the casino in Monticello, New York.
    - Growth was focused along designated corridors (I-84, I-80, I-78, I-476, and along the Delaware Water Gap).
    - Greenfield development was emphasized with a higher land consumption ratio.
- *Regional Infrastructure Trajectory*: Our model includes current roads and rail. After modeling, an analysis of energy infrastructure (electric and pipeline) will be released.
    - Planned stations for the Lackawanna cutoff were included
- *Conservation Efforts*: Non-forested wetlands are fully protected, forested or shrub wetlands have moderate to weak protection and we included protected lands as indicated in the PAD-US data. The Nature Conservancy's secured areas layer was included in our exclusion/attraction layer. The Upper Delaware Scenic & Recreational River Corridor was removed from excluded areas.
- *Sea Level Rise and Storm Surge Risk:* We accounted for a global average of 6 feet (1.8 meters) sea level rise and Category 2 storm surge risk for the basin, and added moderate repulsion of growth (with a gradient depending on depth) in affected areas.

[12] Integrated Climate and Land-Use Scenarios, version 1.3.2. County Population Projections. Environmental Protection Agency. https://www.epa.gov/iclus

"Centers" Land Cover Scenario: Amenity driven development in urban centers (population growth in historic centers)

The "centers" land cover scenario explores a future with higher than baseline conservation efforts and growth occurring in existing historic centers. (Corresponding PKC2070 scenario: smart growth and high conservation).

- *Population Growth Trajectory*: We based the population trajectory in the DRB state forecasts to 2020 and the EPA Integrated Climate and Land-Use Scenarios (ICLUS[13]) Basecase (BC) population forecast to 2070 (see **Figure 5**). The BC forecast relies on moderate fertility, domestic migration, and net international migration rates, which reflect recent historical rates. Summary statistics for the resulting urban land cover change trajectory are presented in **Table 1**.
- *Regional Build-Out Trajectory*: our model considered accessibility to different resources: transportation (e.g. roads and intersections), urban density, and recreational resources (natural areas and water) as positive drivers to attract development. Large-scale plans for development were also included, such as the casino in Monticello, New York.
    - Growth was deemphasized along roads and growth corridors and emphasized around existing/historic urban centers. Higher infill rates are assumed.
- *Regional Infrastructure Trajectory*: Our model includes current roads and rail. After modeling, an analysis of energy infrastructure (electric and pipeline) will be released.
- *Conservation Efforts*: Non-forested wetlands are fully protected, forested or shrub wetlands have moderate to weak protection and we included protected lands as indicated in the PAD-US data. The Nature Conservancy's secured areas layer was included in our exclusion/attraction layer. The Upper Delaware Scenic & Recreational River Corridor was removed from excluded areas.
    - Strong protection of at least 100 ft. buffer was placed around all exceptional value high quality streams
    - Complete protection of contribution zones and flat zones as delineated in The Nature Conservancy (TNC)'s active river layer
    - All slopes >15% were completely protected
- *Sea Level Rise and Storm Surge Risk*: We accounted for a global average of 6 feet (1.8 meters) sea level rise and Category 2 storm surge risk for the basin, and added moderate repulsion of growth (with a gradient depending on depth) in affected areas .

Urban land cover trajectories:

To observe and summarize change over time, we present total developed land cover for the observational time period (2001, 2006, and 2011) and for each forecast scenario for 2030 and 2070 for three areas of interest: the full modeling domain (DRB and Delmarva intersecting counties), the 43 counties intersecting the DRB, and the DRB boundary (**Table 1)**. Observational data for 2001-2011 were derived from the NLCD and forecasts, along with standard error, were

[13] Integrated Climate and Land-Use Scenarios, version 1.3.2. County Population Projections. Environmental Protection Agency. https://www.epa.gov/iclus

calculated as the average of 100 Monte Carlo trials per year. We initially calculated developed land cover area for NHDPlus catchments for the entire modeling domain, and then summarized the catchment data for each region of interest.

Table 1: Developed land in acres for the observational time period (2001-2011) and for forecasts of development in the baseline and alternative scenarios (2030-2070). Standard error is given in acres for the 95% confidence interval over 100 Monte Carlo trials.

Scenario	Year	Full Modeling Region (DRB and Delmarva)	DRB Counties (43 counties total)	DRB Boundary
(Observed)	2001 2006 2011	2,906,382.4 2,999,793.8 3,063,321.8	2,698,458.0 2,787,104.5 2,848,222.1	1,595,968.0 1,645,858.6 1,678,948.4
Baseline *Corridors* *Centers*	2030	3,309,192.7 ± 11,142.7 3,403,487.4 ± 13,900.3 3,219,059.6 ± 7,665.8	3,085,253.4 ± 10,580.9 3,174,051.7 ± 13,161.6 2,998,819.1 ± 7,298.2	1,804,675.9 ± 5,957.8 1,858,721.4 ± 7,523.3 1,758,753.5 ± 4,138.1
Baseline *Corridors* *Centers*	2070	3,581,884.7 ± 19,731.7 3,869,169.2 ± 25,026.8 3,370,276.6 ± 11,986.1	3,348,679.0 ± 18,732.8 3,619,945.9 ± 23,598.3 3,145,203.8 ± 11,407.4	1,948,892.7 ± 11,080.8 2,117,175.4 ± 13,594.7 1,838,785.0 ± 6,608.7

Urban land trajectories within the Delaware River Basin boundary for each of the three scenarios are summarized in **Figure 6**. Note that the corridors scenario predicts the highest levels of development, while the centers scenario has the lowest.

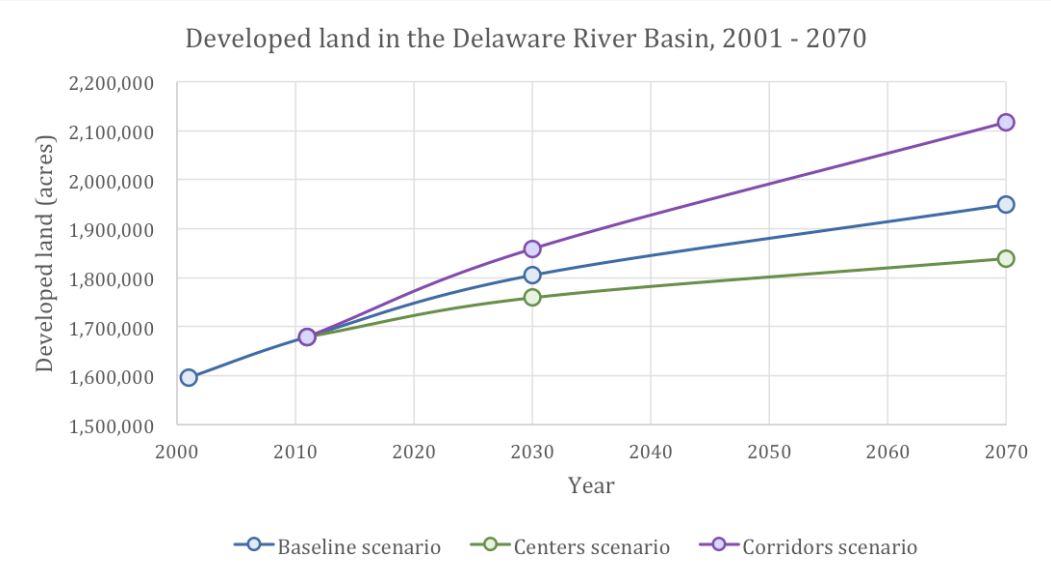

Figure 6: Urban land cover change trajectory within the DRB boundary from 2001 - 2011 (observed from NLCD) and from 2011 - 2070 (DRB2070 Version 2 forecast) for the baseline and alternative scenarios.

Appendix 1. Data Available in the ArcMap Document

To visualize the results of the 2070 forecasts, we are providing a zip file that includes an ArcMap document and these data sets:

- DRWI cluster boundaries (for reference)
- DRB and county boundaries (for reference)
- National Hydrography Dataset Plus (NHDPlus, version 2.0) catchments symbolized based on the proportion of the catchment that is occupied by developed land cover (e.g. catchments in the <1% category have less than 1% of developed land cover in any given time period) for the observational time periods of 2001 and 2011, and for 2030 and 2070 under each forecast scenario. These are the same catchments that are used in SRAT.
    - We note that these are the only time periods symbolized in the ArcMap document. Decadal summaries from 2020 to 2070 are available in the attribute tables.

We have saved the ArcMap document as version 10.5, 10.4, 10.3, and 10.1 to ensure compatibility with your version. These are identical except for the version. All data sets include an item description that can be referred to for additional information.