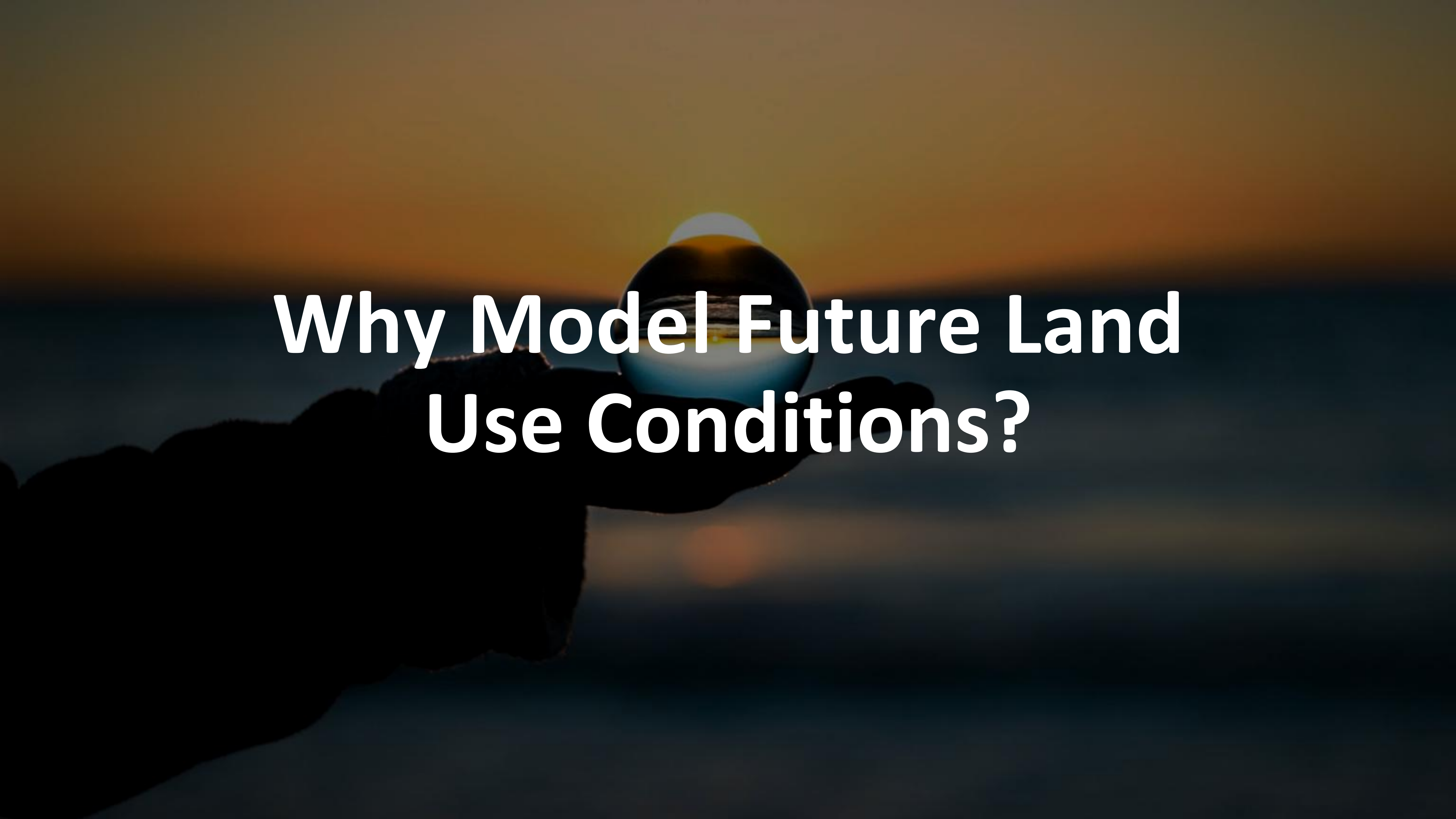
Simulating Future Development in the Chesapeake Bay Watershed

Modeling the Effects of Population, Employment, and Renewable Energy on Land Use Change

Peter Claggett, Labeeb Ahmed, Michelle Katoski, Sarah McDonald, and Jackie Pickford
U.S. Geological Survey

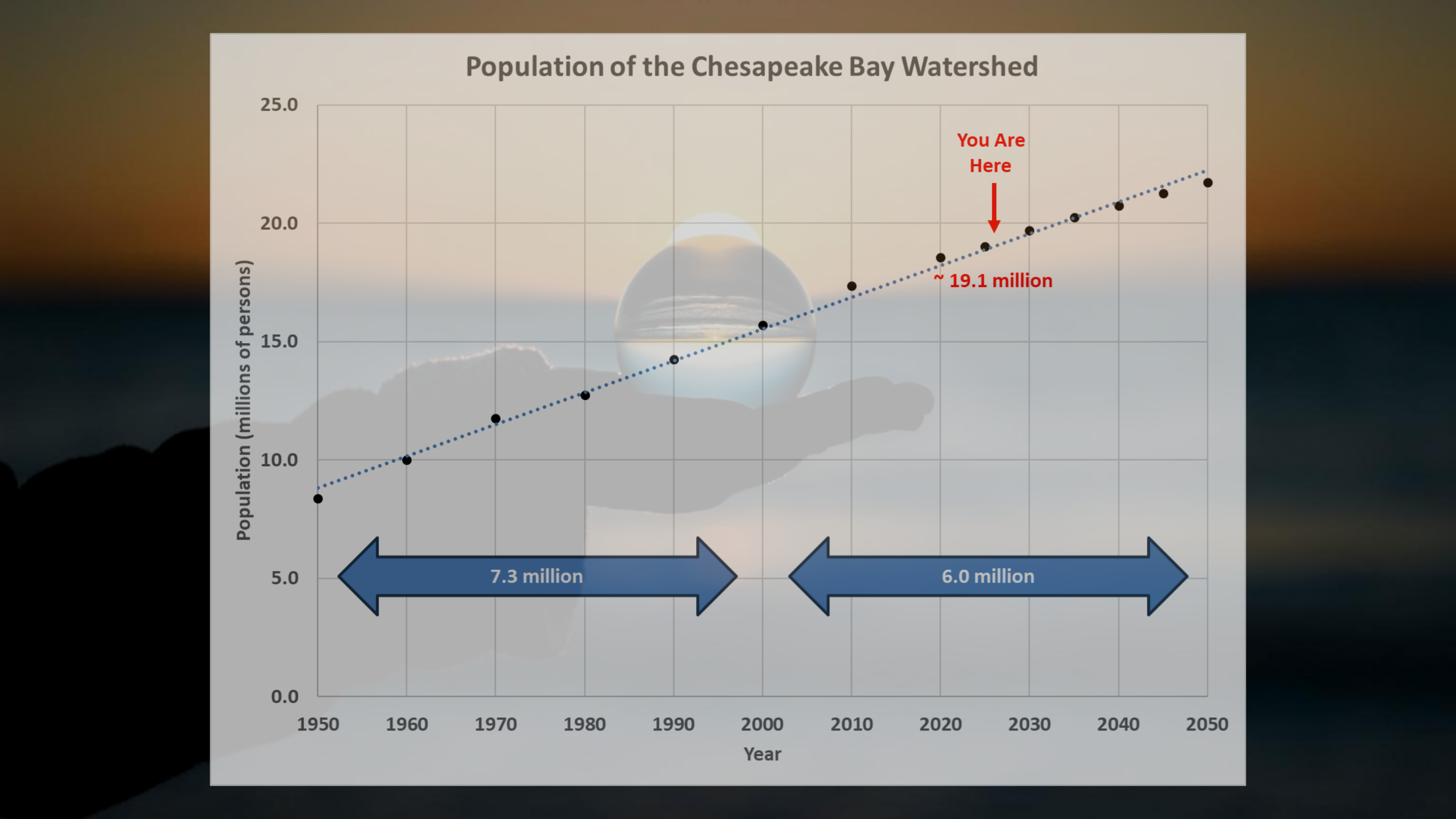
Land Use Workgroup Meeting
June 17, 2026

U.S. Department of the Interior
U.S. Geological Survey


Why Model Future Land
Use Conditions?

Large-scale ecosystem restoration and infrastructure projects take decades to accomplish.

Over decades, population growth coupled with changes in technology, climate, and energy production may significantly alter the landscape, challenging assumptions behind today’s restoration strategies and decisions.


Population of the Chesapeake Bay Watershed
25.0
20.0
15.0
10.0
5.0
0.0
Population (millions of persons)
You Are Here
~ 19.1 million
7.3 million
6.0 million
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year

Role of Future Land Use in Phase 7 CAST and Bay Agreement

1. Annual CAST Progress runs are based on an interpolation between the latest mapped land use (2022) and the “Business As Usual” (BAU) forecast for 2040.

2. Long-range water quality assessments (2075) on the effects of changing environmental conditions require changes in land use to be represented as one of those conditions.

3. Assessing development pressure on wildlife habitat, healthy watersheds, brook trout, and tidal land USWG: Review and recommend forecast of solar fields for the “Business As Usual” (BAU) forecast scenario for the year 2040.

Role of the Workgroups & Goal Teams

LUWG: Review and recommend “Business As Usual” (BAU) forecast scenario for the year 2040.

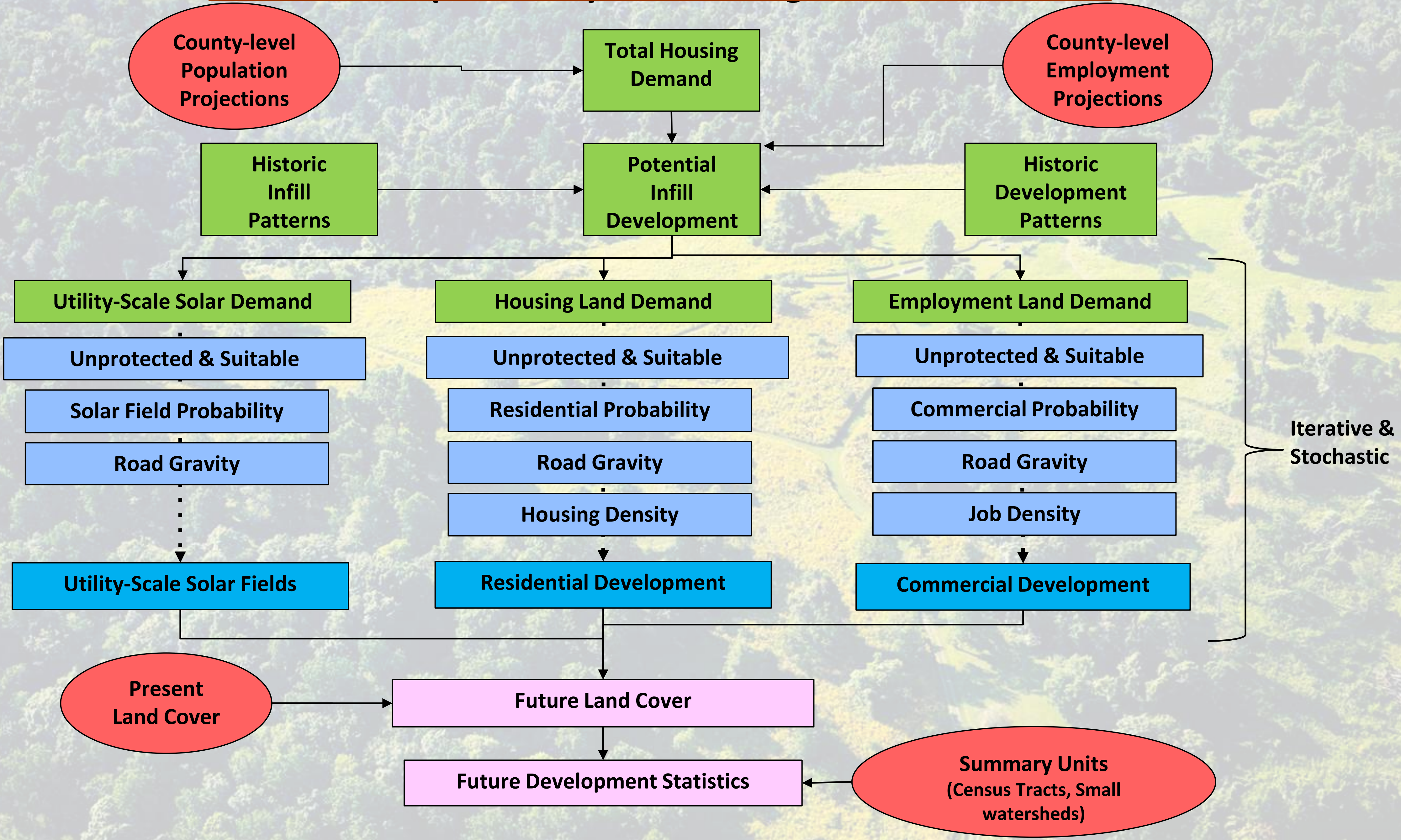
- understand model assumptions, data, and methodology
- recommend analyses, adjustments, and alternative future scenarios

USWG: Review and recommend forecast of solar fields for the “Business As Usual” (BAU) forecast scenario for the year 2040.

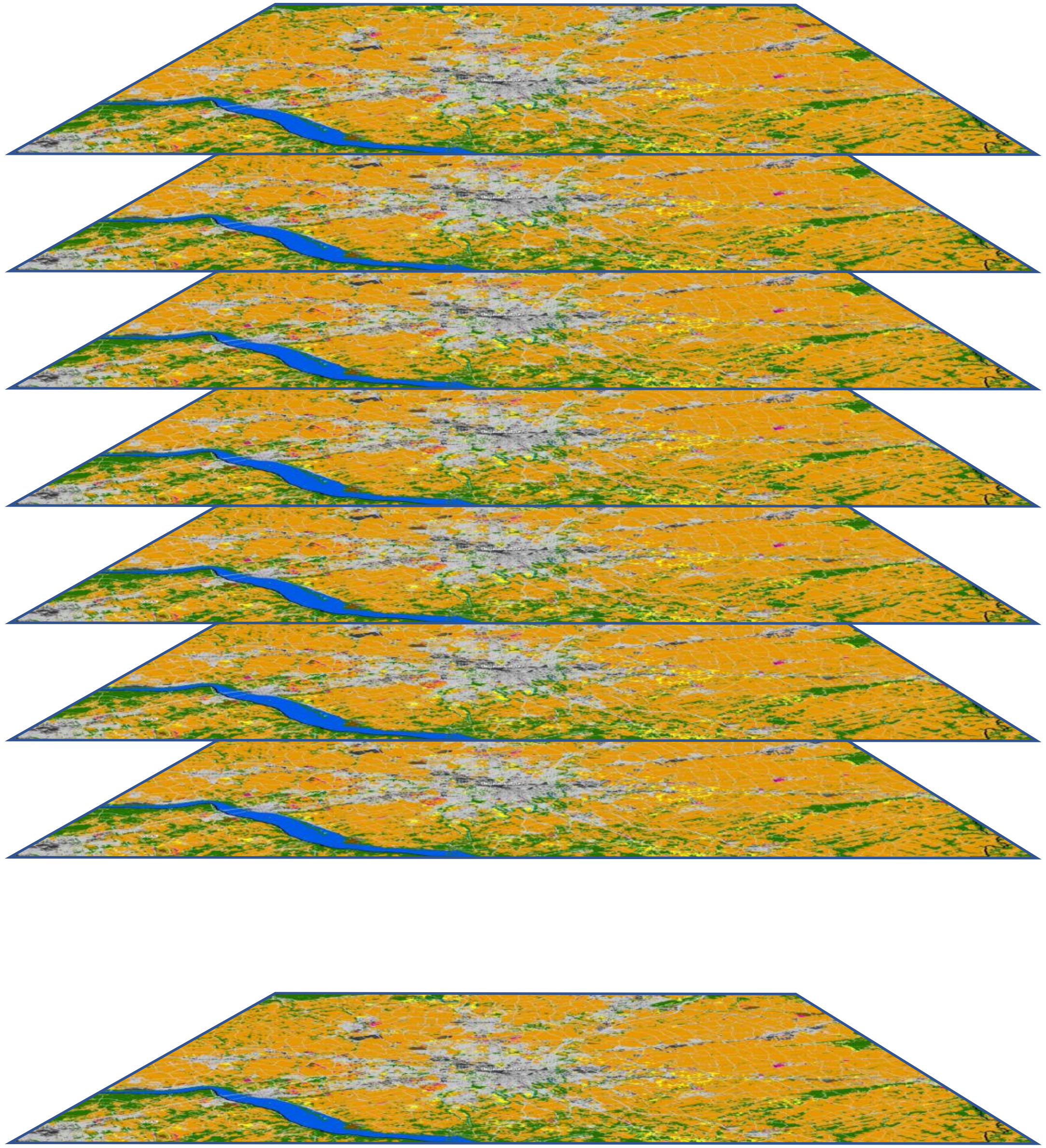
- understand model assumptions, data, and methodology
- recommend analyses, adjustments, and alternative future scenarios

CWGT: Approve “Business As Usual” (BAU) forecast scenario for the year 2040.

Chesapeake Bay Land Change Model v7



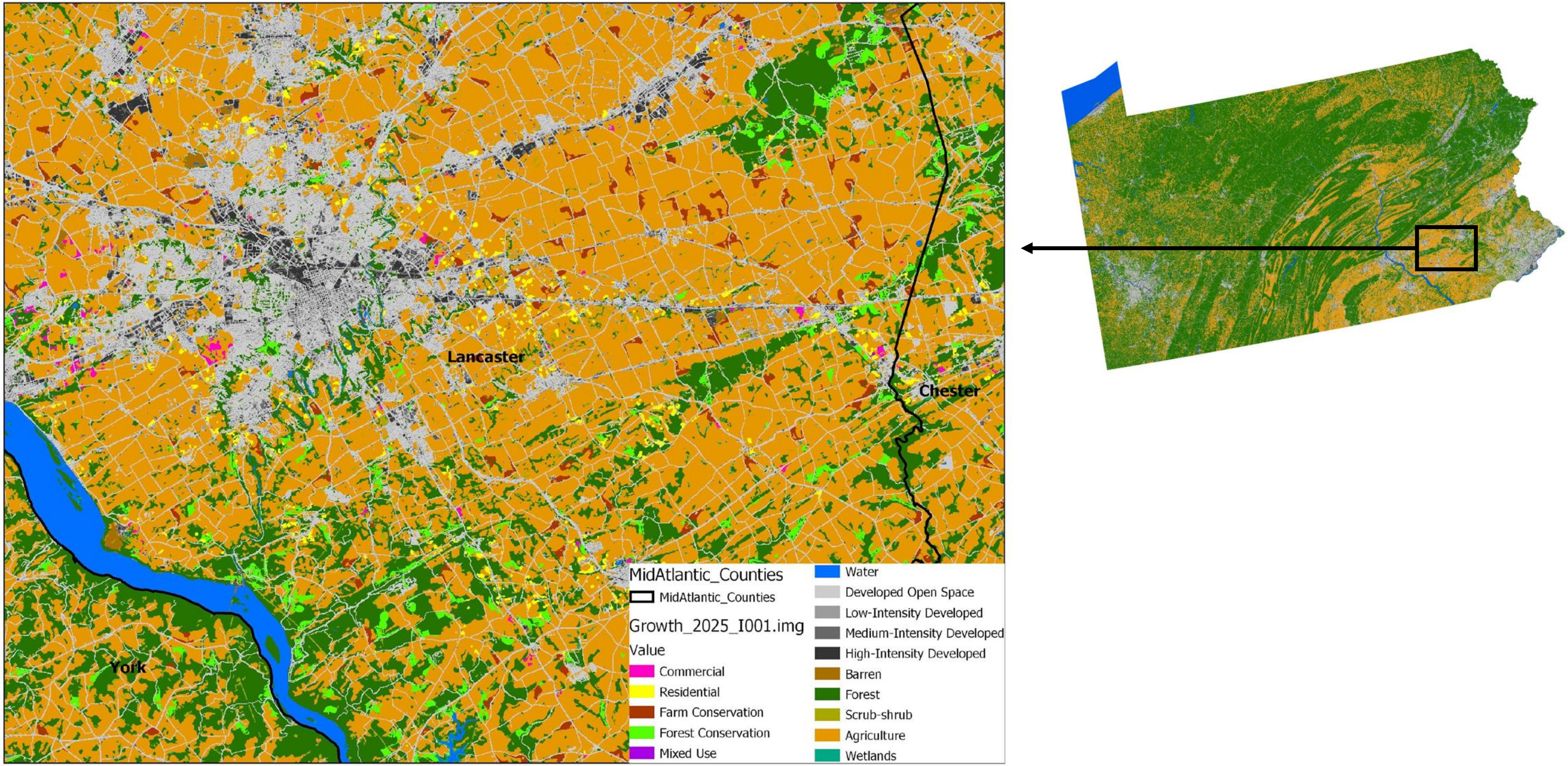
Multiple Stochastic Iterations



Every county is simulated 101 times for each scenario and target year, i.e., 2040.

Average of simulations by summary unit = **future development**

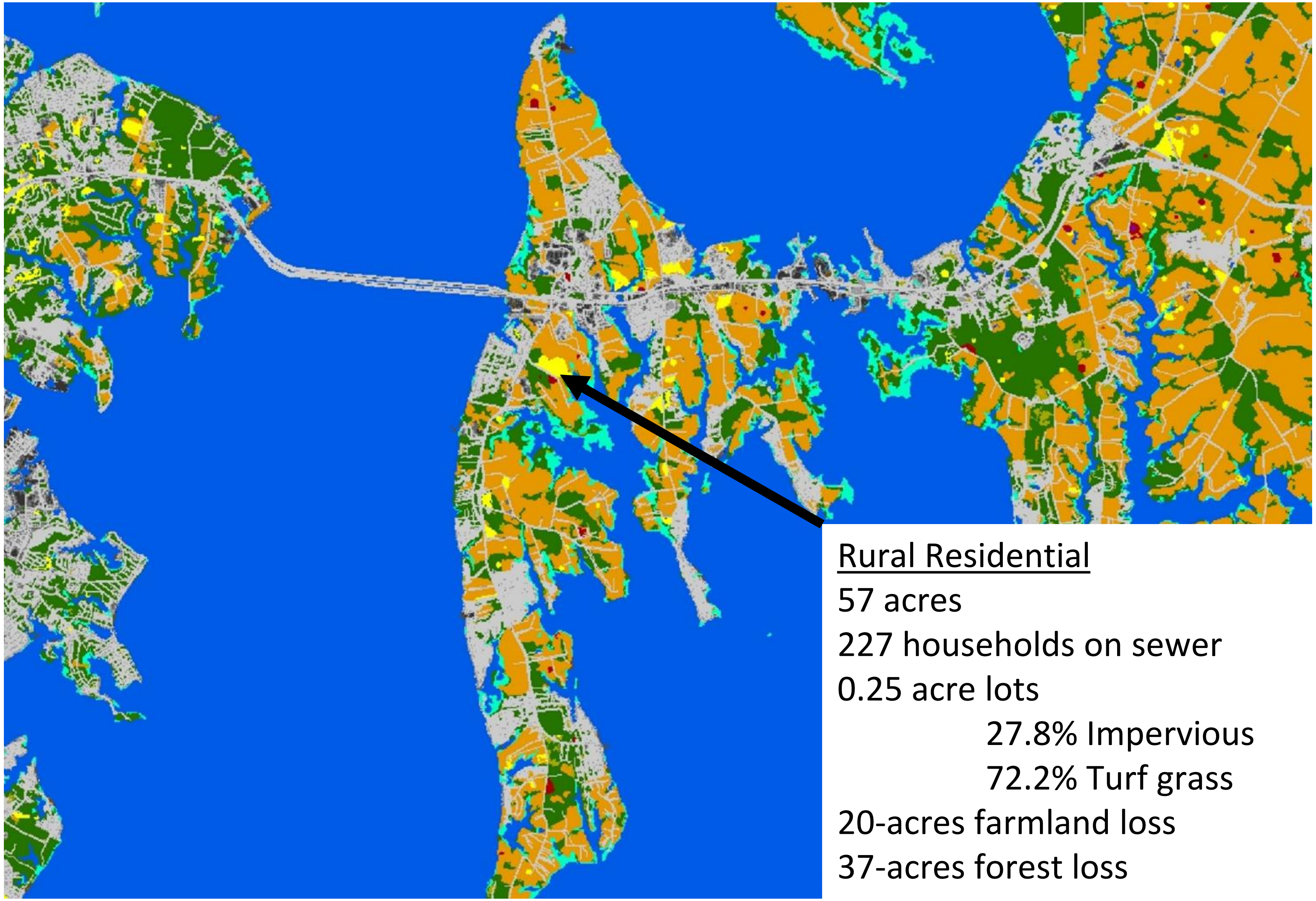
Relative Standard Deviation = **estimate of uncertainty**



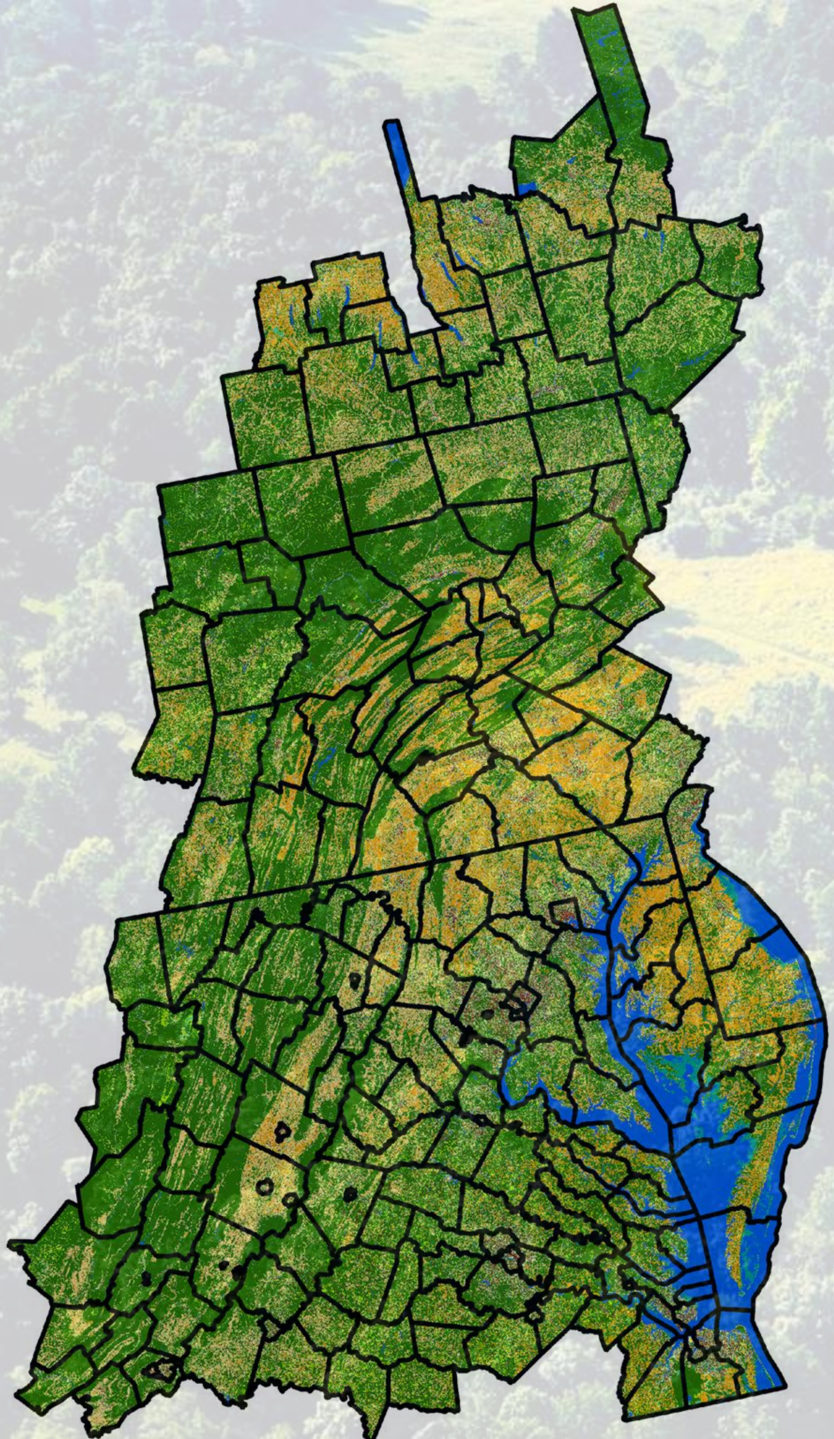
Simulated year 2025 residential, commercial, and mixed-use development and farm and forest land conservation in southeastern Pennsylvania, USA.

Land Change Model Outputs: Summary Statistics

- Impervious surface and turf grass expansion
- Forest conversion to development
- Farmland conversion to development
- Future population on sewer and septic



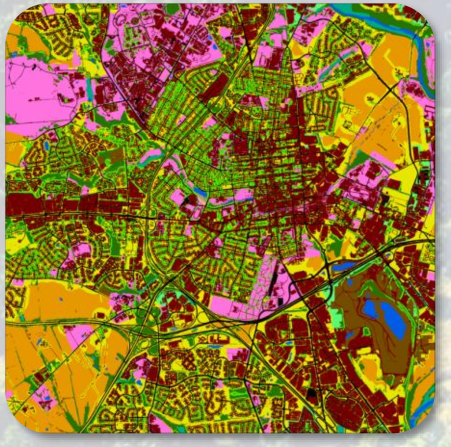
Rural Residential
57 acres
227 households on sewer
0.25 acre lots
27.8% Impervious
72.2% Turf grass
20-acres farmland loss
37-acres forest loss



High-Resolution Land Use / Land Cover (LULC) Data

- **Mapped extent**
  - 205 counties intersecting or adjacent to the Chesapeake Bay watershed
  - 99,000 square miles
- **Spatial Resolution**
  - 1-squarre meter cells
- **Temporal Resolution**
  - 2013/14, 2017/18, 2021/22
- **Categorical Resolution**
  - 56 Land Use/Land Cover classes

Chesapeake Bay Program Land Use/Land Cover: A Brief Project History



2013/14
- 16-classes
- First 1-meter LULC product

2017

2017/18
- 54-classes
- First 1-meter LULC Change product (2013/14 – 2017/18)

2022

2021/22
- 56-classes
- Three dates of 1-meter LULC and three LULC Change products

2024

2025/26
- 56-classes?
- First time mapping land cover and change with AI

2028

Land Use/Land Cover Monitoring
With each newly mapped year, the previous year(s) are remapped using the same methods for consistent change detection

Mapping developed residential and commercial areas

- Parcel data attributed with:
  - USPS Residential Delivery Indicator (RDI)
  - Impervious Area
  - Impervious Area in Structures
- Institutional polygons (schools, colleges, sports venues, churches)
- Other developed areas (cemeteries, landfills, golf courses, power infrastructure)
- Protected lands

<u>Commercial</u>

"Retail Sales/Wholesale/Professional Services“
"Other Urban or Built-up Land“
"Industrial“
"Other Commercial“
"Utilities“
"Junk/Salvage Yards“
“Vehicle Related Activities”
"Warehouses and Temporary Storage"
"Airports"
"Marinas/Port Facilities/Docks“

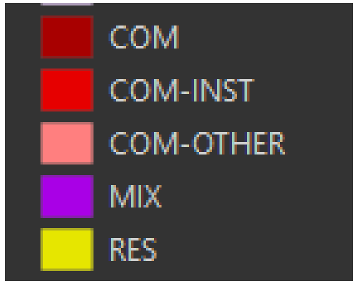
<u>Comm-Open</u>
"Airports"
“Recreational”

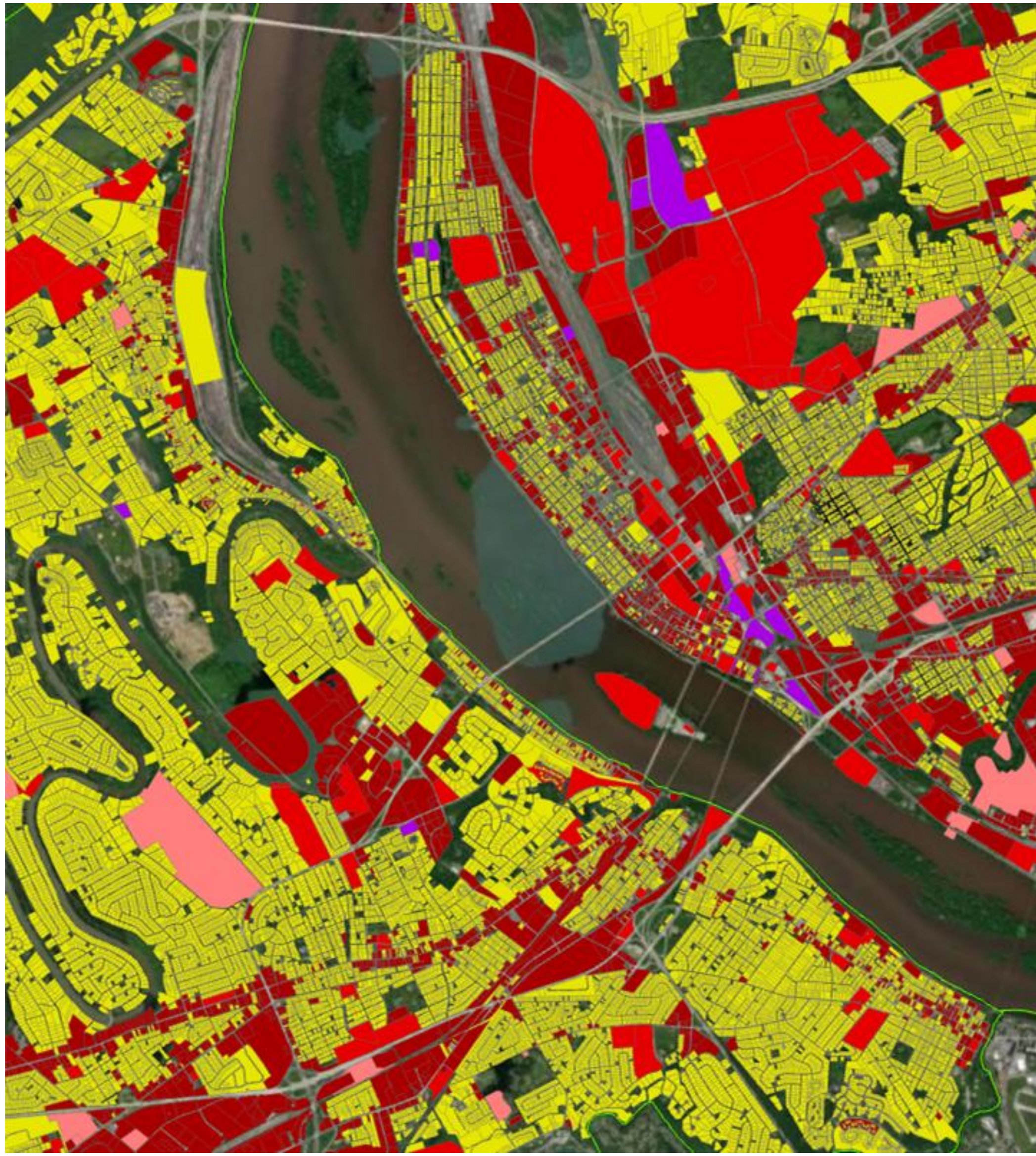
<u>Comm-Institutional</u>
"Institutional/Governmental“

<u>Residential</u>

"Multi-Family Dwellings“
"Mobile Home Parks/Courts“
"Mixed Single and Multi-Family Residential“
"Mobile home Parks/Courts“
"Single Family Dwellings“

<u>Excluded classes</u>
Agricultural
Parking lots





Harrisburg, PA

Mapping residential and commercial densities by Census Block

1. Attribute 2020 Census Blocks with total housing units and total jobs.

1. Estimate developed residential and commercial areas within each Census Block

Housing Density = housing units / residential area

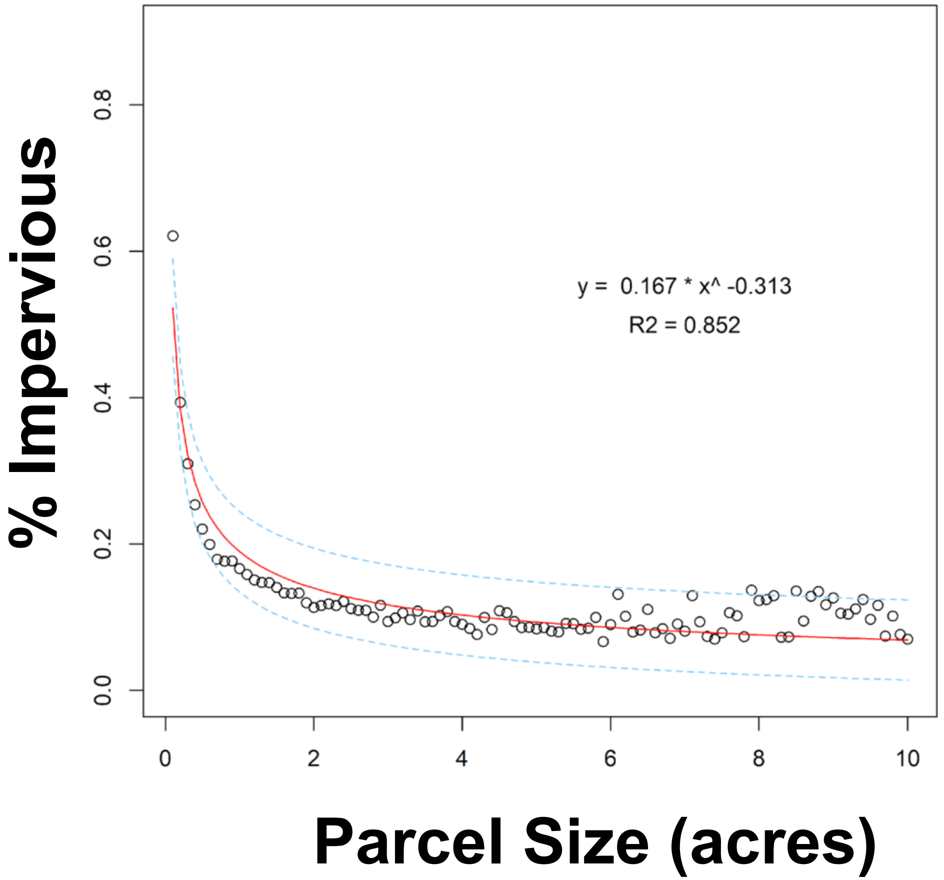
Job Density = jobs / commercial area

Housing Density Raster
Units per 30m Cell

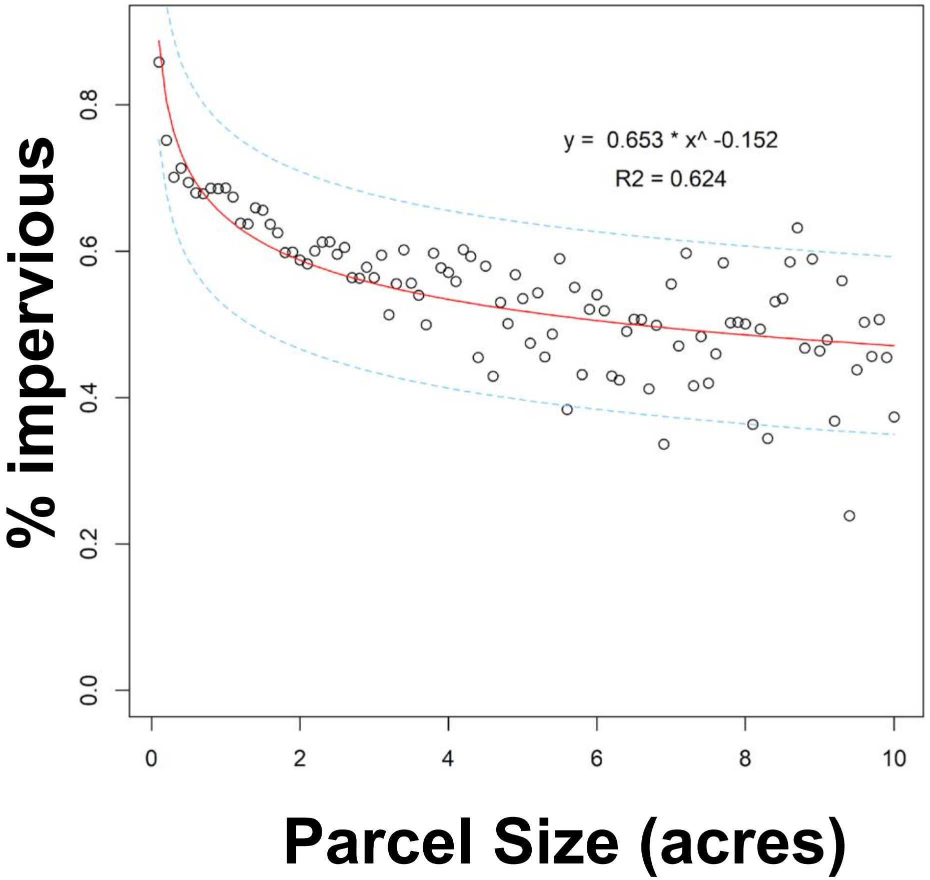
Harrisburg, PA

Estimating impervious cover from parcel size (state-specific equations)

Residential



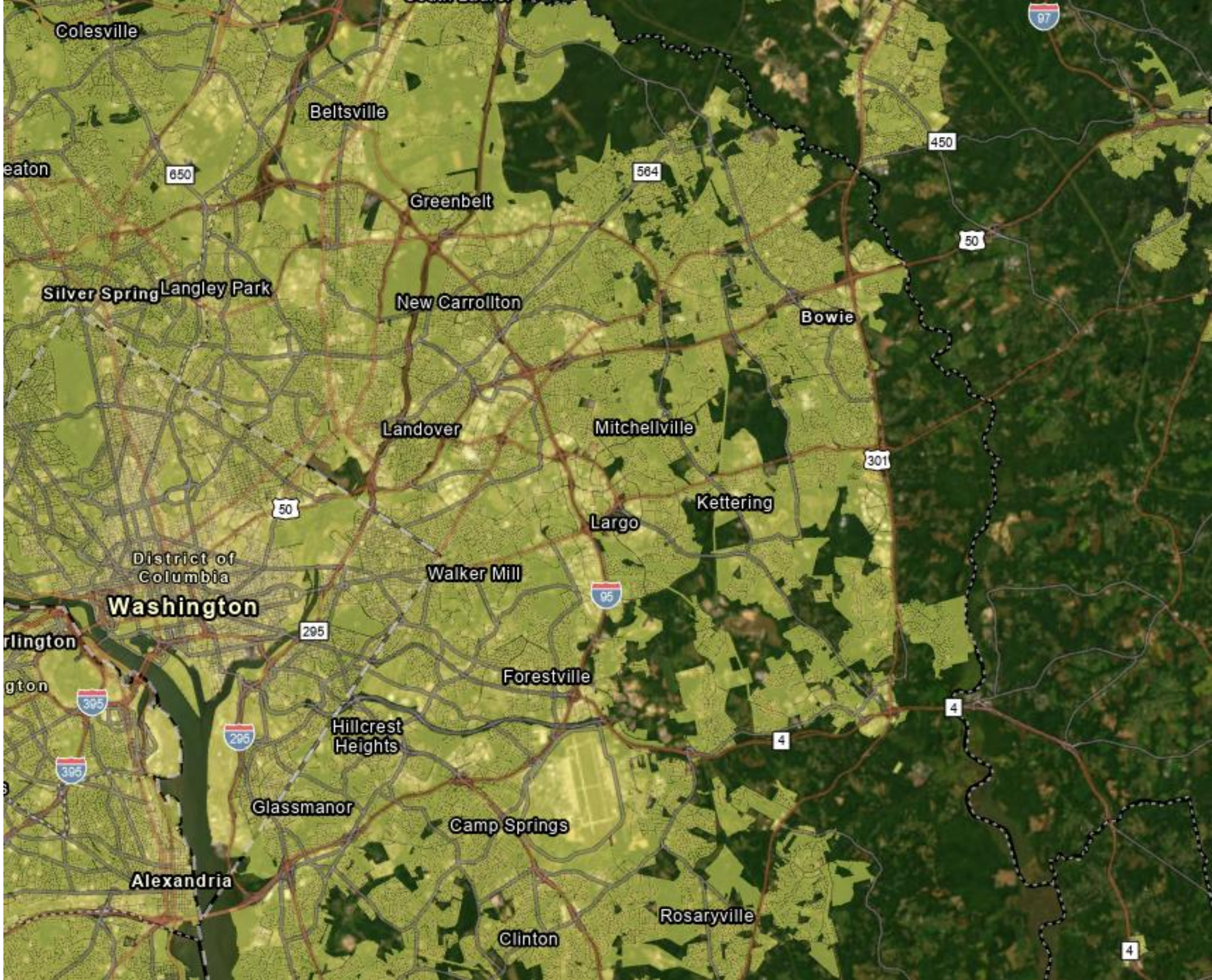
Commercial



- Mean percent impervious for parcels binned at 0.1-acre intervals up to 10 acre lots.
- Power functions fit to the data produced best model fit.
- Residential model displays lower residuals, values begin to deviate at lot sizes >= 6 acres
- Commercial model displays higher residuals as parcel size increases

Mapping Sanitary Sewer Service Areas

Parcel-scale map of areas connected to sewer for all counties within or adjacent to the Chesapeake Bay watershed



Mapping Septic Systems

Parcel-scale map of septic footprint and septic point data for all counties within or adjacent to the Chesapeake Bay watershed

= sewer service area

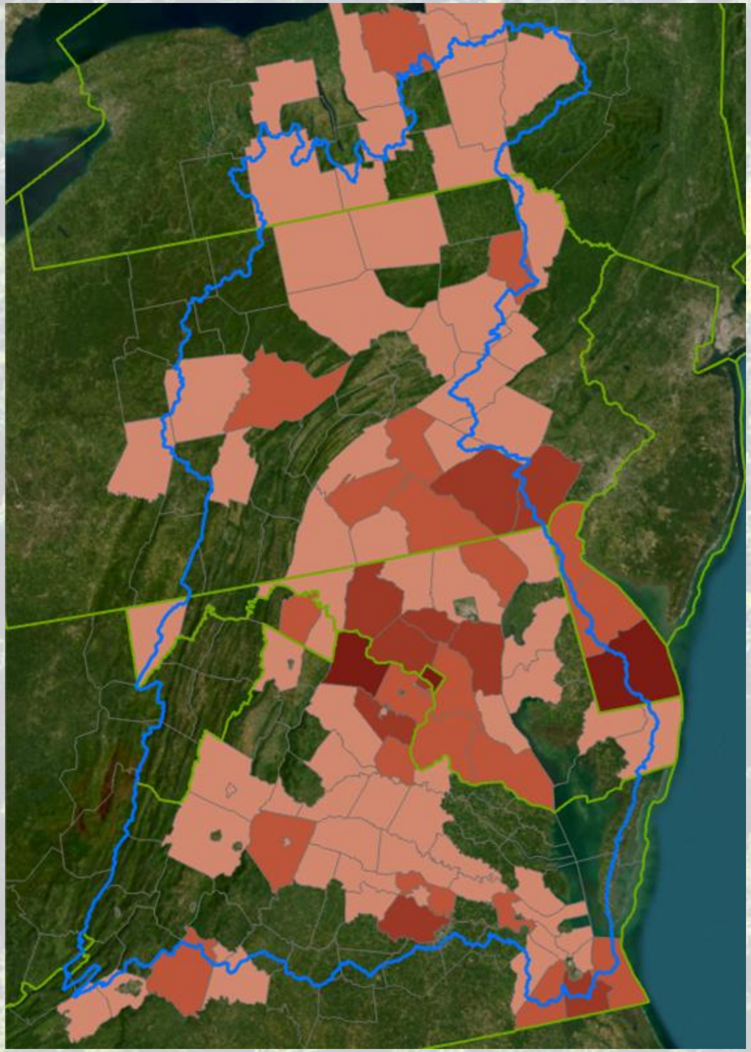
= septic footprint

= septic systems

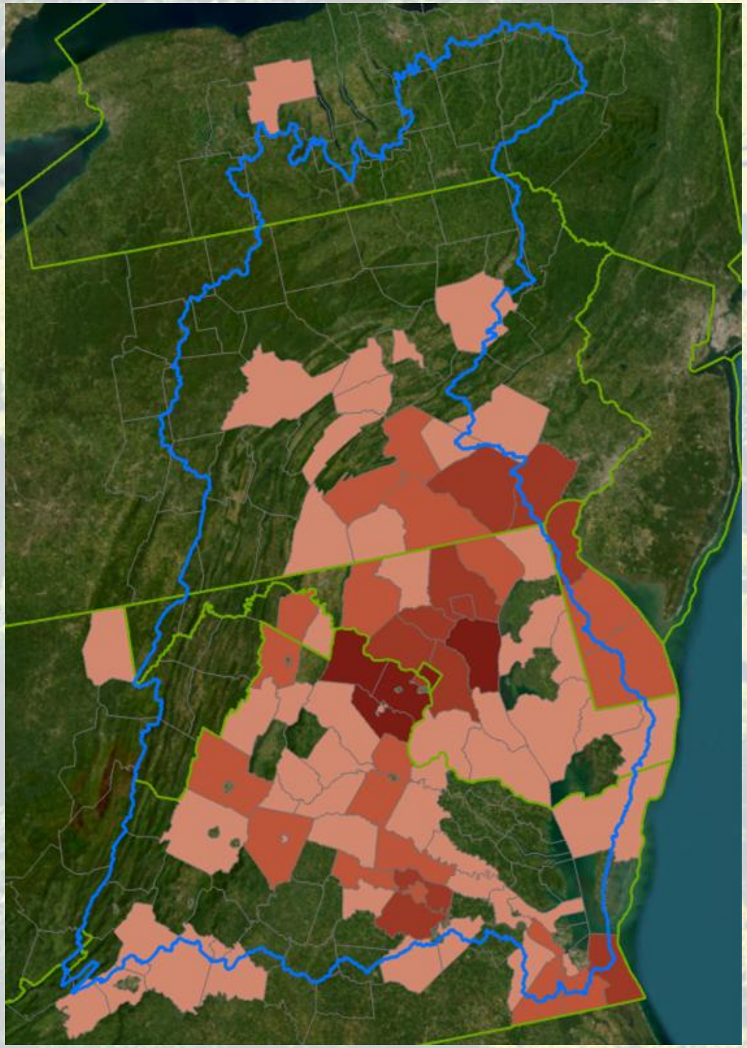
This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.

Chesapeake Bay Region Observed Growth
2010 - 2020

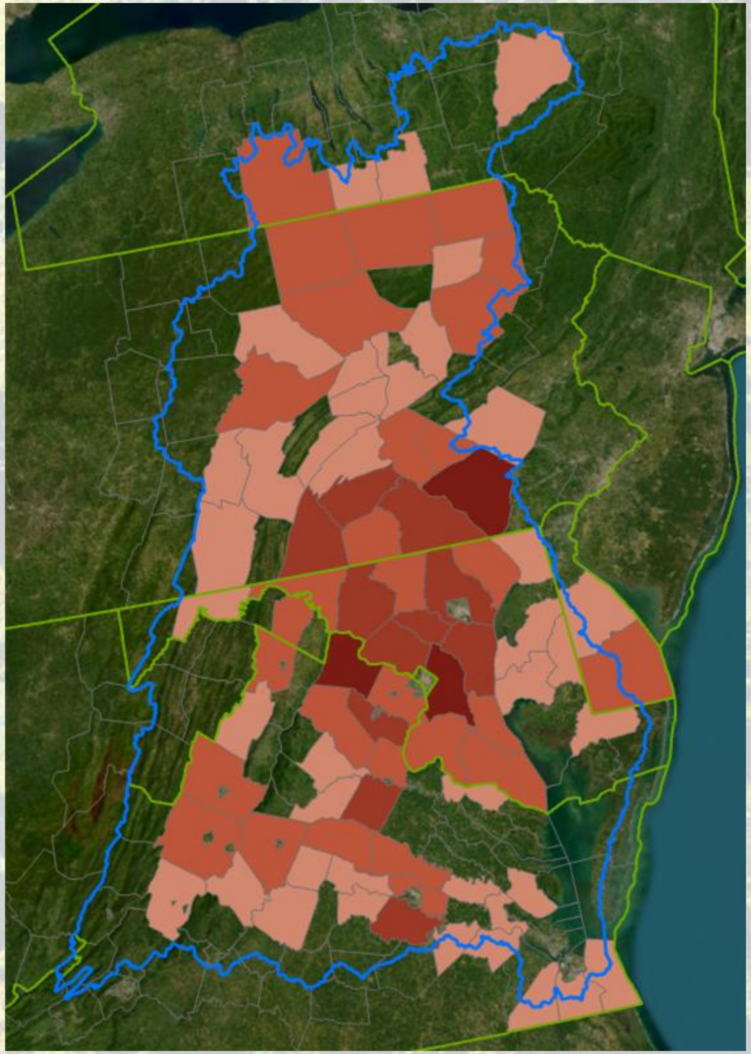
Housing Growth: 0.41 million



Job Growth: 1.09 million

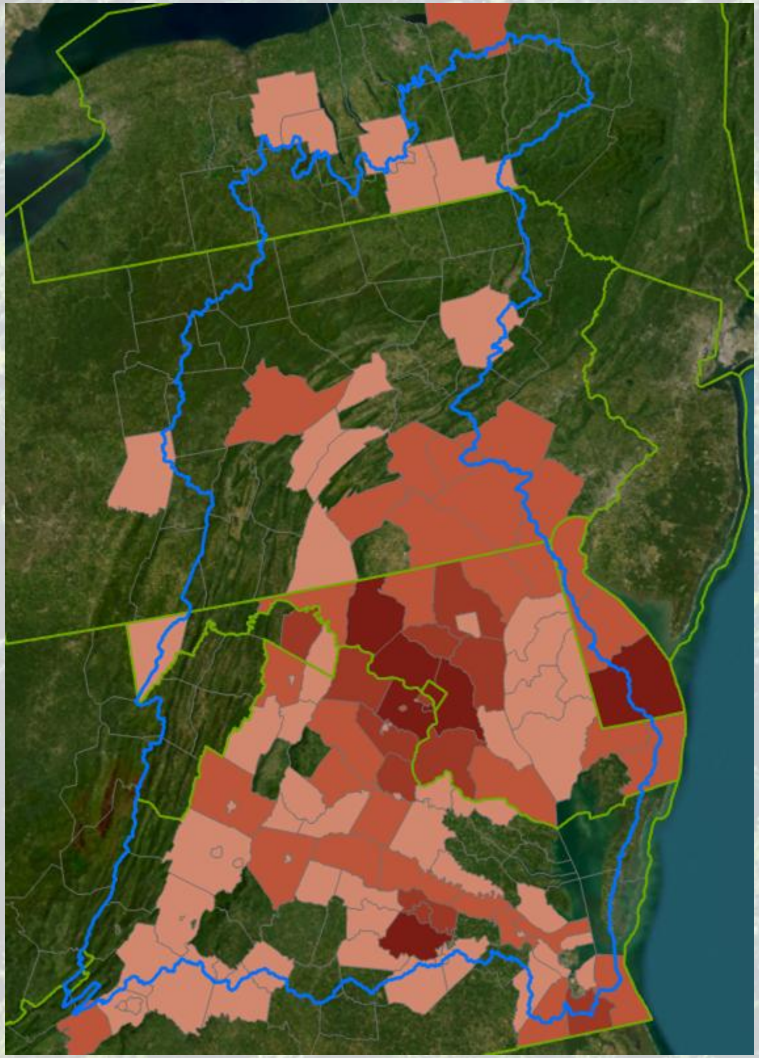


Observed Growth: 172,802 acres

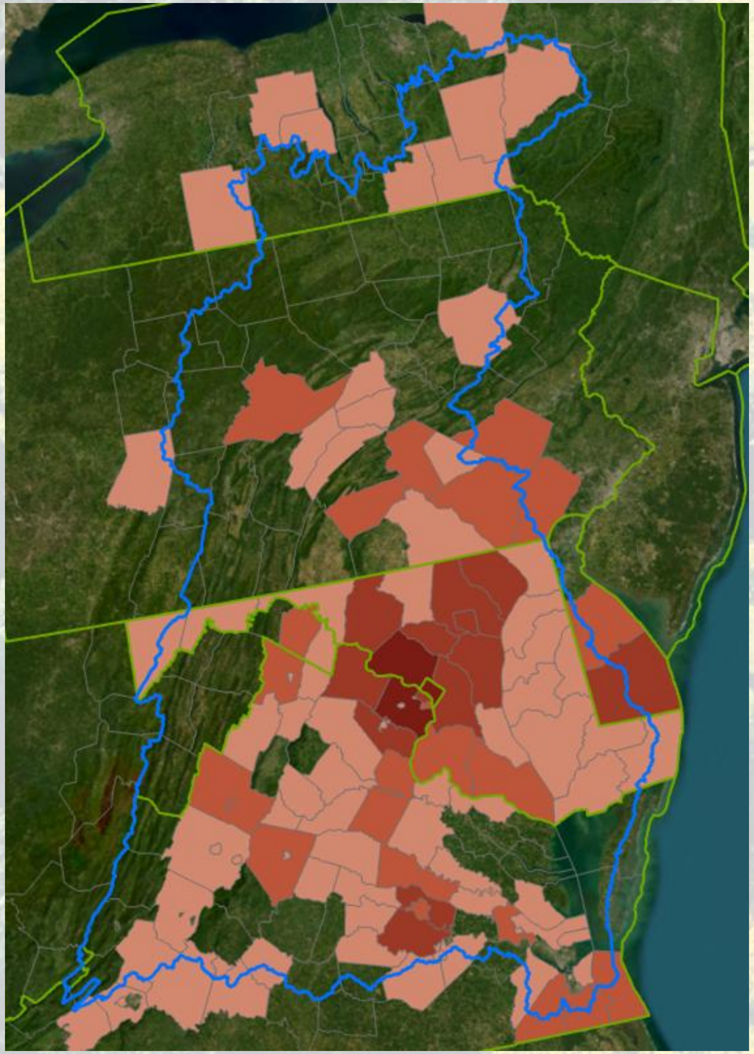


Chesapeake Bay Region Future Growth 2020 - 2050

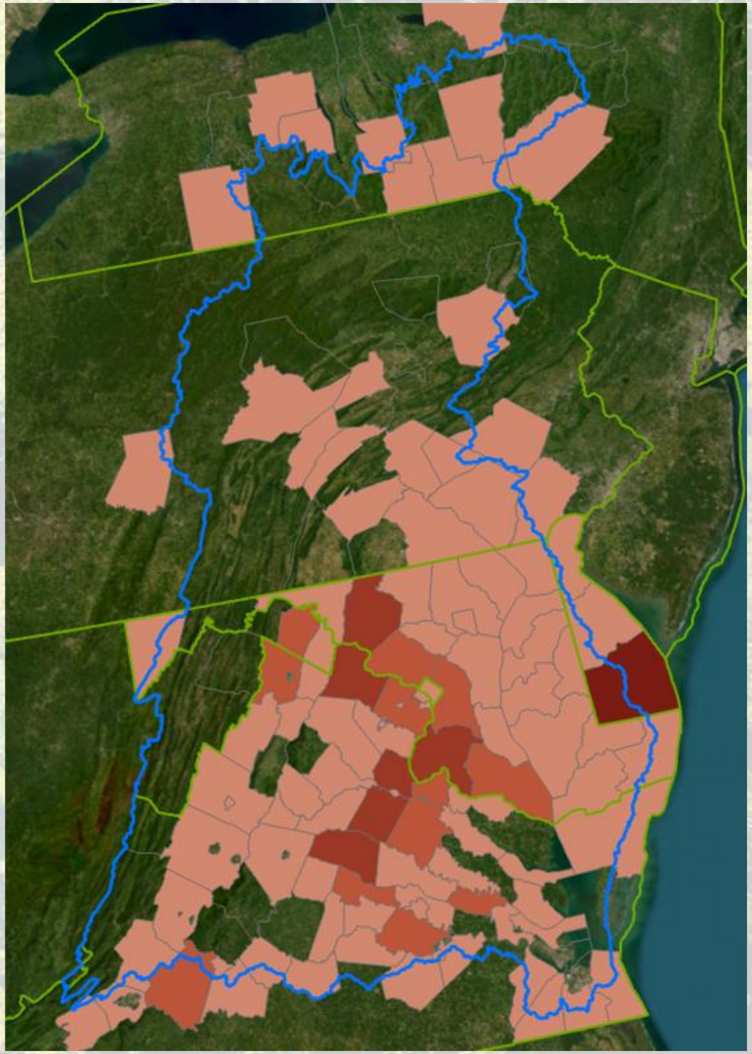
Additional Housing: 1.99 million



Additional Jobs: 2.73 million

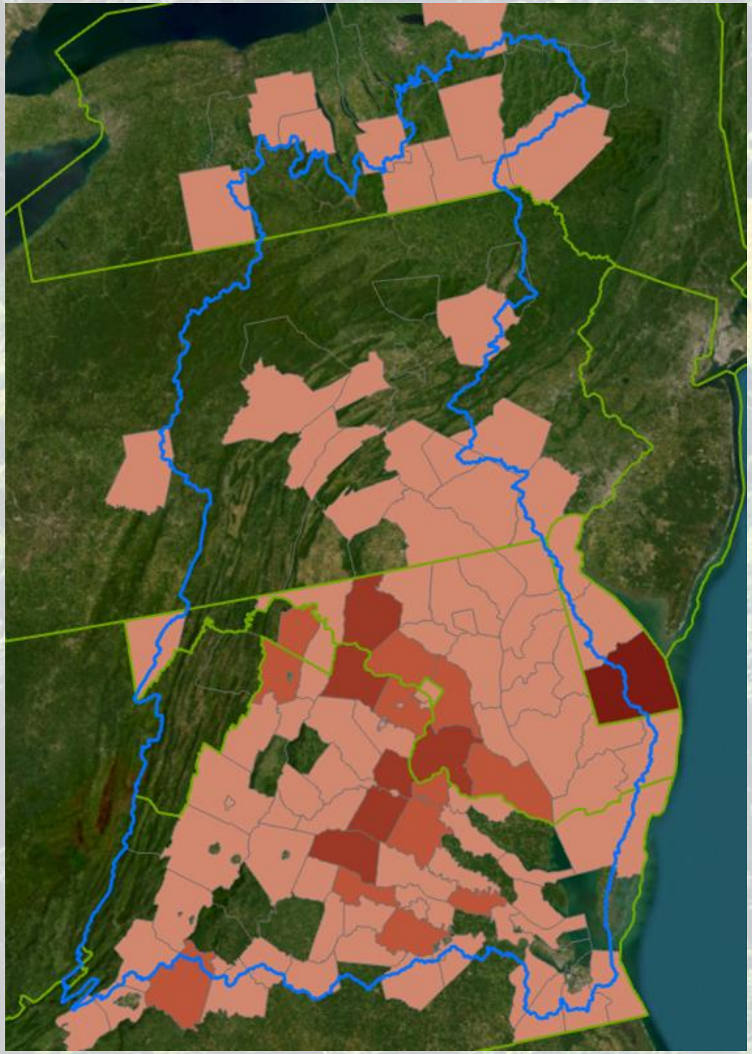


Simulated Growth: 317,822 acres

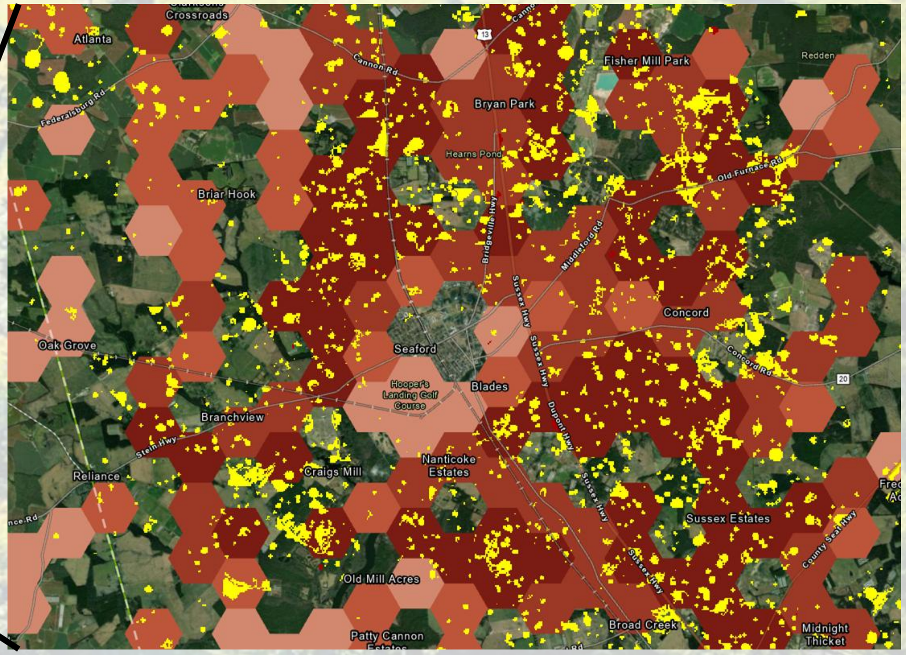


Chesapeake Bay Region Future Land Use
2020 - 2050

Simulated Growth: 317,822 acres

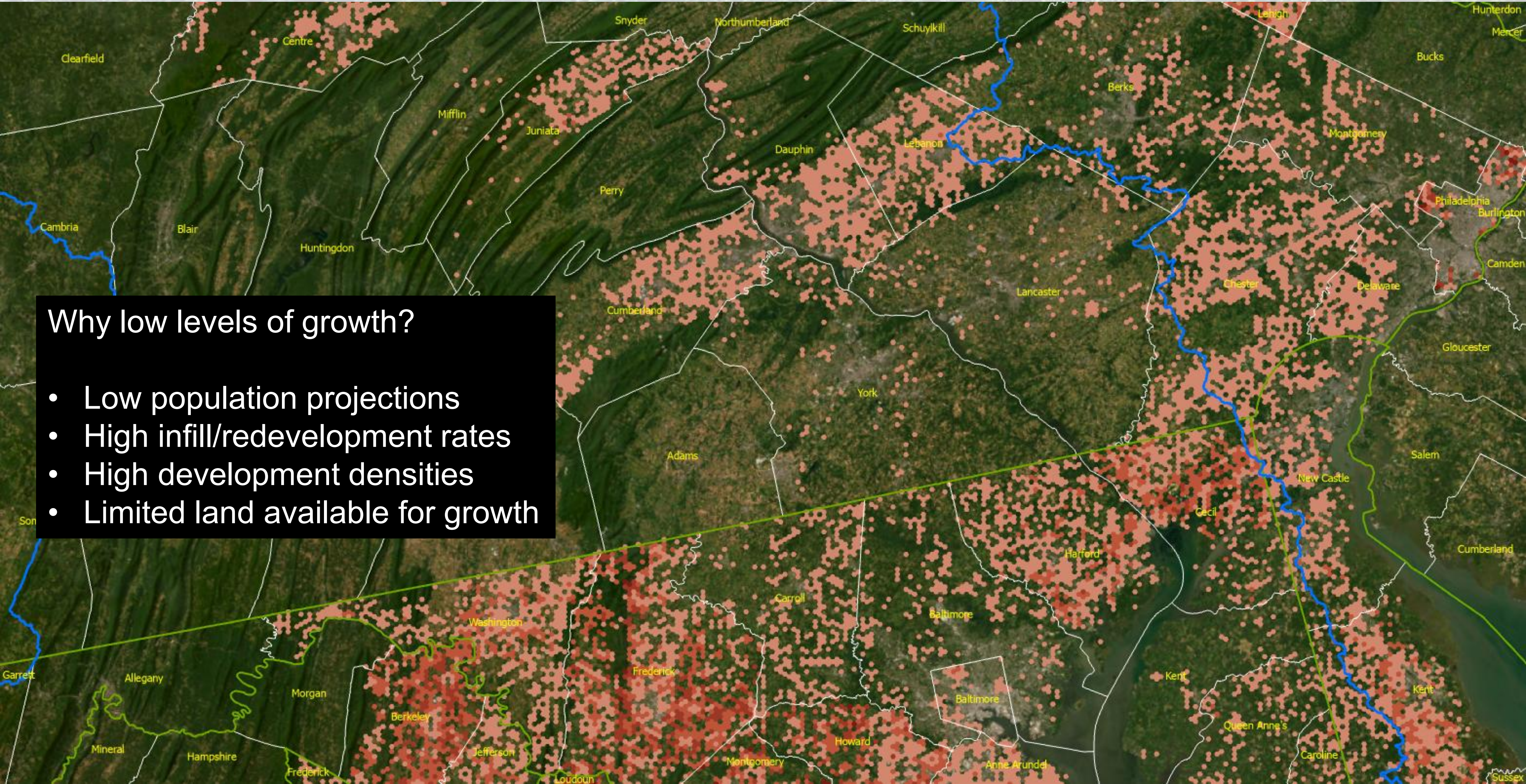


Simulated Growth: 317,822 acres



Seaford, DE

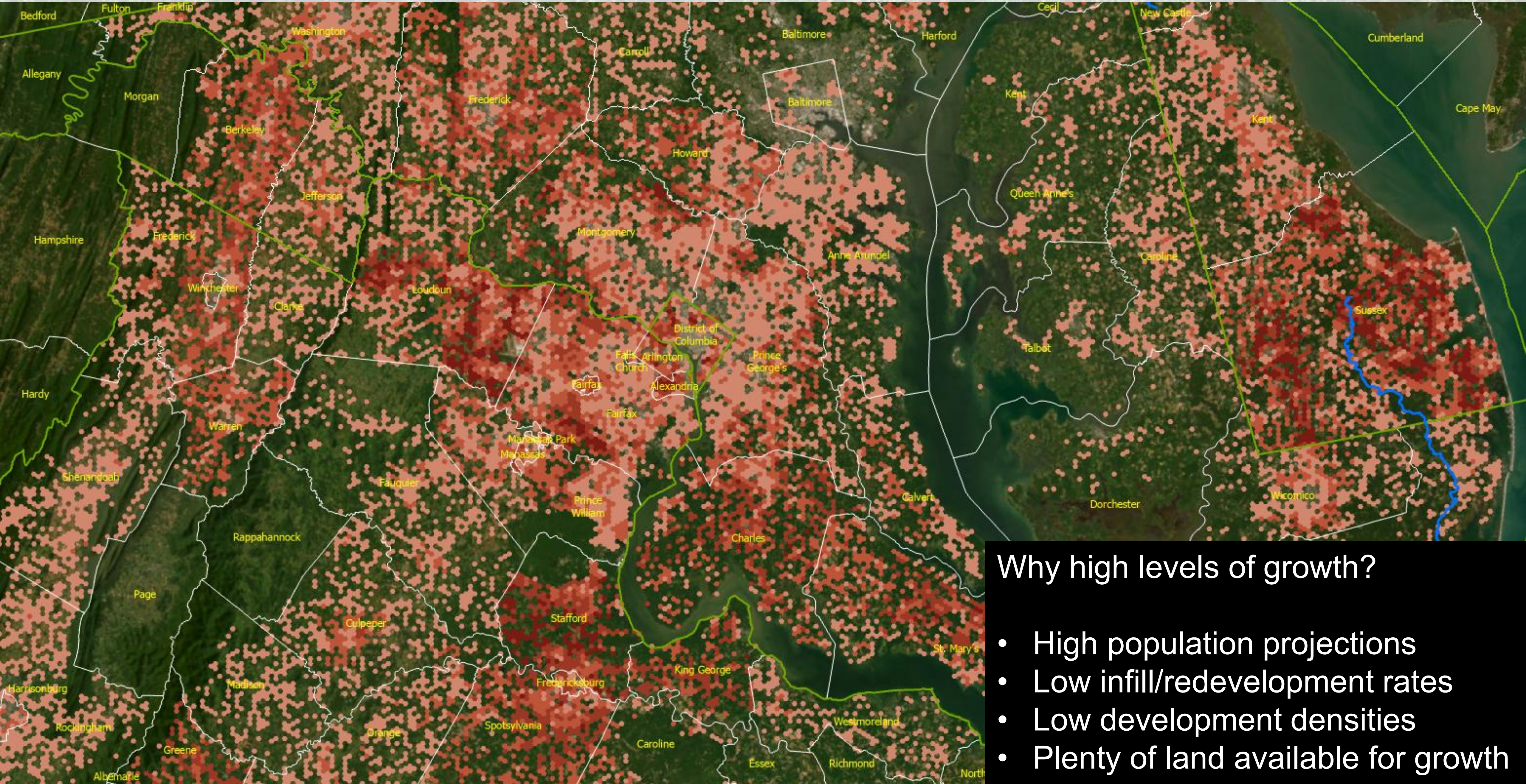
2050 Development: Northern Maryland and Southeastern Pennsylvania



Why low levels of growth?

- Low population projections
- High infill/redevelopment rates
- High development densities
- Limited land available for growth

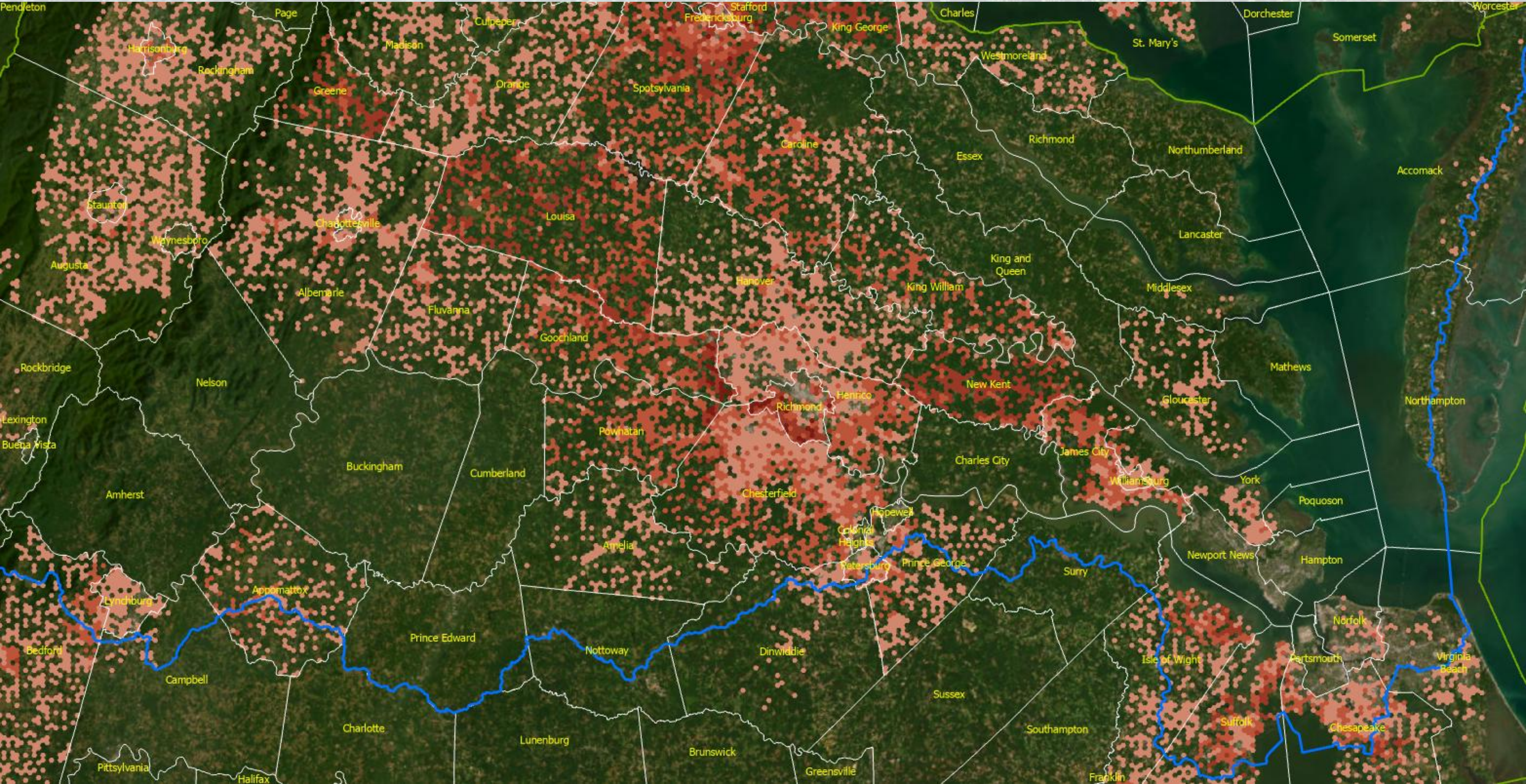
2050 Development: Northern Virginia and Central Maryland



Why high levels of growth?

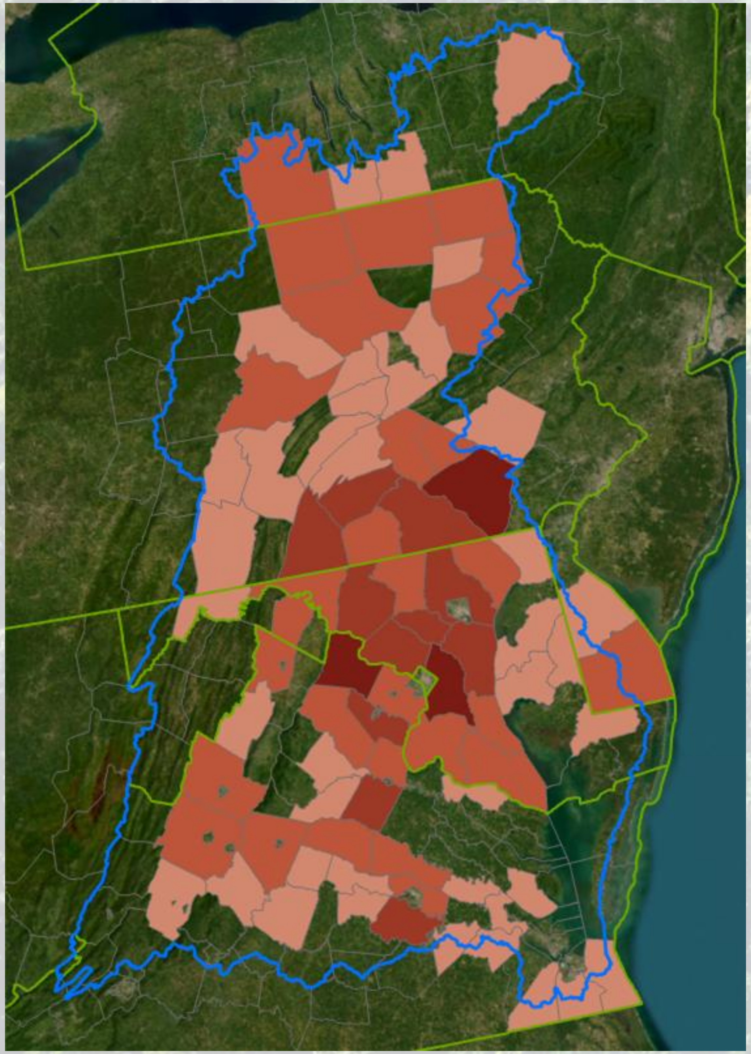
- High population projections
- Low infill/redevelopment rates
- Low development densities
- Plenty of land available for growth

2050 Development: Southern and Central Virginia

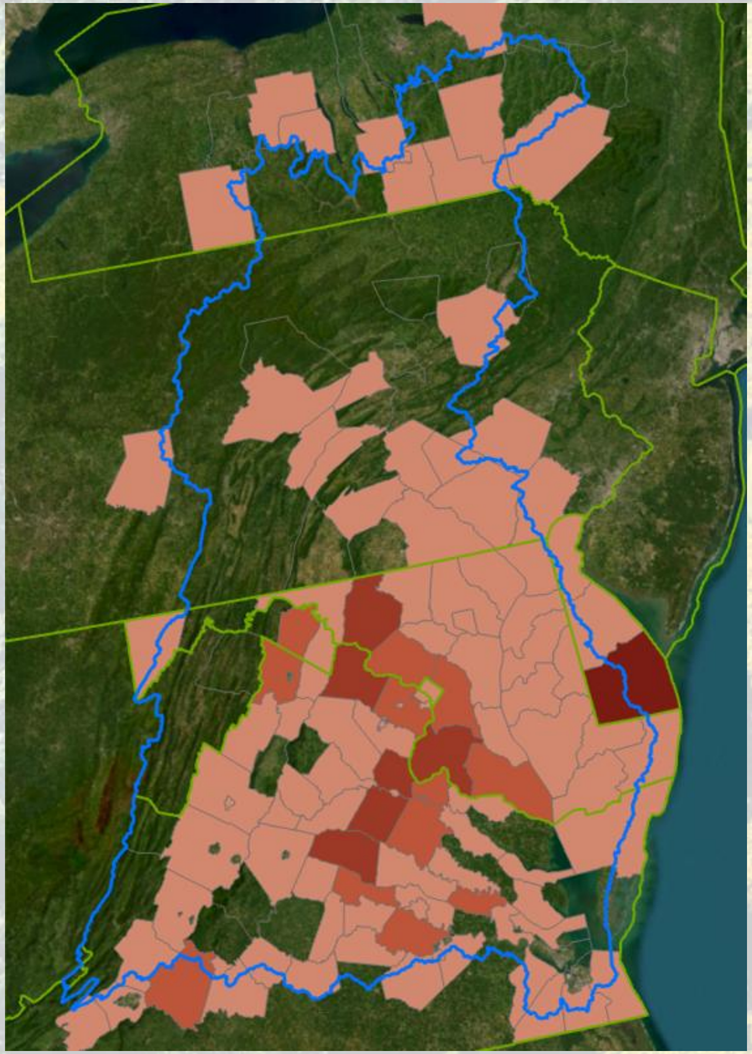


Chesapeake Bay Region Future Land Use 2020 - 2050

Observed Growth: 172,802 acres



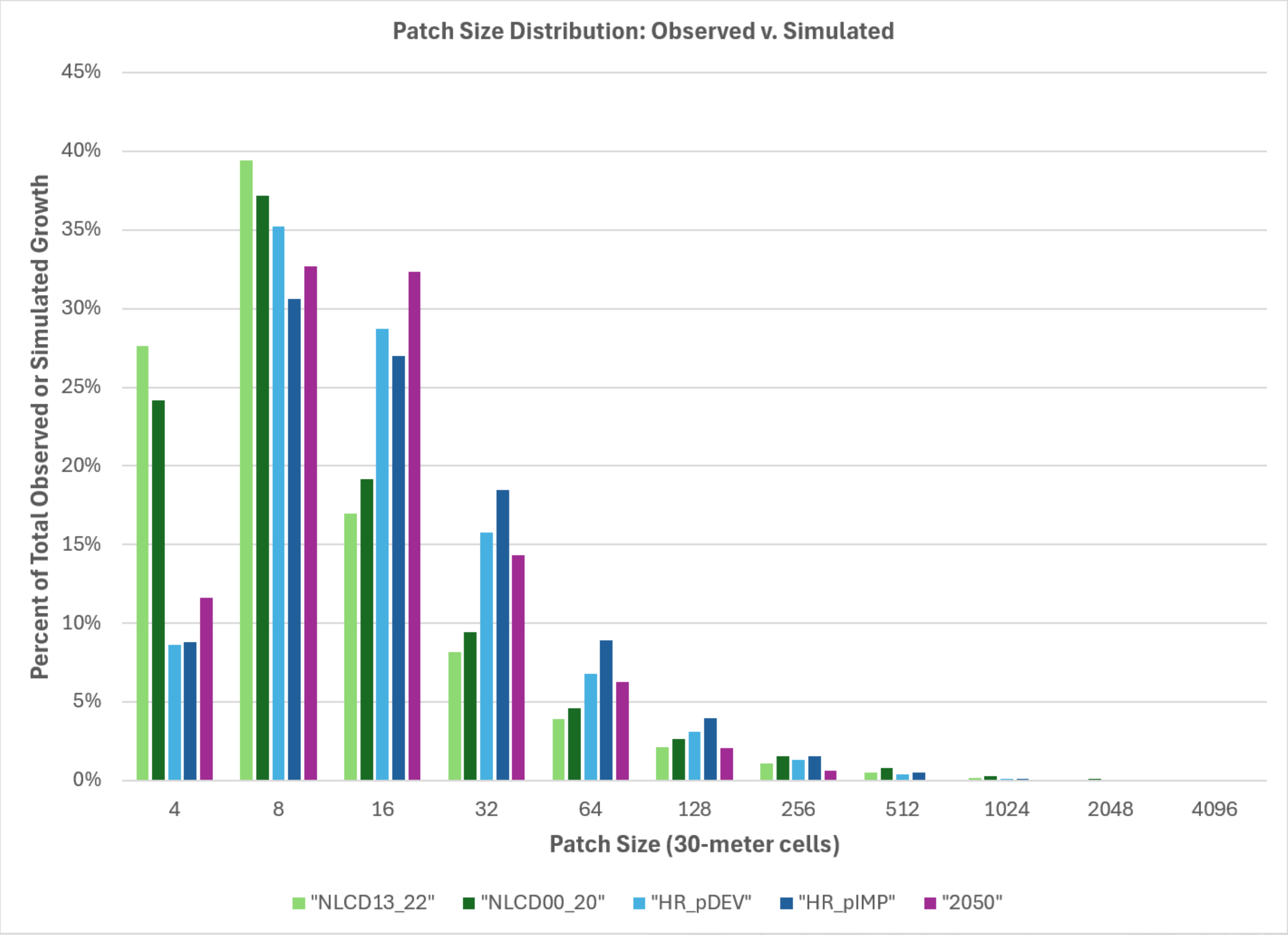
Simulated Growth: 317,822 acres



Annual Rate of Growth (acres)

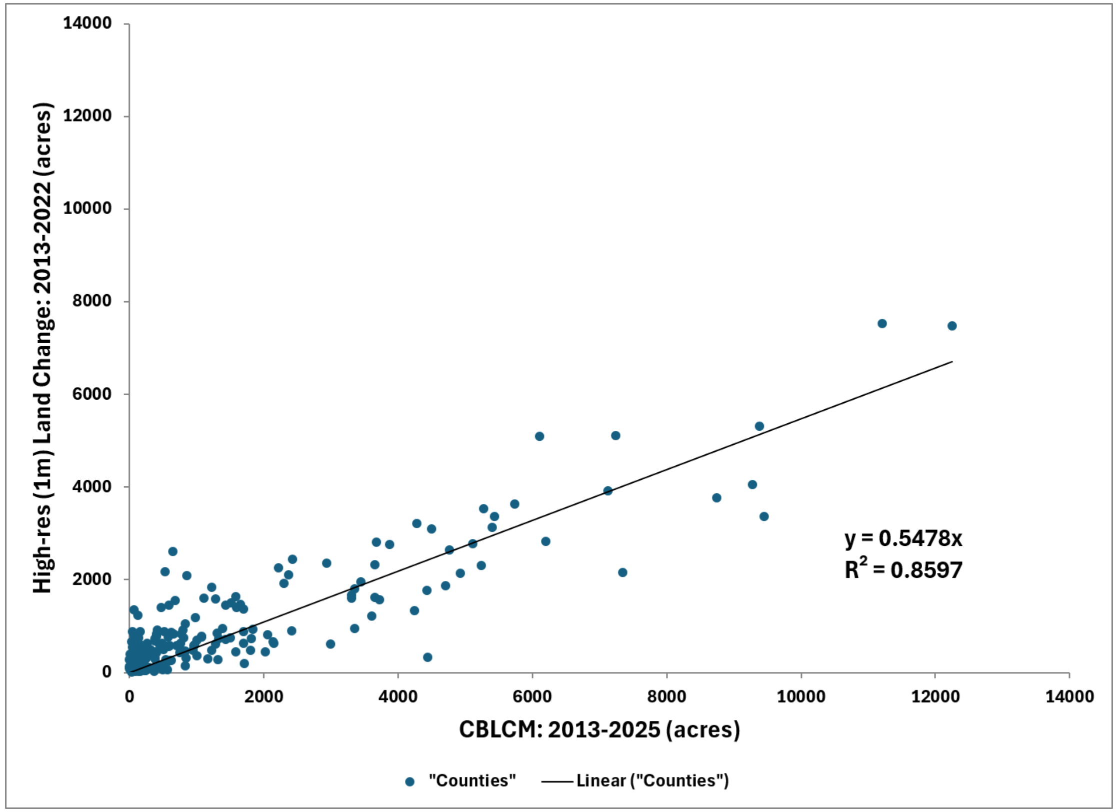
State	Observed	Simulated
DC	(2)	53
DE	1,233	1,686
MD	3,176	3,703
NY	1,518	394
PA	5,774	721
VA	8,805	8,926
WV	1,286	407

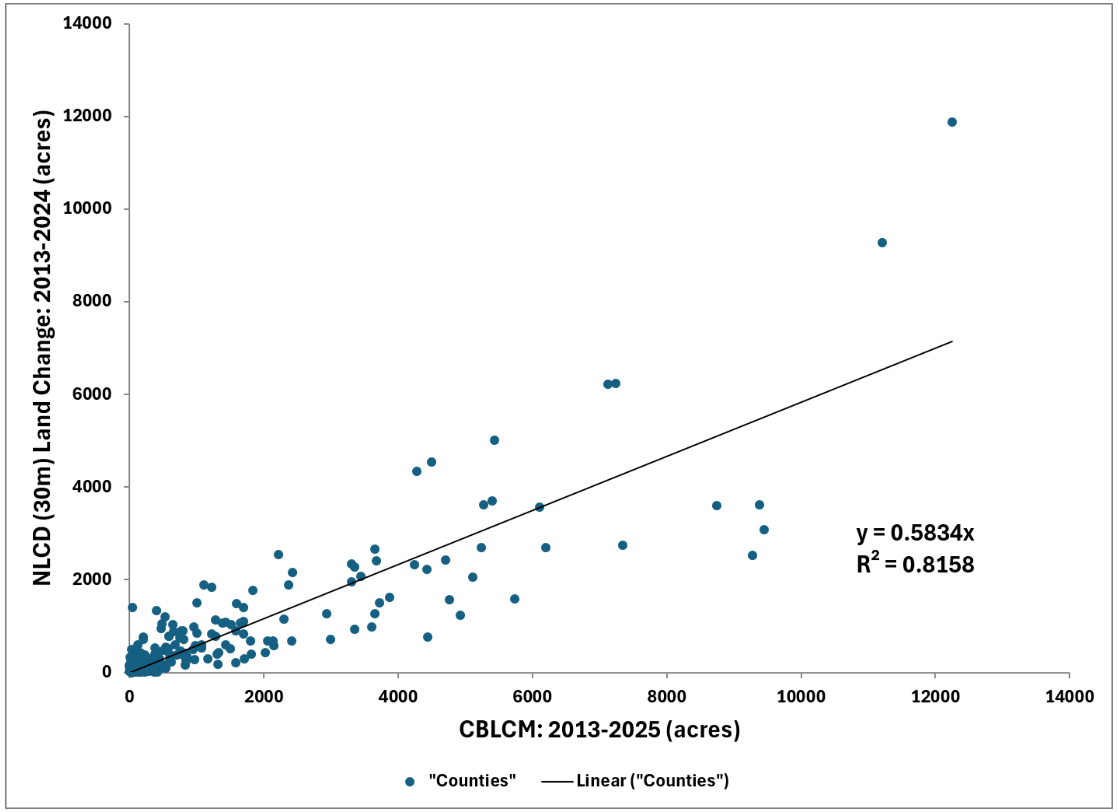
Verifying Patch Size Distribution



Model Validation

Original (CBLCM v3a) Phase 6 Forecast to 2025





CBLCM v3a forecast ~50% more growth than observed in the high-res and NLCD land change datasets over similar periods
CBLCM v3a overestimated growth mostly in high-growth counties (e.g., Spotsylvania, Sussex, Loudon, Anne Arundel)

Why the current model is less likely to overestimate growth to the same degree:

- Current population projections based on the 2020 Census are lower than those available mid-2010's*
- Residential and commercial infill rates are 19% and 25% higher respectively, in CBLCM v7 compared to CBLCM v3a.
- Residential densities are 2x higher and commercial densities are 4x higher

* The current projected change in population from 2020-2040 for Lancaster, PA is 50% lower than it was in the mid-2010's.

Model Validation

Future validation steps:

- Compare infill/redevelopment estimates derived from MD and DE parcel data with CBLCM estimates.
- Compare observed and simulated growth relative to distance to roads and urban areas.
- Compare observed vs simulated patterns of growth at different spatial scales: 0.1 km^2, 1 km^2, 10 km^2.

Claggett et al., 2023. https://doi.org/10.1111/1752-1688.13131

Future Utility-Scale Solar (Virginia example)

Status (currently installed): 7.8 GW

Dominion Power 2035 projection: +12.2 GW

VCU 2035 projection: +11.3 to +21.1 GW

(based on USS providing 8% to 15% of modeled electricity demand)

Using PJM's expected annual growth rate of 7.7%, extrapolating VCU's low-range scenario, +11.3 GW, to 2040 yields: +20.1 GW

Forecast land conversion by 2040 (20.1 GW * 7 Acres/MW): 140,700 acres

Forecasted development (excluding solar) by 2040: 92,649 acres

Pitt, D., J. Ciminelli, and J. LaPrad (2025). Utility-Scale Solar in Virginia – Current Trends and Future Impacts.

+ 100,000 watershed acres in other states

USGS

science for a changing world