COMMONWEALTH of VIRGINIA

Virginia ConservationVision: Watershed Model

2017 Edition

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Virginia ConservationVision:
Watershed Model
2017 Edition

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Abstract

The Virginia ConservationVision Watershed Model quantifies the relative importance or value of lands for protecting water quality and watershed integrity. The model incorporates topographic and edaphic characteristics, position in the landscape relative to hydrological features and drinking water sources, and subwatershed integrity based on landscape composition, aquatic species assemblages, and estimated pollution loads.

The purpose of the model is to establish geographic priorities for conservation, restoration, or urban stormwater management, depending on land cover type. Priority for conservation is assigned to forests, wetlands, shrublands, natural grasslands, and undeveloped beaches. Priority for restoration is assigned to croplands, pasture/hay, and developed open space. Priority for stormwater management is assigned to low-, medium-, and high-intensity developed areas and barren lands.

The model is one of several in a suite of state-wide conservation planning and prioritization models developed by the Virginia Natural Heritage Program and partners, known collectively as Virginia ConservationVision. The Watershed Model can be used in conjunction with other data to help prioritize conservation, restoration, and management efforts.

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Introduction

The Virginia Department of Conservation and Recreation (DCR), Division of Natural Heritage (DNH), has a mission to protect Virginia's native plant and animal life and the ecosystems upon which they depend, with a focus on globally and state rare species and exemplary natural communities. As human populations and demand for resources expand, natural areas and rural lands are increasingly threatened by encroaching development. The Virginia Land Conservation Foundation (VLCF) provides state funding to purchase or establish conservation easements on various lands of conservation concern (DCR n.d.). Given limited funds, it is essential to have a means of prioritizing lands worthy of preservation. As part of its work, DNH and partners develop and maintain a suite of geospatial models intended to guide strategic land conservation and management decisions. This suite of models is known as Virginia ConservationVision. The models under the ConservationVision umbrella address a variety of conservation issues and priorities, and include a Natural Landscape Assessment Model, a Cultural Model, a Recreation Model, an Agricultural Model, a Development Vulnerability Model, a Forest Conservation Values Model, and a Watershed Model.

The purpose of the Virginia Watershed Model is to quantify the relative importance or value of land as it contributes to water quality and watershed integrity. It provides some of the information needed for prioritizing lands for conservation in the interest of maintaining green infrastructure across the state. This model replaces an earlier edition produced by DNH and the Department of Forestry in 2007, called a "Watershed Integrity Model" (Ciminelli and Scrivani 2007). It borrows ideas from the Chesapeake Bay Program's "Water Quality Protection Model" produced as part of their Resource Lands Assessment (CBP 2008). It also adopts the strategy, described by Barten and Ernst (2004), to separately prioritize lands for conservation, restoration, and stormwater management depending on land cover type, resulting in three primary outputs rather than one.

Since the production of the earlier models, the Multi-Resolution Land Characteristics Consortium (MRLC) released the 2011 edition of the National Land Cover Database (NLCD) (Homer et al. 2015), and the Natural Resources Conservation Service (NRCS) has provided greatly improved soils data in the form of the gSSURGO database (Soil Survey Staff n.d.). The current model, described in this report, takes advantage of the more recent land cover and soils data, combining these with a variety of other spatial data sets using a suite of Geographic Information Systems (GIS) tools.

A Watershed Approach to Clean Water

Clean water is essential both for human health and for maintaining healthy populations of other species, especially those dependent on aquatic habitats. Point sources of water pollution, such as effluent from water treatment plants and industrial facilities, have been closely regulated in the United States since the 1970s, thanks to passage of the Clean Water Act (USEPA 2018). Nonpoint source (NPS) pollution results when rainfall, snowmelt, or irrigation water flows across or through the ground, picking up pollutants along the way and depositing them in surface or ground water. Nonpoint sources are diffuse rather than concentrated, and thus more difficult to control, but their influence on water quality is now reportedly greater than that of point sources (USEPA 1996, 2016). A national program to control NPS pollution was established in 1987, when Congress enacted Section 319(h) of the Clean Water Act. Through this program, states, territories, and tribes can obtain guidance and grant funding from the U.S. Environmental Protection agency to implement their own projects and programs to control NPS pollution (USEPA 2016).

Among the many pollutants contributing to NPS pollution, the top pollutants are nutrients (particularly nitrogen and phosphorus), suspended solids and sediments, and pathogens (USEPA 2016). To tackle the problem of NPS pollution, it is beneficial to apply a watershed approach that prioritizes protection of the most critical lands needed to protect water quality at the source (Adamus and Bergman 1995, Randhir et al. 2001, Ernst 2004, Barten and Ernst 2004, Zhang and Barten 2009). Case studies have shown that the provision of financial incentives to upstream landowners to maintain, sustainably manage, and/or restore forests (i.e., “green infrastructure”) can be more cost effective for maintaining water quality than investments in “grey infrastructure” such as new water filtration plants (Hanson et al. 2011, Talberth et al. 2012).

Soil type, topography, and land cover all influence the amount of pollutants reaching surface waters and aquifers. Soils with a low infiltration rate have high potential for producing large volumes of stormwater runoff, and large volumes of runoff can transport high pollutant loads directly to water sources. Soil erodibility influences how much sediment is available for transport by the surface runoff (Renard et al. 1997). Topography influences the path and speed of water as it moves across the land or transitions to underground aquifers, as well as the distance it must travel to reach a stream or other concentration of water (Gallant and Wilson 2000). This in turn influences how much of the original pollutant load emanating from a piece of land ultimately ends up in a body of water. Land cover determines the types and amounts of pollutants emanating from a piece of land (USEPA 2016), and interacts with soil type to influence erosion and runoff volumes (Cronshey et al. 1986, Renard et al. 1997). Forest cover, in particular, is highly valued for the watershed services it provides, including water flow regulation, erosion control, pollution filtration, and freshwater supply (Hanson et al. 2011).

Model Components

The Virginia ConservationVision Watershed Model encompasses a suite of raster datasets and associated maps in which importance or value of lands for protecting water quality and watershed integrity is scaled from 0 (least important or valuable) to 100 (most important or valuable). The Watershed Model consists of three primary raster datasets representing conservation priorities, restoration priorities, and stormwater management priorities. Priorities are derived from four major components: soil sensitivity, landscape position, watershed integrity, and land cover (Figure 1).

The soil sensitivity component of the model prioritizes protection, restoration, and management of lands with “sensitive” soils, with sensitivity defined in terms of the potential for erosion and runoff. The most sensitive soils are highly erodible, have low drainage capacity, and occur on steep slopes. On a parcel with sensitive soils, a disturbance event such as forest clearing is expected to cause a greater reduction in water quality downstream than a similar event on an otherwise similar parcel with less sensitive soils. Similarly, restoration efforts to improve watershed integrity are expected to have a greater return on investment in areas with more sensitive soils, all else equal (Barten and Ernst 2004).

The landscape position component of the model prioritizes protection of lands that are likely to have the most impact on water resources based on proximity, accounting for distance as well as, for surface waters, the direction of water flow. It is comprised of two subcomponents, one assessing relative importance to the drinking water supply, and the other assessing importance to any waters or wetlands, regardless of their relation to drinking water sources. For the drinking water subcomponent, the model incorporates location data for both surface water intakes and groundwater sources (i.e., wells), and also considers the population served by each water source.

For the hydrological zone subcomponent, the model incorporates the distance along the flow path to the nearest stream, river, waterbody, or wetland, in recognition of the importance of buffer zones (Wenger 1999, Klapproth and Johnson 2009). The model places special emphasis on protecting headwaters because of their strong influence on downstream waters (Alexander et al. 2007). It also incorporates distance to, and density of, sinkholes as a proxy for the potential influence on groundwater. Sinkholes, caves, springs, losing streams, and underground drainage networks are characteristic of karst topography, which occurs in regions underlain by water-soluble, carbonate bedrock such as limestone or dolomite (Hubbard 2014, Weary and Doctor 2014). Sinkholes provide a conduit for surface waters, and any pollutants they may carry, to directly enter groundwater aquifers (DNH n.d., DGMR 2015). Once underground, water follows unpredictable paths, and can move up to several kilometers per day, as indicated by dye trace studies in Virginia (DNH n.d.). The direct connection between surface water and groundwater, combined with fast and largely unpredictable underground flow patterns, makes groundwater in karst regions especially vulnerable to pollution.

The watershed integrity component of the model quantifies the relative integrity of subwatersheds, defined by the 12-digit hydrologic unit (HUC 12) boundaries of the Watershed Boundary Dataset (USGS and NRCS 2013). Integrity is measured as a composite of four subcomponents, including a biotic factor, a pollution factor, and two landscape composition factors. For the biotic subcomponent, the model uses the modified Index of Biotic Integrity (mIBI), which is assigned to each subwatershed by the Healthy Waters/INSTAR program, based on occurrences of certain aquatic species indicative of stream health (Neely et al. 2010). For the pollution subcomponent, the model uses estimates of nitrogen, phosphorus, and sediment pollutant loads for each subwatershed, calculated for Virginia’s NPS Pollution Assessment and Prioritization (Huber 2014, DEQ 2018). The landscape composition subcomponents of watershed integrity include the percent cover of impervious surfaces, and the percent cover of forests and wetlands combined, as assessed for each subwatershed based on data from the National Land Cover Database (Homer et al. 2015). The amount of forest cover and impervious surfaces within a drainage and/or stream buffer zone has been shown to have significant impacts on water quality (Wenger 1999, Booth et al. 2002). Impervious surfaces decrease the amount of water that can infiltrate the ground, and cause higher volumes and velocity of stormwater runoff, thereby transporting accumulated pollutants quickly and efficiently directly into downstream waters (Arnold and Gibbons 1996). Stream quality can be significantly impacted when impervious surfaces comprise more than 25% of the landscape (NOAA n.d.). In contrast, forests mitigate some of these impacts by slowing water flow and filtering out pollutants before they enter water bodies (Klapproth and Johnson 2009, Hanson et al. 2011).

Following the example of Barten and Ernst (2004), the (local) land cover component of the model quantifies the relative priorities of different land cover types for three objectives: conservation, restoration, or stormwater management. The three objectives were assumed to be mutually exclusive, meaning that any given land cover could have a non-zero priority for only one of the three objectives. Forests, wetlands, and other "natural" type land covers were assigned conservation priorities. Agricultural lands and developed open space were assigned priorities for restoration. Developed and barren lands were assigned priorities for stormwater management.

Methods

Spatial Data Processing

ArcGIS software (ESRI 2015) was used for all spatial data processing. In addition to using standard ArcGIS tools, we developed a toolbox containing a set of custom ModelBuilder tools and Python script tools to carry out the necessary procedures. This toolbox is available on GitHub (https://github.com/VANatHeritage/ConsVision_WatershedModel).

Input datasets are listed in Table 1, and datasets produced are listed in subsequent tables. As needed, all input datasets were clipped to the relevant area of interest, and reprojected to the Albers Equal Area coordinate system to match the NLCD data prior to processing. Where applicable, an NLCD raster was used as a snap raster to set cell size and alignment for all raster processing and vector-to-raster transformations. Unless otherwise stated, a pixel resolution of 30 m was used. Once all processing was complete, deliverable products were reprojected to the Virginia Lambert coordinate system to match other state spatial data, and clipped to the Virginia state border.

Soil Sensitivity Component

Runoff Score

We used the drainage class assigned by NRCS (Soil Survey Staff n.d.) as a proxy for runoff potential. Although the hydrologic soil group, not the soil drainage class, has been used in runoff equations (Cronshey et al. 1986), the two are related. Drainage class was chosen over hydrologic soil group for use in the model because it includes finer subdivisions, with seven classes instead of four. We extracted drainage class data from the gSSURGO Soils Database (Soil Survey Staff n.d.). We developed a table (Table 2) that crosswalks drainage classes to runoff scores ranging from 0 (low runoff potential) to 100 (high runoff potential), then attached runoff scores to each pixel in the gSSURGO map unit raster. Because the gSSURGO raster had a 10-m pixel resolution, after processing it was aggregated (by mean values) to 30-m resolution to match other model components. The output Runoff Score raster dataset represents the relative propensity of the soil for producing high runoff volumes.

Erosion Score

The Erosion Score raster dataset represents the relative propensity for soil erosion, and is based on a measure of erodibility known as the K-factor (Cronshey et al. 1986, Renard et al. 1997). A table assigning K-factor values to map units was extracted using the tool “Map Soil Properties and Interpretations” in the Soil Data Management Toolbox for ArcGIS (NRCS 2015). The original K-factor values ranged from 0.02 to 0.55, but were linearly rescaled to erosion scores ranging from 0 (low erosion potential) to 100 (high erosion potential). The erosion score values were then attached to each pixel in the gSSURGO map unit raster. Following recommendations in the OpenNSPECT Technical Guide (NOAA 2014), all pixels with missing K-factor values were assigned a value of 0.30, yielding a score of 55. The final output raster was aggregated to 30 m pixels using mean cell values.

Slope Score

Slope steepness is a third contributor to the soil sensitivity component, since steeper slopes are prone to higher runoff velocities and more erosion (Cronshey et al. 1986, Renard et al. 1997). We used a raster representing slope in degrees (10 m pixel resolution), which had been previously derived by Virginia Natural Heritage Program staff from National Elevation Dataset tiles (USGS n.d. -a). This was aggregated up to 30-m pixel resolution. Aggregated slope values were rescaled to scores ranging from 0 (flat slopes) to 100 (steepest slopes). To produce the final Slope Score raster, slope values ≤ 3 were set to a score of 0, values ≥ 27 were set to a score of 100, and intermediate values were linearly rescaled between those extremes.

Soil Sensivity Score

The Soil Sensitivity Score was calculated as the mean of the Runoff, Erosion, and Slope Scores. Values in the Soil Sensitivity Score raster thus range between 0 (low soil sensitivity) and 100 (high soil sensitivity). An overview of the geoprocessing steps leading to the Soil Sensitivity Score is presented in Figure 2, and a summary of the datasets produced for this component is presented in Table 3.

Landscape Position Component

Drinking Water Score

The Drinking Water Score raster dataset represents the relative importance of lands, based on landscape position, for protecting sources of drinking water. It is based on data obtained in November 2016 from the Virginia Department of Health, Office of Drinking Water (ODW). The data included a point feature class representing locations of surface water intakes and groundwater sources (wells), and a polygon feature class representing the entire catchment draining to each surface water intake. The polygons represent ODW's "Zone 2" assessment area for surface water sources (VDH 1999). The original point feature class was updated to include a new field estimating the population served by each source, calculated from existing fields in the attribute table. The Drinking Water Score was calculated simply as the greater of two sub-scores described below: the Surface Water Score and the Groundwater Score.

Surface Water Score

For each source water point (analyzed separately), a series of steps was carried out to produce two rasters, representing a "distance score" and a "density score". First, a buffer of 150 m was applied to the point. The buffer zone was added to the point's associated catchment polygon, and the two areas combined were used as an analysis mask for subsequent operations, resulting in null values for cells outside the mask area.

Next, a raster representing the Euclidean distance to the point was generated. Euclidean distances were rescaled to scores ranging from 0 (farthest) to 100 (closest). For surface waters, within the larger "Zone 2" catchment polygon, ODW uses a radius of 5 mi (8047 m) to delimit the "Zone 1" assessment area (VDH 1999). Therefore, distances ≤ 8047 m from the point were set to a score of 100. Distances ≥ 80,470 m were set to a score of 0, and values between these extremes were linearly rescaled to range from 0 to 100. The output raster was called the "distance score." We then derived a "density score" raster from the distance score raster using the following conversion:

Equation 1:

$$Density\ Score = Population\ Served * Distance\ Score/100$$

Once the individual score rasters had been produced for each surface water point, they were combined to generate summary score rasters. The summary distance score raster was derived by taking the maximum across all individual distance scores. The summary density score raster was derived by taking the sum across all individual density scores and then converting to a score between 0 and 100. Values ≤ 1000 were set to a score of 0, values ≥ 100,000 were set to a score of 100, and values between these extremes were linearly rescaled to range from 0 to 100. The two summary scores were averaged to obtain the final Surface Water Score raster.

Groundwater Score

As with source water points, we derived two rasters representing scores for proximity and population served. However, ODW did not delineate catchment polygons for the groundwater points because recharge areas for groundwater are not generally known. Thus, analyses considered potential impacts from all directions. In calculations used to convert distances to scores, we used thresholds based on the radii used by ODW to delineate "Zone 1" and "Zone 2" assessment areas for groundwater sources (VDH 1999). The radius for Zone 1 is 1000 ft (305 m), and the radius for Zone 2 is 1 mi (1609 m).

We first generated a raster representing Euclidean distance to the nearest groundwater point. Euclidean distances were rescaled to scores: distances ≤ 305 m (i.e., within Zone 1) were set to a score of 100; distances ≥ 1609 m (i.e., outside Zone 2), were set to a score of 0, and values between these extremes were linearly rescaled to range from 0 (farthest) to 100 (closest). The output was called the "distance score."

Next, we performed a kernel density analysis of the ground water source points, using a search radius of 1609 m and the estimated population served as the density factor. The output raster thus represented population served in terms of density (persons/mi^2). The kernel density output was rescaled to produce a "density score" raster, with scores ranging from 0 to 100. Values greater than an upper limit of 100,000 were set to a score of 100, and values between 0 and the upper limit were linearly rescaled to range from 0 to 100. This output was called the "density score." The distance and density scores were averaged to obtain the final Groundwater Score raster.

Hydro Zone Score

The Hydro Zone Score raster dataset represents the relative importance of lands, based on landscape position, for protecting surface water features, wetland features, and/or groundwater in karst zones. The Hydro Zone Score was calculated simply as the greater of two sub-scores: the Flow Distance Score and the Karst Score, described below.

Flow Distance Score

The Flow Distance Score raster dataset represents the relative importance of lands for protecting surface water and wetland features. It is derived from a Flow Distance raster and a Headwaters Indicator raster. The Headwaters Indicator raster indicates presence or absence within a headwater catchment. It was developed from NHDPlus data (McKay et al. 2012), which includes stream reaches, catchments delineated for each stream reach, and tabular data that can be used to identify the subset of reaches that are headwaters. To create the headwaters indicator, we extracted the headwater catchments, assigned them a value of 100, and converted them to a raster. The remaining raster pixels, not within headwater catchments, were set to value of 0.

The Flow Distance raster represents the distance down along flowpaths to the nearest water or wetland. This dataset had been previously developed by the Virginia Natural Heritage Program from National Hydrography Dataset data (USGS n.d. -b) in combination with NHDPlus version 2 (McKay et al. 2012). Values in the Flow Distance raster were converted to scores ranging from 0 (farthest) to 100 (closest). Distances ≤ 30 m were set to 100, distances ≥ 300 m were set to 0, and values were linearly rescaled between those extremes. In the final Flow

Distance Score raster, scores were modified to give greater weight to areas within headwater catchments. For cells within the headwater catchments, the flow distance score was unaltered, but outside the headwater catchments, the score was reduced to 75% of the original value.

Karst Score

The Karst Score raster dataset represents the relative importance of lands for protecting groundwater in karst zones based on distance to, and density of, known sinkholes. This dataset was derived from a polygon feature class representing sinkhole locations, obtained from the Virginia Department of Mines, Minerals, and Energy in January, 2017. To prepare the sinkholes data for further processing, we first dissolved polygons to eliminate any overlaps. A new field was added to the attribute table, and the value was set to 1 if the shape area was ≤ 100 m^2; otherwise it was set to (shape area)/100. This value was used to determine the number of random points to generate for each polygon.

After generating random points within the sinkhole polygons, the points were used in a kernel density analysis, using a search window of 10 km, with the output raster representing point density (points/km^2). Density values were converted to scores ranging from 0 (low density) to 100 (high density). Density values ≥ 250 were set to 100, and values between 0 and 250 were linearly rescaled to range from 0 to 100. This output was called the “density score.”

We converted the dissolved sinkhole polygons to raster format, then generated a raster representing Euclidean distance to the nearest polygon. Euclidean distances were converted to scores by setting values ≤ 300 m to 100, setting values ≥ 10 km to 0, and linearly rescaling values between those extremes. This output was called the “distance score”. The karst density and distance scores were averaged to obtain the final Karst Score raster.

Landscape Position Score

The Landscape Position Score was calculated as the weighted mean of the Hydro Zones score (weight 0.67) and the Drinking Water Score (weight 0.33). Values in the Landscape Position Score raster thus range between 0 (little or no impact on drinking water sources and sensitive hydrological zones) and 100 (high impact). The sequence of geoprocessing steps used to derive the Landscape Position Score raster is illustrated in Figure 3, and datasets produced are itemized in Table 4.

Watershed Integrity Component

The watershed integrity component of the model is based on characteristics within each subwatershed represented by the HUC 12 boundaries of the national Watershed Boundary Dataset (USGS and NRCS 2013). Thus, unlike other model components, all pixels within a subwatershed have the same value for each characteristic. The watershed integrity component was derived from four raster datasets that score forest and wetland cover, impervious surface cover, biotic integrity, and estimated pollution loads within each subwatershed (Figure 4). Datasets produced for this component are itemized in Table 5.

Forest-Wetland Score

The Forest-Wetland Score is based on the proportional cover of forests and wetlands within the subwatershed. It is derived from the National Land Cover Database (NLCD) land cover classification from 2011 (Homer et al. 2015). The land cover data was reclassified by setting all pixels representing open water to null, all pixels representing any forest or wetland type to a value of 1, and all other land cover categories to 0. We then calculated the proportional cover of forests and wetlands (combined) within the non-water portion of each HUC 12 boundary. Proportional cover values were rescaled to scores ranging from 0 (lowest cover of forests and wetlands) to 100 (highest cover). Proportional cover values ≤ 0.15 were set to a score of 0, values ≥ 0.85 were set to a score of 100, and intermediate values were linearly rescaled between those extremes.

Impervious Score

The Impervious Score is based on the proportional cover of impervious surfaces within the subwatershed. It is derived from the NLCD imperviousness dataset from 2011 (Homer et al. 2015), in which raster values represent the percent cover of impervious surfaces within each cell rather than discrete land cover classes. All pixels representing open water were set to to null, and remaining pixel values in the imperviousness dataset were divided by 100 to convert percentages to proportions (values ranging from 0 to 1). We then calculated the zonal mean to determine the proportional cover of impervious surfaces within the non-water portion of each HUC 12 boundary. The zonal mean values were rescaled to scores ranging from 0 (highest impervious cover) to 100 (lowest cover). Proportional cover values ≤ 0.05 were set to a score of 100, values

≥ 0.25 were set to a score of 0, and intermediate values were linearly rescaled between those extremes.

Biotic Score

The Biotic Score represents the relative integrity of the subwatershed based on aquatic species assemblages. This raster was derived from a table containing a set of "Modified Index of Biotic Integrity" (mIBI) values (Neely et al. 2010) for each subwatershed, obtained in March 2016 from the Center for Environmental Studies at Virginia Commonwealth University. We converted the mIBI values to scores ranging from 0 (lowest mIBI) to 100 (highest mIBI). In theory, mIBI values could range from 6 to 30, but in practice they ranged from 8 to 24. The mIBI value 8 was assigned the score 0, the mIBI value 24 was assigned the score 100, and intermediate values were linearly rescaled between these extremes. The scored tabular values were joined to the subwatershed polygons, which were then converted to a raster dataset.

Pollution Score

The Pollution Score raster represents the relative integrity of the subwatershed based on estimated pollution loads. This raster was derived from a table containing a set of pollution load estimates for each subwatershed (Huber 2014, DEQ 2018), obtained from the Virginia DCR Division of Soil and Water Conservation. Estimates for nitrogen, phosphorus, and sediment loads were included in the table. We converted the pollution load estimates to scores ranging from 0 (highest pollution level) to 100 (lowest pollution level). Each pollutant was rescaled with a different linear function depending on the minimum and maximum values of the input data for that pollutant. The scores for the three pollutants were averaged with equal weights to obtain a summary pollution score. The summary score values were joined to the subwatershed polygons, which were then converted to a raster dataset. In theory, the pollution scores could range from 0 to 100, but in practice they ranged from 27 to 99. For that reason, the final Pollution Score raster was linearly rescaled to stretch the values across the full theoretical range.

Watershed Integrity Score

The Forest-Wetland Score, Impervious Score, Biotic Score, and Pollution Score rasters were averaged with equal weights to produce an aggregate score for watershed integrity at the subwatershed level. A few subwatersheds did not have mIBI scores assigned, resulting in data gaps in the Biotic Score raster. We did not attempt to fill in these data gaps; instead, the affected cell values were calculated as the mean of only three input datasets instead of four.

In theory, the watershed integrity scores could range from 0 to 100, but in practice they ranged from 11 to 100. For that reason, the final Watershed Integrity Score raster was linearly rescaled to stretch the values across the full theoretical range.

Land Cover Component

Land cover data was obtained from the National Land Cover Database (NLCD) land cover classification from 2011 (Homer et al., 2015). Using a raster mask indicating potential presence of natural beaches, the NLCD Land Cover dataset was updated to recode "barren land" in these areas as "unconsolidated shore". The updated land cover raster was then reclassified, based on values in Table 6, to create three temporary rasters representing priority multipliers for conservation, restoration, and stormwater management, used in the final prioritizations (Figure 5). The output raster values are on a percentage scale, ranging up to 100%.

Final Prioritization

The final Watershed Model consists of three separate raster datasets representing relative priorities for conservation, restoration, or stormwater management. The sequence of geoprocessing steps used to derive the Conservation Priority Score raster from primary model components is illustrated in Figure 5. Similar diagrams could be drawn for the Restoration Priority and Stormwater Management Priority Score rasters, with appropriate type-specific substitutions for each priority. Datasets produced in the derivation of final prioritizations are itemized in Table 7.

The general approach for calculating a priority score was to first derive an impact score, based on the soil sensitivity and landscape position components, and then to multiply the impact score by priority multipliers derived from the land cover and watershed integrity components (Equation 2).

Equation 2:

$$Priority\ Score = Impact\ Score \times \frac{Land\ Cover\ Multiplier}{100} \times \frac{Integrity\ Multiplier}{100}$$

The impact score in Equation 2 quantifies the relative influence that conservation, restoration, or stormwater management actions could have on maintaining or improving water quality and watershed integrity. The raster representing impact scores was derived by averaging the soil sensitivity and landscape position score rasters with equal weights, then rescaling to span the full value spectrum from 0 to 100.

Unlike the impact score, the land cover and integrity multipliers applied in Equation 2 varied depending on the objective (conservation, restoration, or stormwater management). Derivation of the three land cover multiplier rasters is described above in the "Land Cover Component" section. Watershed multiplier rasters were derived by using two different functions transforming watershed integrity scores into priority multipliers. For the conservation objective, we used a truncated positive linear function, whereas for the restoration and stormwater management objectives, we used a piecewise linear function resulting in a hump-shaped relationship (Figure 6).

Results

The final output of the modeling process described above is three raster datasets covering the state of Virginia. The raster cell values range from 0 to 100, representing relative priorities for conservation, restoration, or stormwater management for the purpose of maintaining or improving watershed integrity and water quality. The spatial distribution of priorities is displayed in Maps 1-22. The data are available for exploration via a web mapping application hosted on ArcGIS Online at https://tinyurl.com/vaconviswater2017. For GIS users and analysts, the prioritization rasters and some additional rasters created as intermediate steps can be downloaded from the DCR-DNH website at http://www.dcr.virginia.gov/natural-heritage/vaconviswater.

Discussion

Model comparison with previous edition

The Virginia Watershed Model of 2017 was developed as an update to the Virginia Watershed Integrity Model of 2007 (Ciminelli and Scrivani 2007), and there is some overlap in the data sources used in the models. However, the current model relies on a greater variety of inputs and employs radically different methods to combine them into model scores. The model values are on different scales, with ranks in the older model ranging from 1 to 5 and scores in the current model ranging from 0 to 100. The most notable difference is that the current model includes three major components to prioritize conservation, restoration, and stormwater management. For this reason, these models should not be compared in an attempt to assess differences between years. The current model is a completely different product, rather than a simple update applying the same methods to newer data.

Model limitations

The maps presented in this report, and the underlying raster models used to produce them, should be considered as a snapshot in time, reflecting ground conditions ca. 2011. The input land cover data and all outputs have a 30 m pixel size, which may be unsatisfactory for detailed planning at fine scales.

This model, like any other model, is limited by the quality of the data inputs as well as by the assumptions made and processes used in combining these inputs. Many decisions had to be made at various processing steps to determine how each input dataset should be scored, and how different datasets should be combined to derive composite scores. The user may or may not agree with how different components were scored or combined. Each user must decide whether this model, or one or more of its components, meets their particular purpose. The model has not been formally validated at this time.

Model applications

The Watershed Model is intended as a guide to land acquisition, protection, restoration, and/or management with a focus on water quality and watershed integrity. We expect the model to be helpful to state and local governments, planning districts, environmental consultants, land trusts, and others involved in land use planning and conservation prioritization. In many, if not most cases, this model should be used in conjunction with other pertinent information and data models, including other ConservationVision models.

We have made our modeling approach as transparent as possible, both to allow for quick updates in the future, and to allow users to produce customized versions of the model as desired. The model is modular, and different users may have different applications for the various components comprising the whole. Most processed data used as inputs to the final model are available on request, so that users can combine components in different ways suited to their specific needs.

Most of the GIS processes used to produce this model are provided as tools within an ArcGIS toolbox, which can be downloaded from our GitHub site at https://github.com/VANatHeritage/ConsVision_WatershedModel. Advanced GIS users may want to "look under the hood" and modify these tools to produce a customized model for their particular area of interest, using different datasets, combining them in different ways, and/or changing various parameter settings.

Future model improvements

We expect to update this model in the future when newer land cover data becomes available. In the meantime, we are happy to consider suggestions for ways in which the model could be improved for the next iteration. Suggestions for improvements should be sent to the lead author.

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Thanks to Roy Soto and Mary Mahoney (Virginia Department of Health, Office of Drinking Water) for providing data on drinking water sources and zones of concern, and for answering various questions; to Karl Huber (Virginia DCR, Division of Soil and Water Conservation) for providing estimates of subwatershed pollutant loads from the Nonpoint Source Pollution Assessment, and for helpful discussions; to Greg Garman and Wil Shuart (Virginia Commonwealth University, Center for Environmental Studies) for providing data on the biotic integrity of subwatersheds; and to Daniel Kestner (Virginia Department of Mines, Minerals and Energy) for providing sinkholes data.

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Tables

Table 1: Data sources used to produce the Virginia Watershed Model

Dataset	Dataset Description	Data Source	Data Use
Drinking Water Sources	Point feature class representing locations of surface water intakes and groundwater sources (wells).	Virginia Department of Health, Office of Drinking Water (ODW). Received November 2016. For more information, see http://www.vdh.virginia.gov/drinking-water/source-water-programs/source-water-assessment-program/.	Landscape Position
Surface Water Zone 2	Polygon feature class representing the entire catchment draining to each surface water intake in the Drinking Water Sources dataset.	Virginia Department of Health, Office of Drinking Water (ODW). Received November 2016. For more information, see http://www.vdh.virginia.gov/drinking-water/source-water-programs/source-water-assessment-program/.	Landscape Position
Streams	Polyline feature class representing streams.	NHDPlus; US Environmental Protection Agency/US Geological Survey/Horizon Systems. Downloaded July 2015. For more information, see http://www.horizon-systems.com/nhdplus.	Landscape Position
Catchments	Polygon feature class representing the immediate catchment boundary for each stream segment.	NHDPlus; US Environmental Protection Agency/US Geological Survey/Horizon Systems. Downloaded July 2015. For more information, see http://www.horizon-systems.com/nhdplus.	Landscape Position
NHDPlus Attributes	Tabular attributes associated with NHDPlus Features.	NHDPlus; US Environmental Protection Agency/US Geological Survey/Horizon Systems. Downloaded July 2015. For more information, see http://www.horizon-systems.com/nhdplus.	Landscape Position

Dataset	Dataset Description	Data Source	Data Use
Flow Distance	Raster dataset (30-m pixels) representing the distance down along flowpaths to the nearest water or wetland.	Virginia Department of Conservation & Recreation, Division of Natural Heritage (DCR-DNH). Derived from the National Hydrography Dataset (NHD; U.S. Geological Survey) and NHDPlus Version 2 data.	Landscape Position
Sinkholes	Polygon feature class representing sinkhole locations.	Virginia Department of Mines, Minerals, and Energy. Received January 2017. For more information, see https://www.dmme.virginia.gov/dgmr/sinkholes.shtml.	Landscape Position
Soils Database	Complex geodatabase containing rasters, vector datasets, and extensive tables describing soil characteristics associated with mapped soil types.	gSSURGO, Natural Resources Conservation Service. Downloaded May 2015. For more information, see https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/geo.	Soil Sensitivity
Slope	Raster dataset (10-m pixels) representing slope (steepness) in degrees.	Virginia Department of Conservation & Recreation, Division of Natural Heritage (DCR-DNH). Derived from 1/3 arc-second National Elevation Dataset tiles obtained in October 2012 from the U.S. Geological Survey.	Soil Sensitivity
Subwatershed Boundaries	Polygon feature class representing subwatershed boundaries at the HUC-12 level.	Watershed Boundary Dataset (WBD), U.S. Geological Survey. Downloaded April 2014. Integrated and delivered with National Hydrography Dataset (NHD) data. For more information, see https://nhd.usgs.gov/wbd.html.	Watershed Integrity
Imperviousness	Raster dataset (30-m pixels) representing percent impervious cover circa 2011.	National Land Cover Database (NLCD), Multi-Resolution Land Characteristics Consortium (MRLC). Downloaded December 2014. For more information, see https://www.mrlc.gov.	Watershed Integrity

Dataset	Dataset Description	Data Source	Data Use
Land Cover	Raster dataset (30-m pixels) representing land use / land cover circa 2011.	National Land Cover Database (NLCD), Multi-Resolution Land Characteristics Consortium (MRLC). Downloaded December 2014. For more information, see https://www.mrlc.gov.	Watershed Integrity; Prioritization
Natural Beach Mask	Raster dataset (30-m pixels) representing general areas in which natural (undeveloped) beaches could be present. Used as a mask to correct NLCD "barren land" class in coastal areas.	Virginia Department of Conservation & Recreation, Division of Natural Heritage (DCR-DNH). Dataset is an interim product from the Virginia Natural Lands Assessment.	Prioritization
Subwatershed ID Crosswalk	Table matching subwatershed identification codes used at the state level with those used at the national level.	Virginia Department of Conservation & Recreation, Division of Soil and Water Conservation (DCR-DSWC). Received January 2016. For more information, see http://www.dcr.virginia.gov/soil-and-water/hu.	Watershed Integrity
mIBI Table	Table assigning "Modified Index of Biotic Integrity" (mIBI) scores to each subwatershed.	Center for Environmental Studies, Virginia Commonwealth University. Received March 2016. For more information, see http://gis.vcu.edu/instar/.	Watershed Integrity
Pollution Loads Table	Table assigning estimated pollution loads for nitrogen, phosphorus, and sediments to each subwatershed.	Virginia Department of Conservation & Recreation, Division of Soil and Water Conservation (DCR-DSWC). Received April 2017.	Watershed Integrity

Table 2: Runoff scores assigned to drainage classes

Drainage Class (from gSSURGO)	Runoff Score
Very poorly drained	100
Poorly drained	90
Somewhat poorly drained	75
Moderately well drained	50
Well drained	25
Somewhat excessively drained	10
Excessively drained	0

Table 3: Datasets produced for the soil sensitivity component of the Watershed Model

Dataset	Dataset Description	Data Inputs Used[1]
Drainage Class Scores Table	Table assigning model scores to drainage classes in the gSSURGO geodatabase.	Soils Database
Runoff Score	Raster dataset representing relative propensity for producing high runoff volumes, based on soil drainage class.	Soils Database; Drainage Class Scores Table
K-factor Scores Table	Table assigning K-factor values and model score equivalents to each gSSURGO map unit.	Soils Database
Erosion Score	Raster dataset representing relative propensity for soil erosion, based on soil K-factor.	Soils Database; K-factor Scores Table
Slope Score	Raster dataset representing relative slope steepness.	Slope
Soil Sensitivity Score	Raster dataset representing the relative importance for impacts to the watershed, based on soil drainage capacity, soil erodibility, and slope steepness. It is the mean of the Runoff Score, Erosion Score, and Slope Score.	Runoff Score; Erosion Score; Slope Score

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[1] Refer to Table 1 for descriptions of inputs

Table 4: Datasets produced for the landscape position component of the Watershed Model

Dataset	Dataset Description	Data Inputs Used[2]
Updated Drinking Water Sources	Point feature class representing source water locations, with additional attribute indicating estimated population served by each point.	Drinking Water Source Points
Surface Water Score	Raster dataset representing relative importance for protecting surface water intakes for drinking water, based on distance to sources, presence within catchments draining to sources, and estimates of population served by each source.	Updated Drinking Water Sources; Surface Water Zone 2
Groundwater Score	Raster dataset representing relative importance for protecting groundwater sources for drinking water, based on distance to nearest source, density of sources, and estimates of population served by each source.	Updated Drinking Water Sources; Surface Water Zone 2
Drinking Water Score	Raster dataset representing relative importance for protecting surface water and groundwater sources for drinking water. It is the greater of the Surface Water Score and the Groundwater Score.	Surface Water Score; Groundwater Score
Headwaters Indicator	Raster dataset representing presence or absence within a headwater catchment.	NHDPlus Attributes; Streams; Catchments

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[2] Refer to Table 1 for descriptions of inputs

Dataset	Dataset Description	Data Inputs Used[2]
Flow Distance Score	Raster dataset representing relative importance for protecting surface water and wetland features, based on distance down along flow paths to the nearest water or wetland. Importance is weighted more heavily for locations within headwater catchments.	Flow Distance; Headwaters Indicator
Karst Score	Raster dataset representing relative importance for protecting groundwater in karst zones based on distance to, and density of, sinkholes.	Sinkholes
Hydro Zones Score	Raster dataset representing relative importance for protecting surface water features, wetland features, and/or groundwater in karst zones. It is the greater of the Karst Score or the Flow Distance Score.	Karst Score; Flow Distance Score
Landscape Position Score	Raster dataset representing the relative importance for impacts to the watershed, based on landscape position relative to hydrological zones and drinking water sources. It is the weighted mean of the Hydro Zones score (weight 0.67) and the Drinking Water Score (weight 0.33).	Hydro Zones Score; Drinking Water Score

Table 5: Datasets produced for the watershed integrity component of the Watershed Model

Dataset	Dataset Description	Data Inputs Used[3]
Forest-Wetland Score	Raster dataset representing relative integrity of the subwatershed, based on the percent cover of forests and wetlands.	Land Cover; Subwatershed Boundaries
Impervious Score	Raster dataset representing relative integrity of the subwatershed, based on the percent cover of impervious surfaces.	Land Cover; Imperviousness; Subwatershed Boundaries
Biotic Score	Raster dataset representing relative integrity of the subwatershed, based on aquatic species assemblages.	mIBI Table; Subwatershed Boundaries; Subwatershed ID Crosswalk
Pollution Score	Raster dataset representing relative integrity of the subwatershed, based on estimated pollution loads of nitrogen, phosphorus, and sediments.	Pollution Loads Table; Subwatershed Boundaries; Subwatershed ID Crosswalk
Watershed Integrity Score	Raster dataset representing the relative integrity of the subwatershed, based on landscape composition, aquatic species assemblages, and pollution loads. It is the mean of the Forest-Wetland Score, Impervious Score, Biotic Score, and Pollution Score, rescaled to cover the full range from 0 to 100.	Forest-Wetland Score; Impervious Score; Biotic Score; Pollution Score

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[3] Refer to Table 1 for descriptions of inputs

Table 6: Priority multipliers assigned to land cover types

	Priority Multipliers[1]		
Land Cover Type	**Conservation**	**Restoration**	**Stormwater Management**
Unconsolidated Shore	100	-	-
Deciduous Forest	100	-	-
Evergreen Forest	100	-	-
Mixed Forest	100	-	-
Scrub / Shrub	100	-	-
Grassland / Herbaceous	50	-	-
Woody Wetlands	100	-	-
Emergent Herbaceous Wetlands	100	-	-
Developed, Open Space	-	17	-
Pasture / Hay	-	51	-
Cultivated Crops	-	100	-
Developed, Low Intensity	-	-	20
Developed, Med. Intensity	-	-	34
Developed, High Intensity	-	-	100
Barren Land	-	-	95

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[1] Multipliers are on a percentage scale, ranging from 0 to 100%.

Table 7: Datasets produced for the land cover component and final prioritization of the Watershed Model

Dataset	Dataset Description	Data Inputs Used
Updated Land Cover	Updated version of NLCD Land Cover in which undeveloped beach pixels classified as "barren land" are recoded as "unconsolidated shore".	Land Cover; Natural Beach Mask
Impact Score	Raster dataset representing the relative influence that conservation, restoration, or stormwater management actions could have on maintaining or improving water quality and watershed integrity, based on soil attributes and position in the landscape.	Soil Sensitivity Score; Landscape Position Score
Conservation Priority Score	Raster dataset representing relative priority for conservation, based on land cover type, impact potential, and watershed integrity. Only forests, wetlands, shrublands, natural grasslands, and undeveloped beaches (unconsolidated shore) have a conservation priority score greater than 0.	Impact Score; Watershed Integrity Score; Updated Land Cover
Restoration Priority Score	Raster dataset representing relative priority for restoration and/or implementation of Best Management Practices, based on land cover type, impact potential, and watershed integrity. Only croplands, pasture/hay, and developed open space have a restoration priority score greater than 0.	Impact Score; Watershed Integrity Score; Updated Land Cover
Stormwater Management Priority Score	Raster dataset representing relative priority for stormwater management, based on land cover type, impact potential, and watershed integrity. Only low-, medium-, and high-intensity developed areas and barren lands have a stormwater management priority score greater than 0.	Impact Score; Watershed Integrity Score; Updated Land Cover

Figures

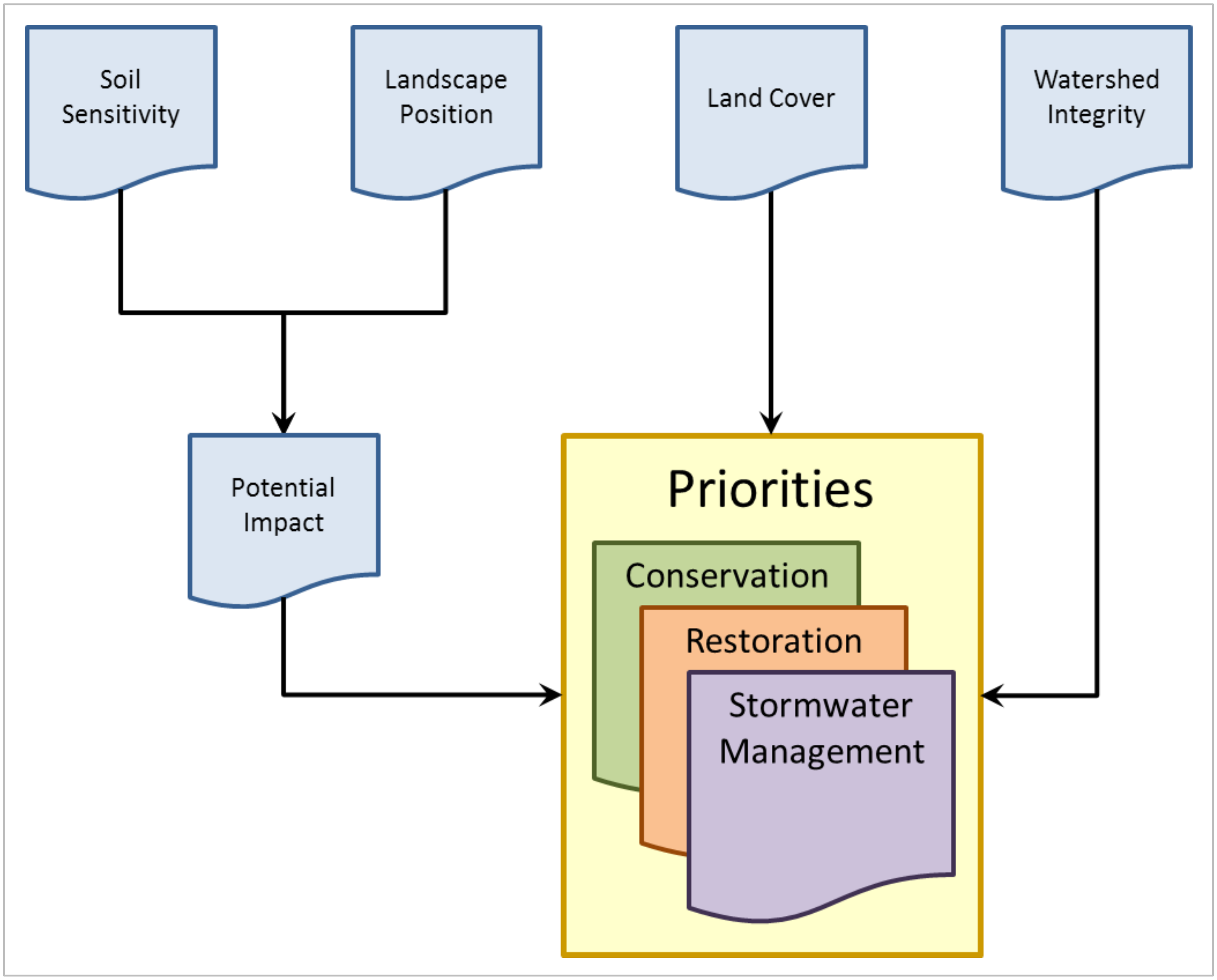


Figure 1: Overview of the Watershed Model.

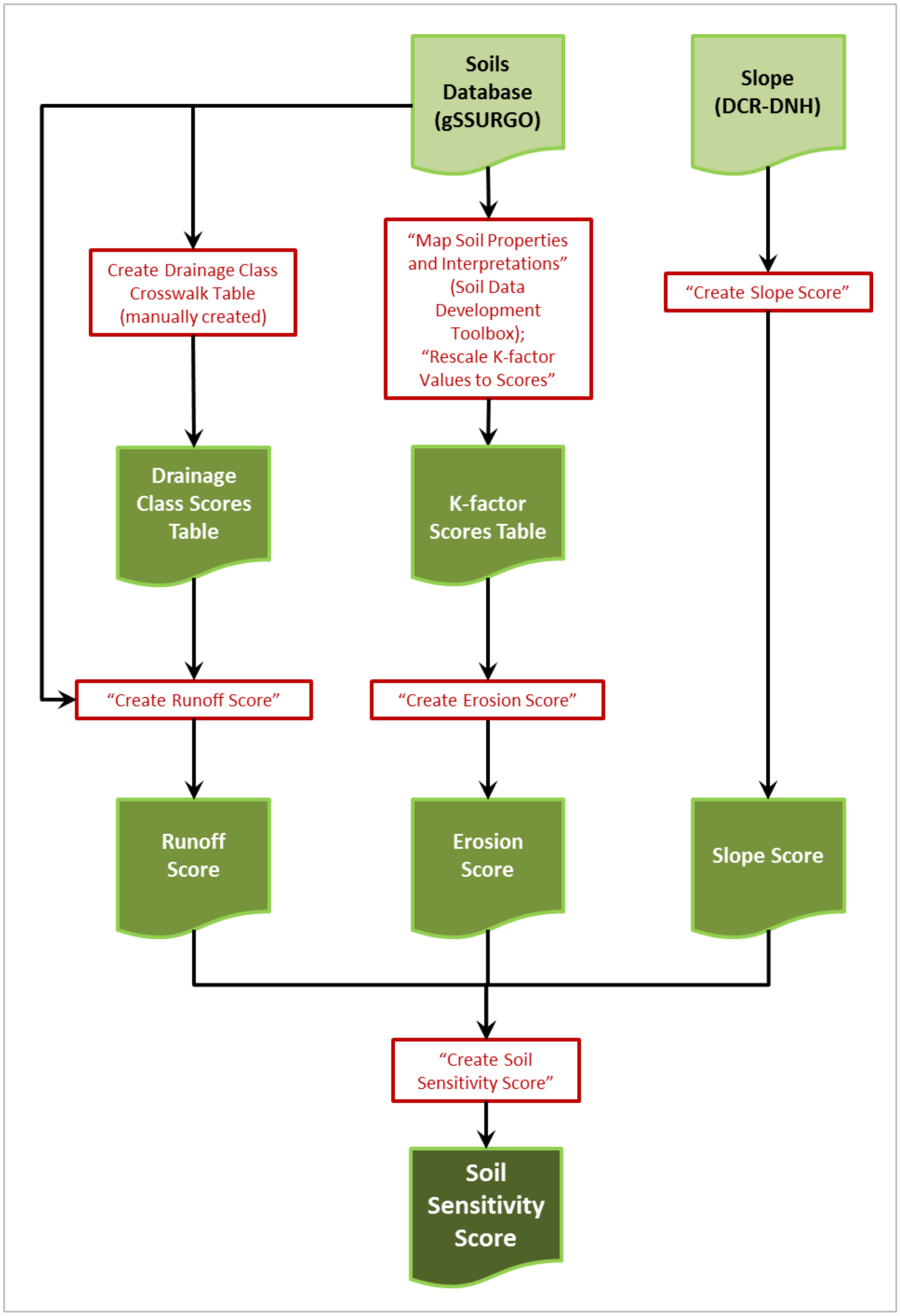


Figure 2: Geoprocessing steps leading to the Soil Sensitivity Score.
Input data sources are represented in the lightest shade of green; refer to Table 1 for descriptions of the input data sources. Intermediate products are shown in a medium shade of green, and the final, primary model component is shown in the darkest shade of green. Red boxes represent geoprocessing steps, and names of custom tools in the Watershed Model toolbox are enclosed in quotes.

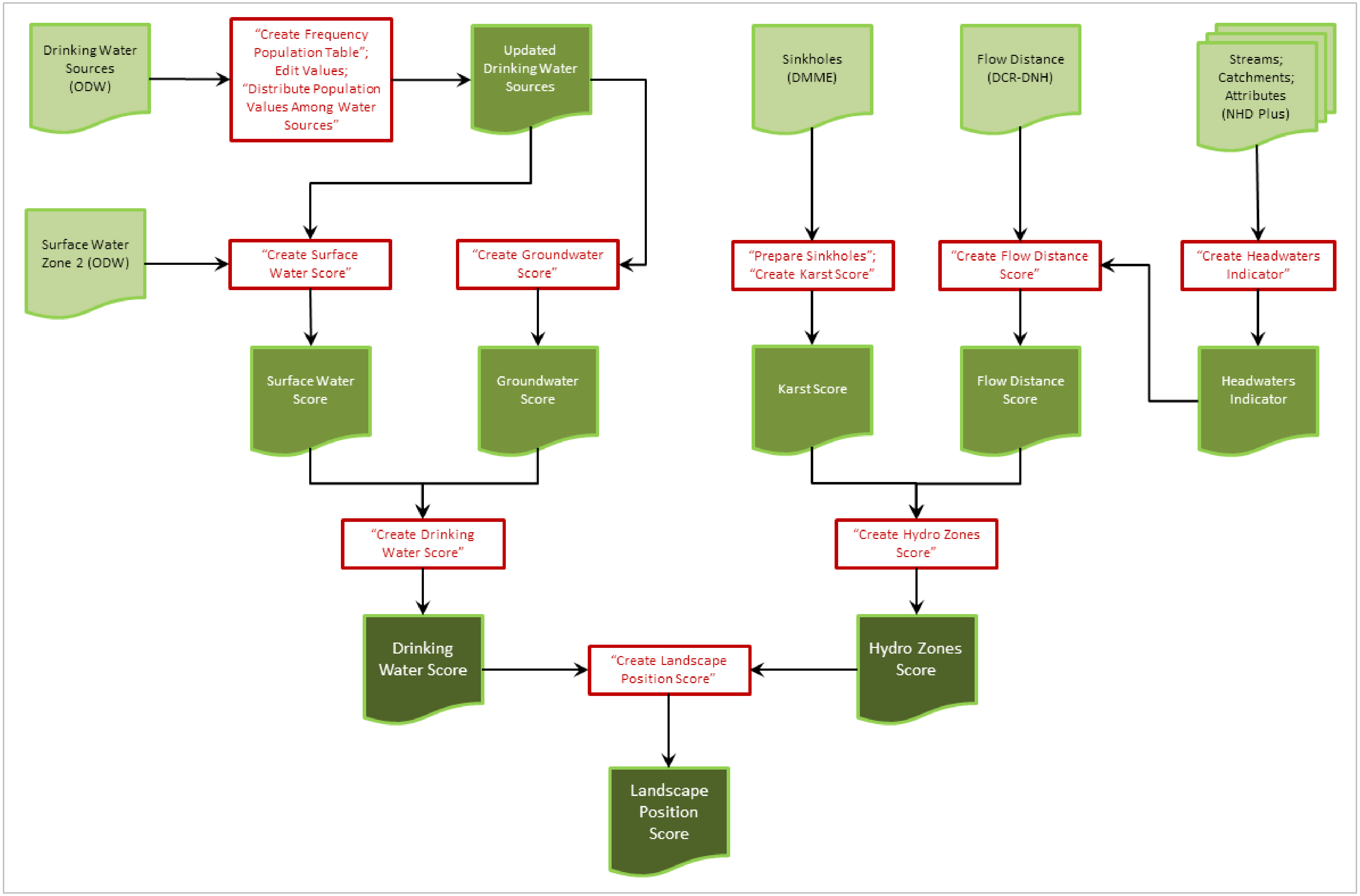


Figure 3: Geoprocessing steps leading to the Landscape Postion Score.
Input data sources are represented in the lightest shade of green; refer to Table 1 for descriptions of the input data sources. Intermediate products are shown in a medium shade of green, and final products, including a primary model component, are shown in the darkest shade of green. A stack is used to represent a set of similar data sources or products. Red boxes represent geoprocessing steps, and names of custom tools in the Watershed Model toolbox are enclosed in quotes.

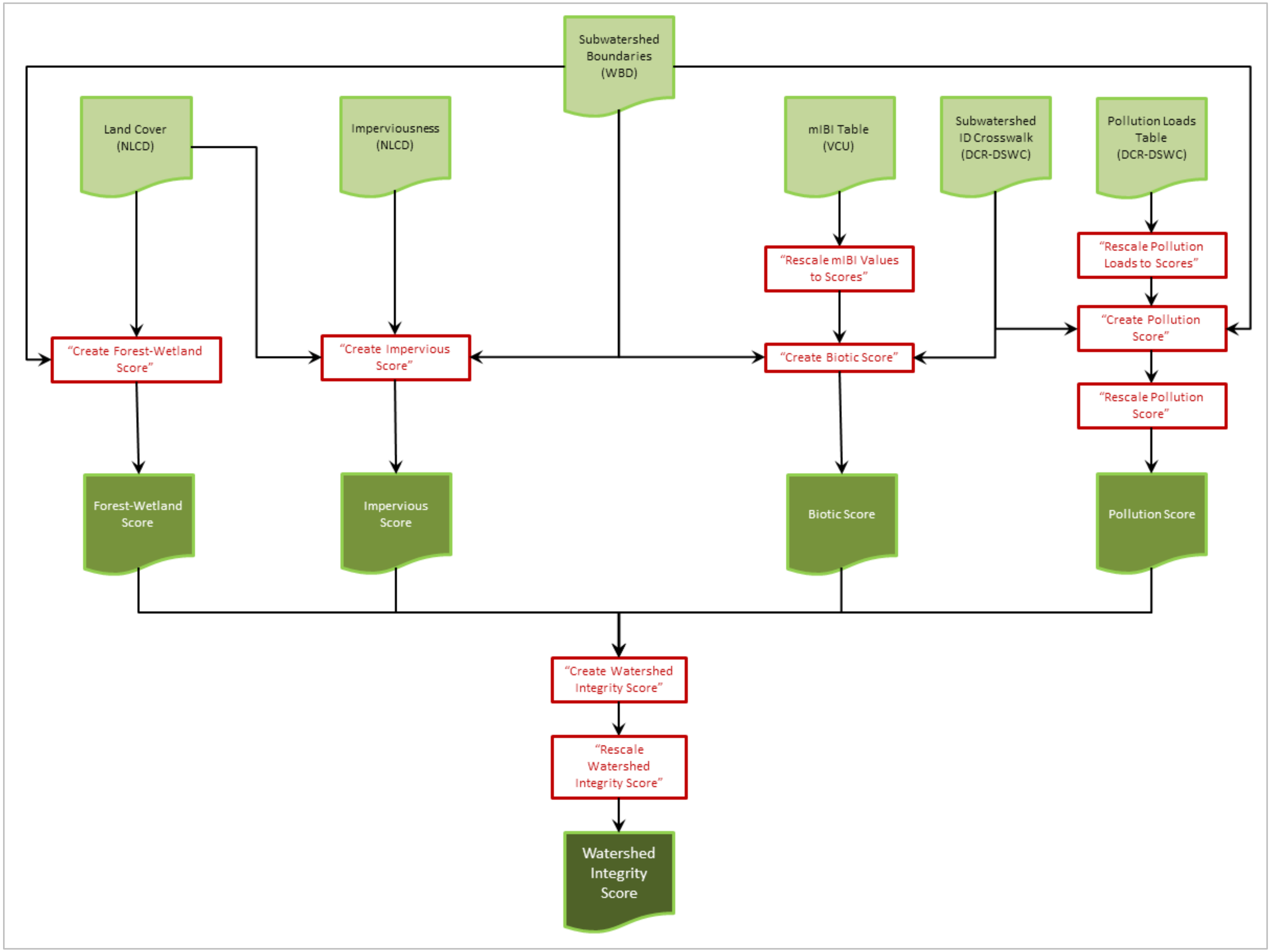


Figure 4: Geoprocessing steps leading to the Watershed Integrity Score.
Input data sources are represented in the lightest shade of green; refer to Table 1 for descriptions of the input data sources. Intermediate products are shown in a medium shade of green, and the final product used as a model component is shown in the darkest shade of green. Red boxes represent geoprocessing steps, and names of custom tools in the Watershed Model toolbox are enclosed in quotes.

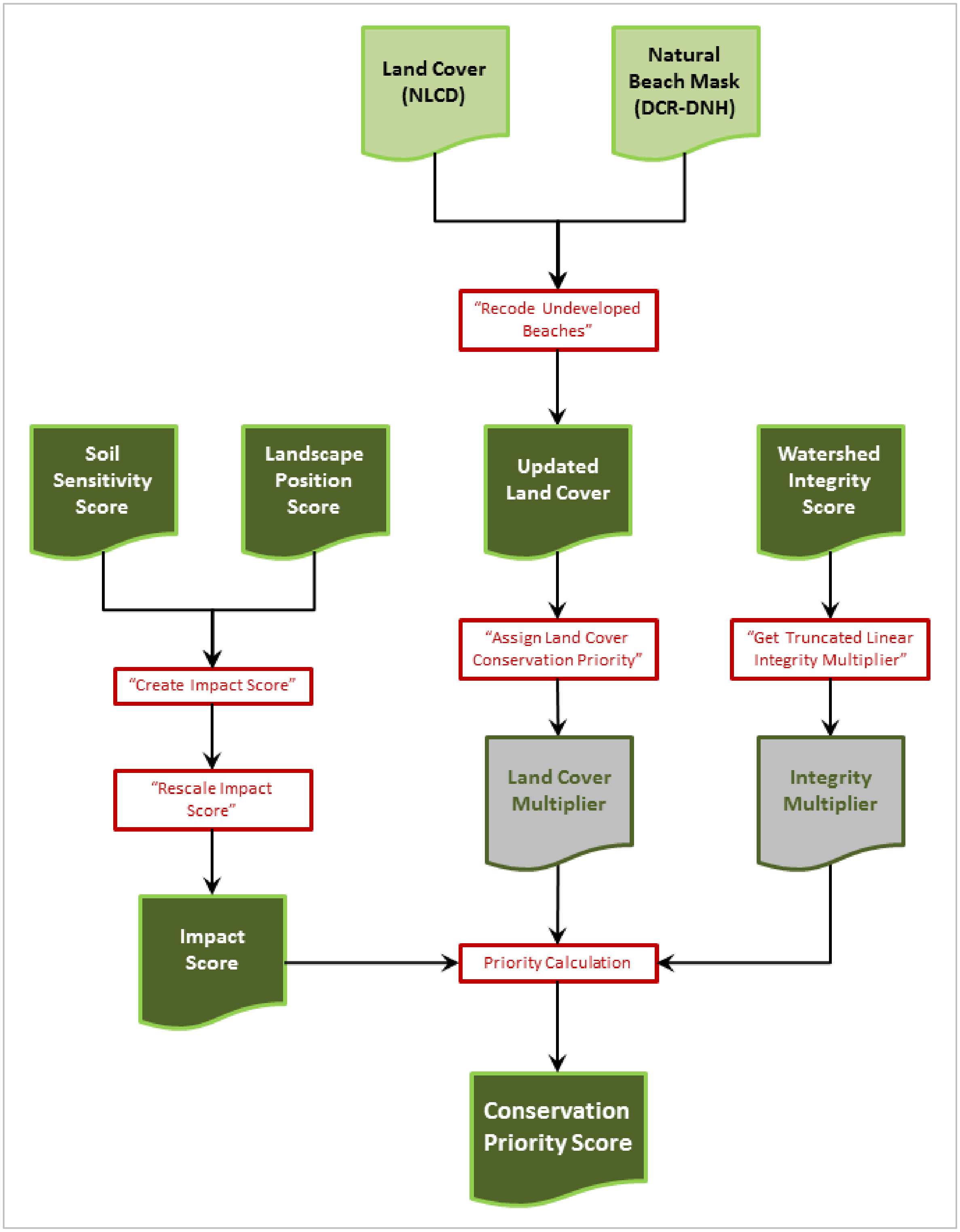


Figure 5: Model components and geoprocessing steps leading to the Conservation Priority Score. Input data sources are represented in the lightest shade of green; refer to Table 1 for descriptions of the input data sources. Final products, including primary model components leading to the final priority score, are shown in a darker shade of green. Temporary products are represented in grey. Red boxes represent geoprocessing steps, and names of custom tools in the Watershed Model toolbox are enclosed in quotes. Geoprocessing steps leading to each of the primary model components are illustrated in subsequent figures.

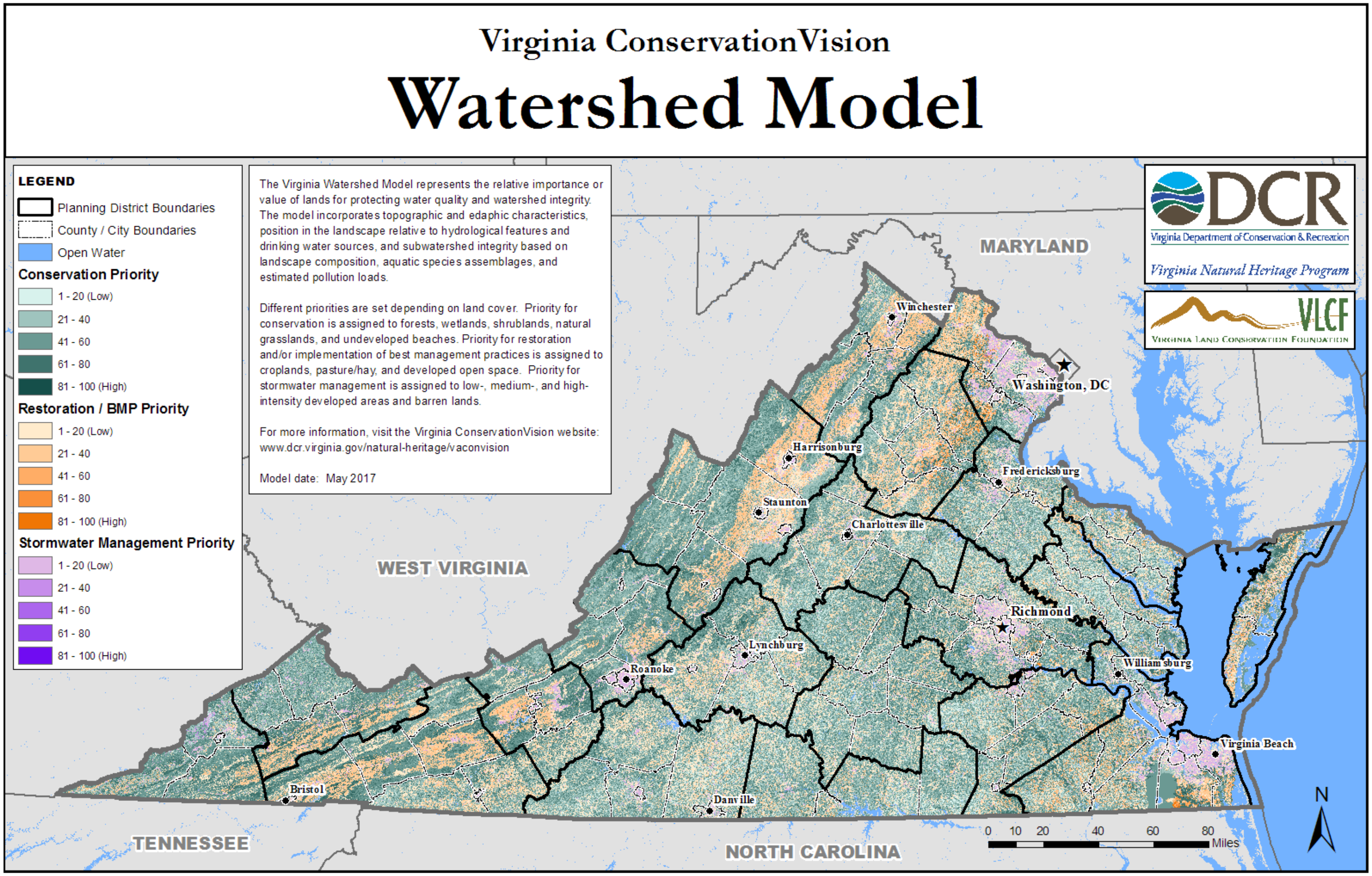
a. Conservation Priority

b. Restoration or Stormwater Management Priority

Figure 6: Relationship between priority multiplier values and watershed integrity scores.

Maps

Map 1: Statewide Watershed Model



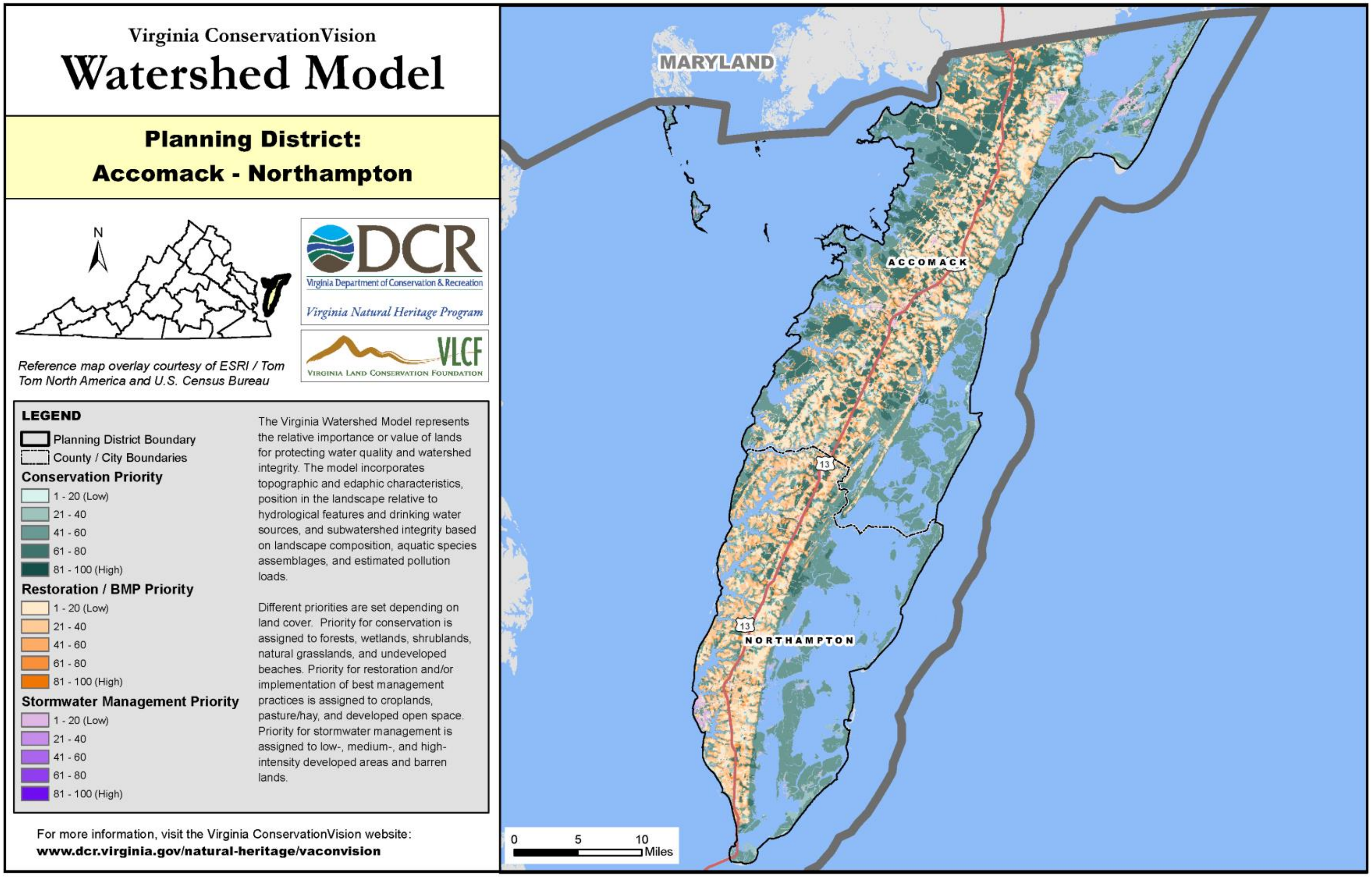
The Virginia Watershed Model represents the relative importance or value of lands for protecting water quality and watershed integrity. The model incorporates topographic and edaphic characteristics, position in the landscape relative to hydrological features and drinking water sources, and subwatershed integrity based on landscape composition, aquatic species assemblages, and estimated pollution loads.

Different priorities are set depending on land cover. Priority for conservation is assigned to forests, wetlands, shrublands, natural grasslands, and undeveloped beaches. Priority for restoration and/or implementation of best management practices is assigned to croplands, pasture/hay, and developed open space. Priority for stormwater management is assigned to low-, medium-, and high-intensity developed areas and barren lands.

For more information, visit the Virginia ConservationVision website: www.dcr.virginia.gov/natural-heritage/vaconvision

Model date: May 2017

Map 2: Accomack-Northampton Planning District



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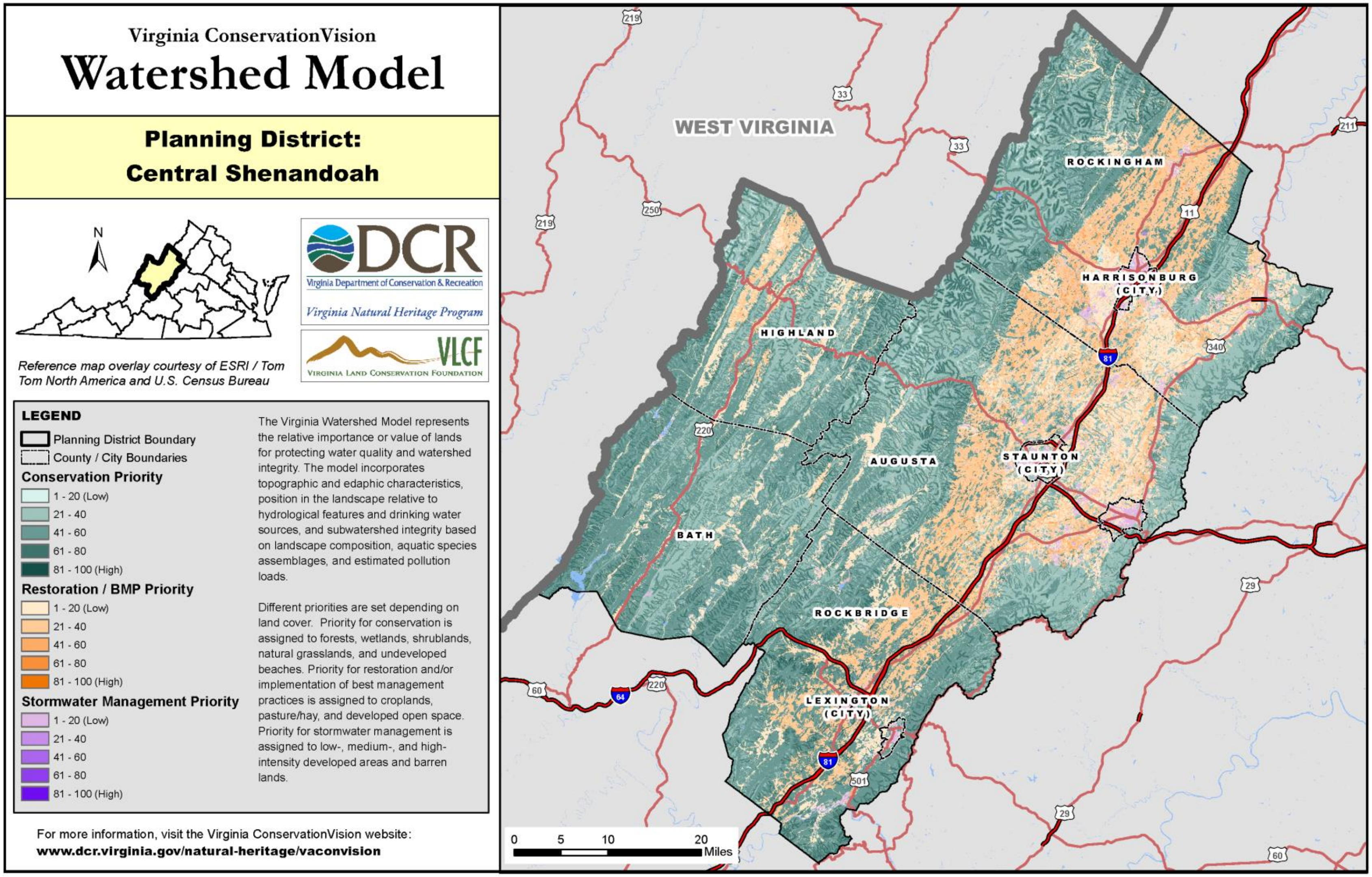
www.dcr.virginia.gov/natural-heritage/vaconvision

Map 3: Central Shenandoah Planning District



The Virginia Watershed Model represents the relative importance or value of lands for protecting water quality and watershed integrity. The model incorporates topographic and edaphic characteristics, position in the landscape relative to hydrological features and drinking water sources, and subwatershed integrity based on landscape composition, aquatic species assemblages, and estimated pollution loads.

Different priorities are set depending on land cover. Priority for conservation is assigned to forests, wetlands, shrublands, natural grasslands, and undeveloped beaches. Priority for restoration and/or implementation of best management practices is assigned to croplands, pasture/hay, and developed open space. Priority for stormwater management is assigned to low-, medium-, and high-intensity developed areas and barren lands.

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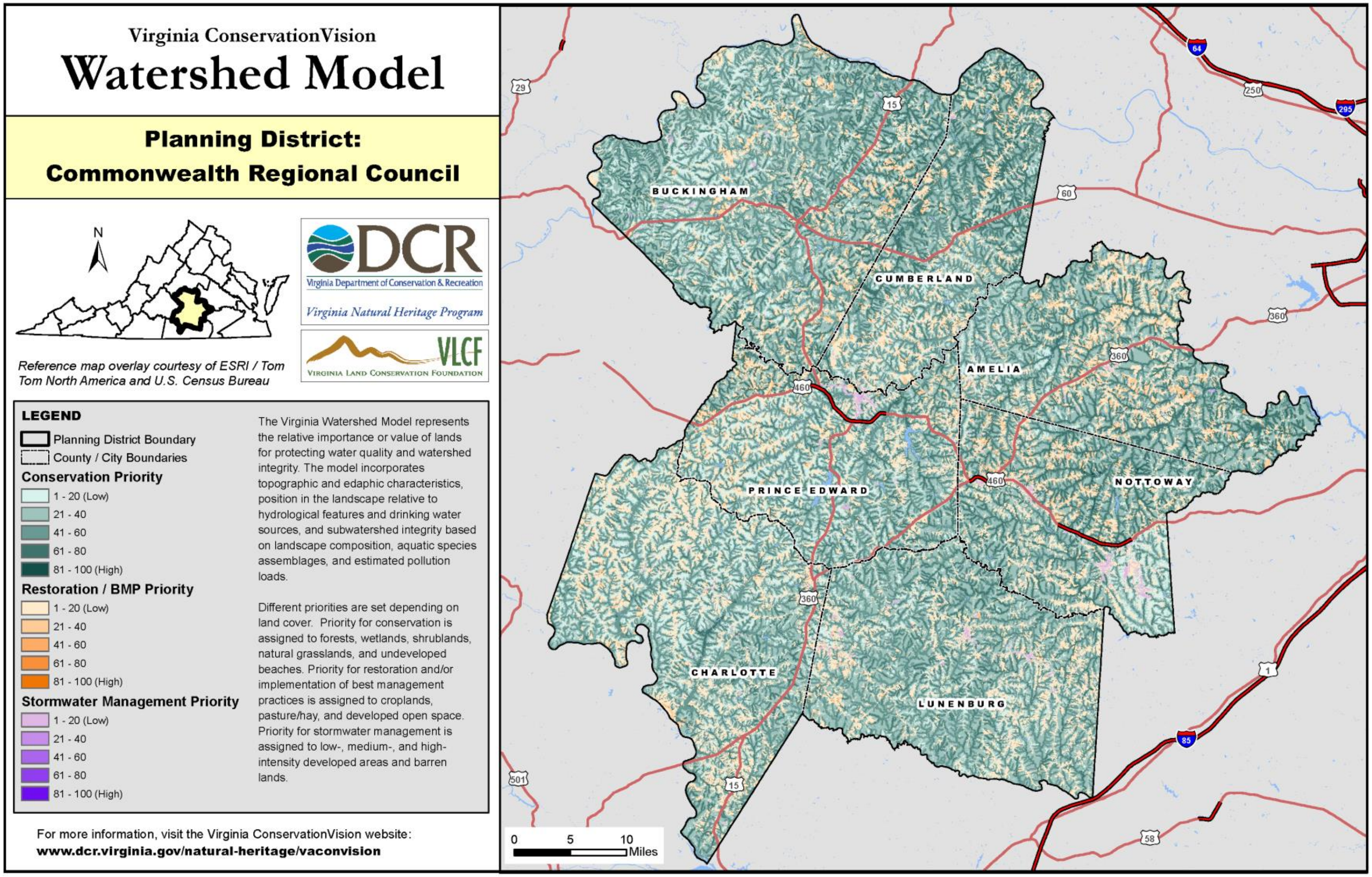
www.dcr.virginia.gov/natural-heritage/vaconvision

Map 4: Commonwealth Regional Council Planning District

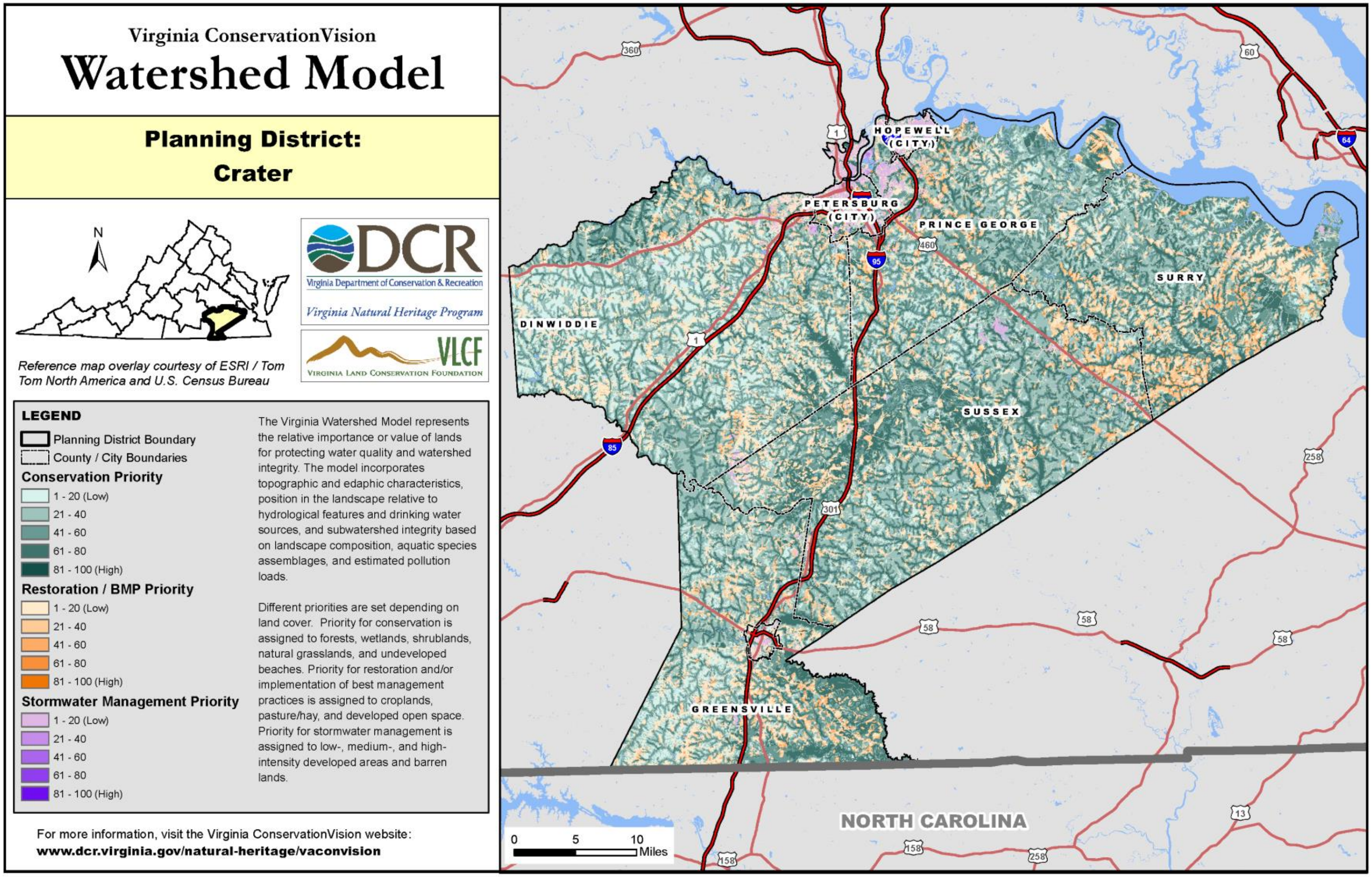


The Virginia Watershed Model represents the relative importance or value of lands for protecting water quality and watershed integrity. The model incorporates topographic and edaphic characteristics, position in the landscape relative to hydrological features and drinking water sources, and subwatershed integrity based on landscape composition, aquatic species assemblages, and estimated pollution loads.

Different priorities are set depending on land cover. Priority for conservation is assigned to forests, wetlands, shrublands, natural grasslands, and undeveloped beaches. Priority for restoration and/or implementation of best management practices is assigned to croplands, pasture/hay, and developed open space. Priority for stormwater management is assigned to low-, medium-, and high-intensity developed areas and barren lands.

For more information, visit the Virginia ConservationVision website:
www.dcr.virginia.gov/natural-heritage/vaconvision

Map 5: Crater Planning District



Virginia ConservationVision

Watershed Model

Planning District:
Crater

Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

LEGEND

Planning District Boundary
County / City Boundaries

Conservation Priority
1 - 20 (Low)
21 - 40
41 - 60
61 - 80
81 - 100 (High)

Restoration / BMP Priority
1 - 20 (Low)
21 - 40
41 - 60
61 - 80
81 - 100 (High)

Stormwater Management Priority
1 - 20 (Low)
21 - 40
41 - 60
61 - 80
81 - 100 (High)

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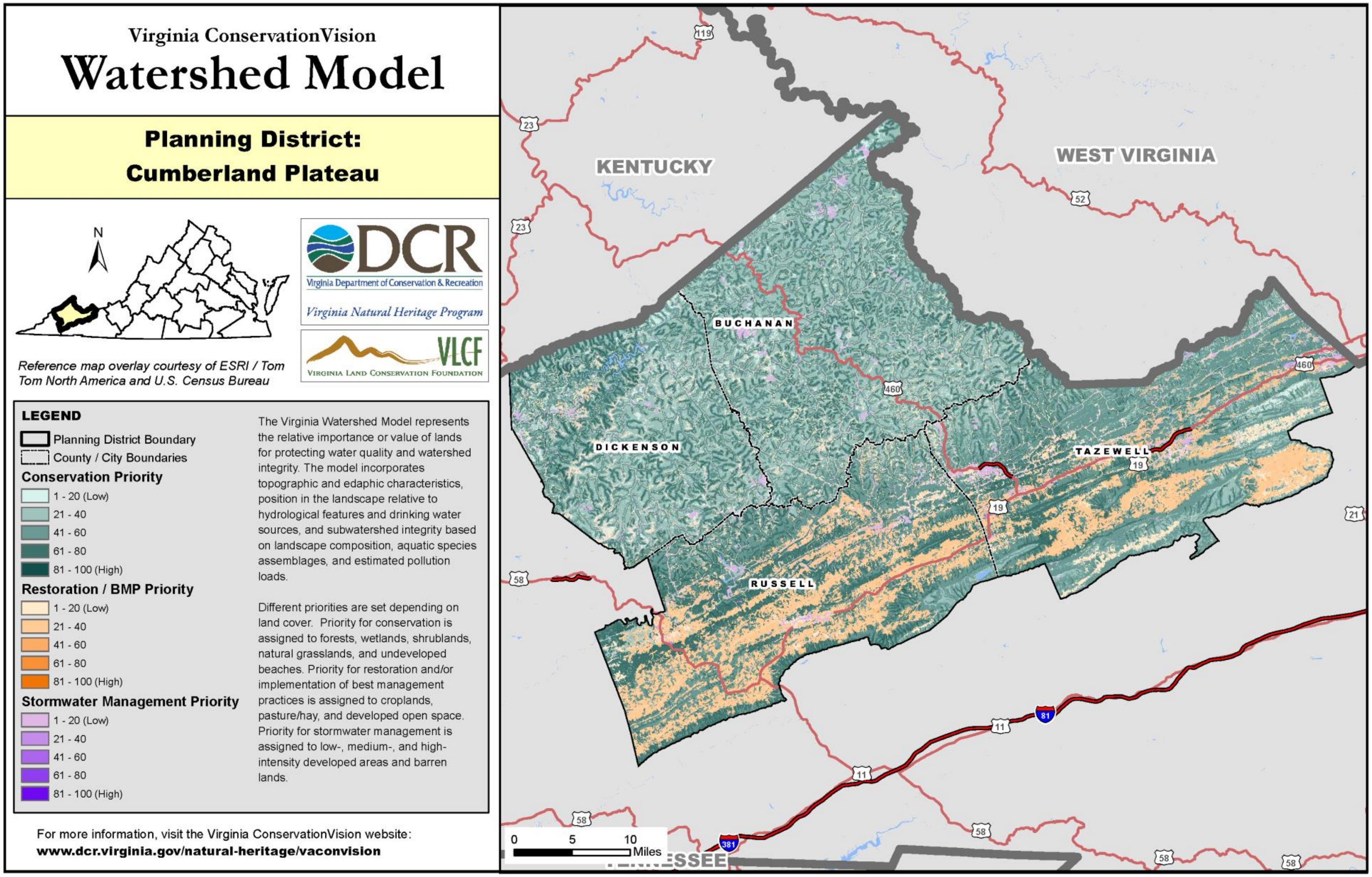
Map 6: Cumberland Plateau Planning District



Virginia ConservationVision

Watershed Model

Planning District: Cumberland Plateau

Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

LEGEND

- ▭ Planning District Boundary
- ⬚ County / City Boundaries

Conservation Priority

- ▨ 1 - 20 (Low)
- ▨ 21 - 40
- ▨ 41 - 60
- ▨ 61 - 80
- ▨ 81 - 100 (High)

Restoration / BMP Priority

- ▨ 1 - 20 (Low)
- ▨ 21 - 40
- ▨ 41 - 60
- ▨ 61 - 80
- ▨ 81 - 100 (High)

Stormwater Management Priority

- ▨ 1 - 20 (Low)
- ▨ 21 - 40
- ▨ 41 - 60
- ▨ 61 - 80
- ▨ 81 - 100 (High)

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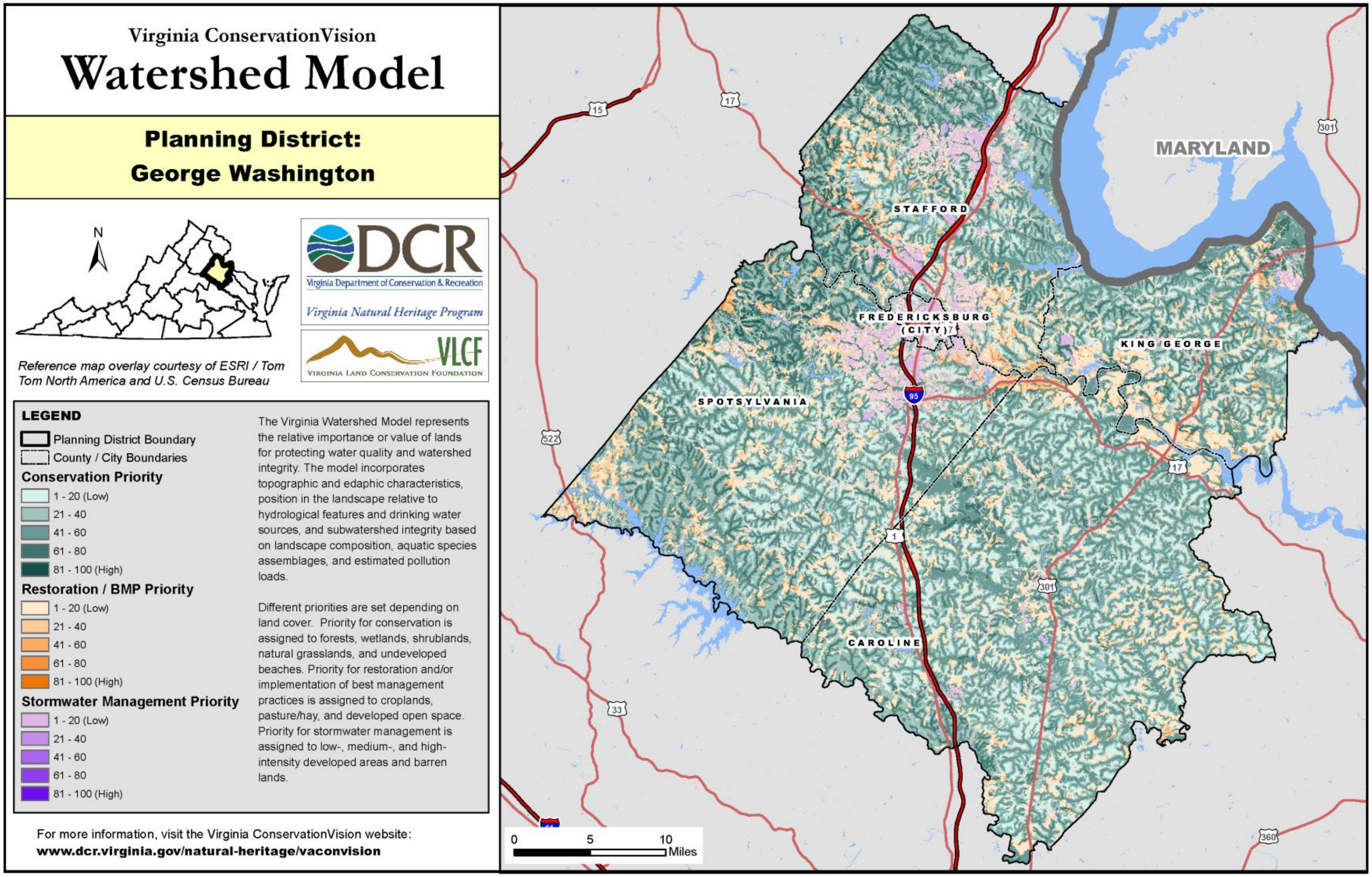
Map 7: George Washington Planning District



Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

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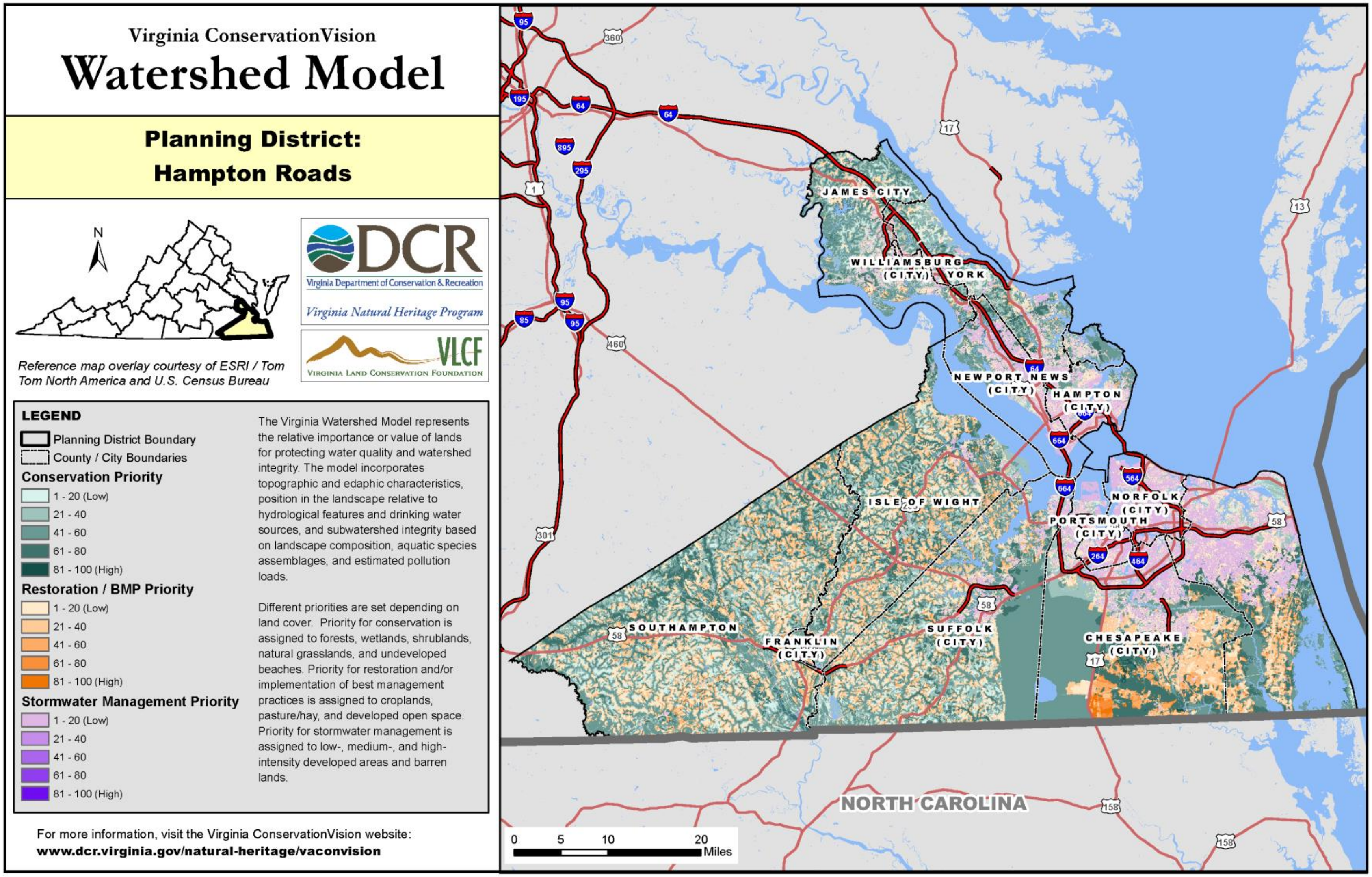
Map 8: Hampton Roads Planning District



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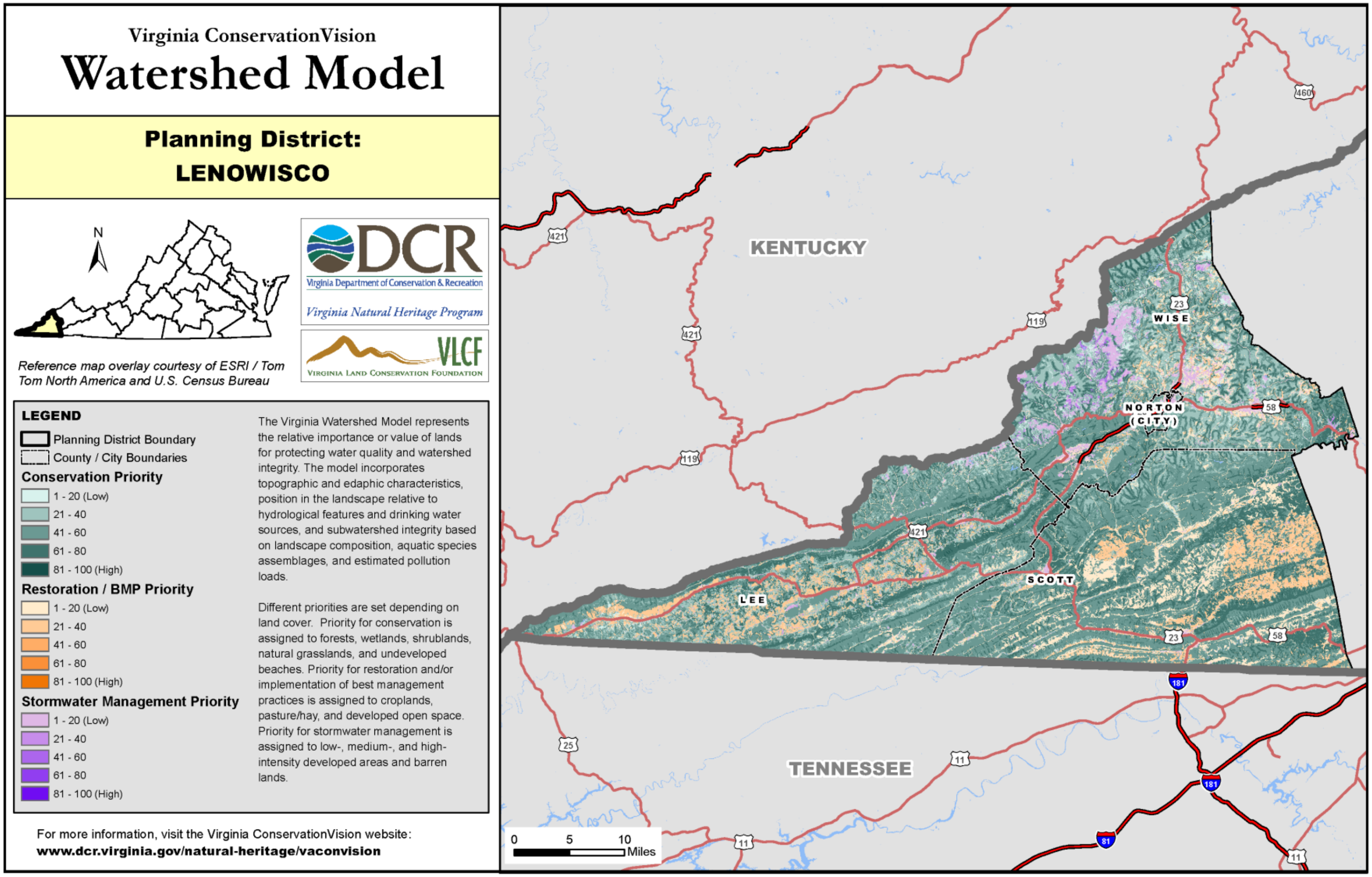
Map 9: LENOWISCO Planning District



Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

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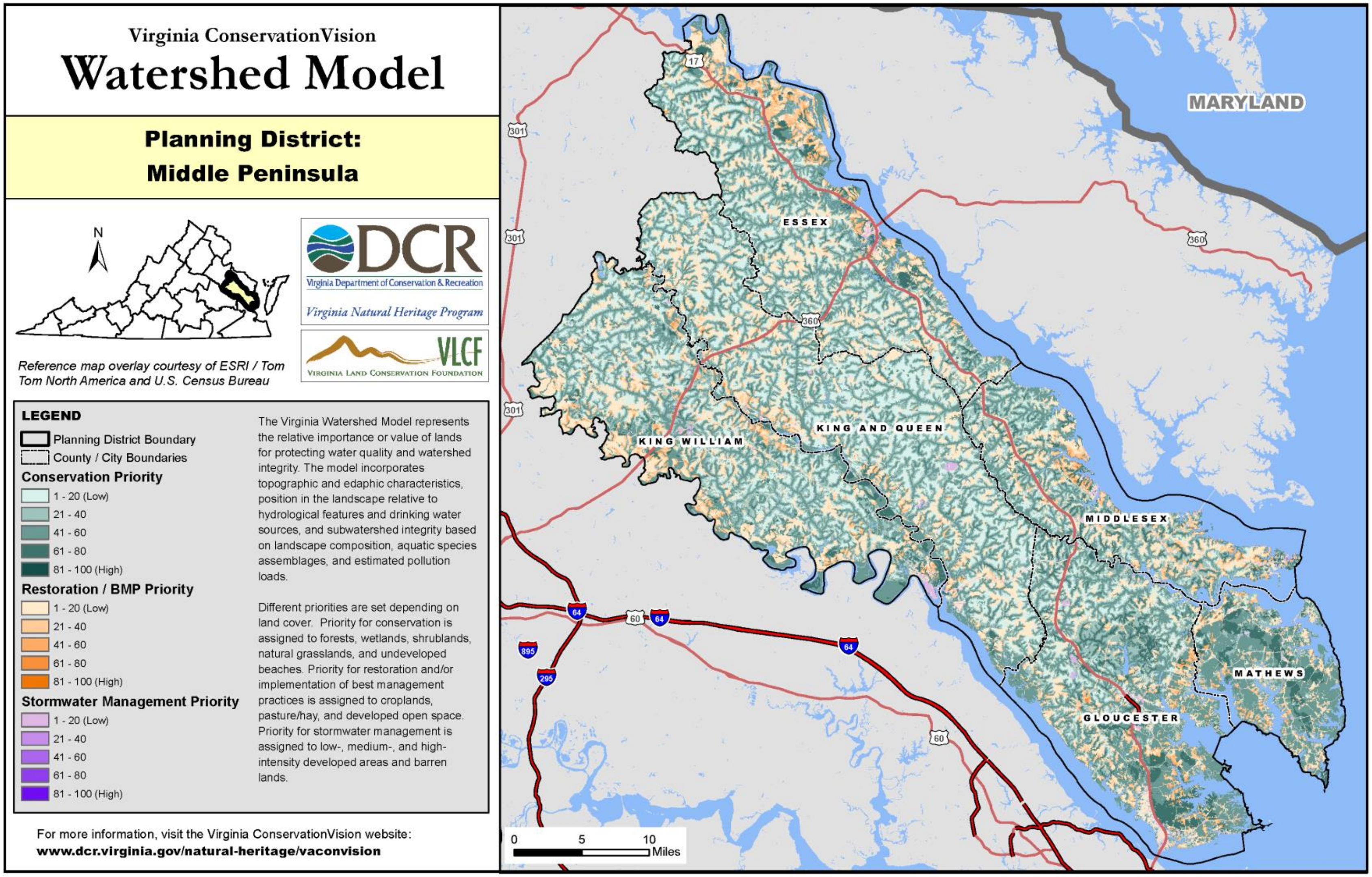
Map 10: Middle Peninsula Planning District



Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

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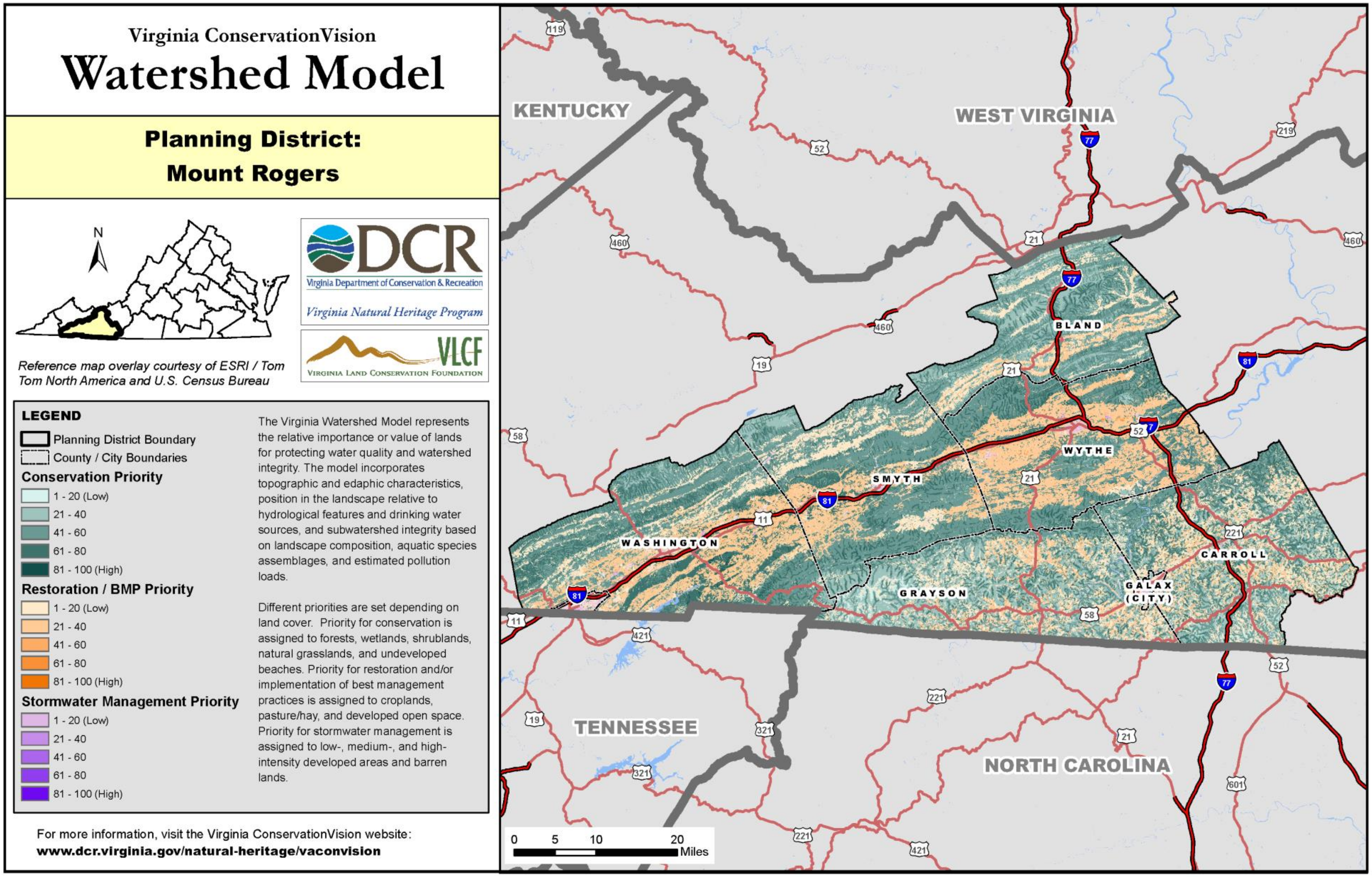
Map 11: Mount Rogers Planning District



Virginia ConservationVision

Watershed Model

Planning District: Mount Rogers

Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

LEGEND

- Planning District Boundary
- County / City Boundaries

Conservation Priority

- 1 - 20 (Low)
- 21 - 40
- 41 - 60
- 61 - 80
- 81 - 100 (High)

Restoration / BMP Priority

- 1 - 20 (Low)
- 21 - 40
- 41 - 60
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- 81 - 100 (High)

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- 1 - 20 (Low)
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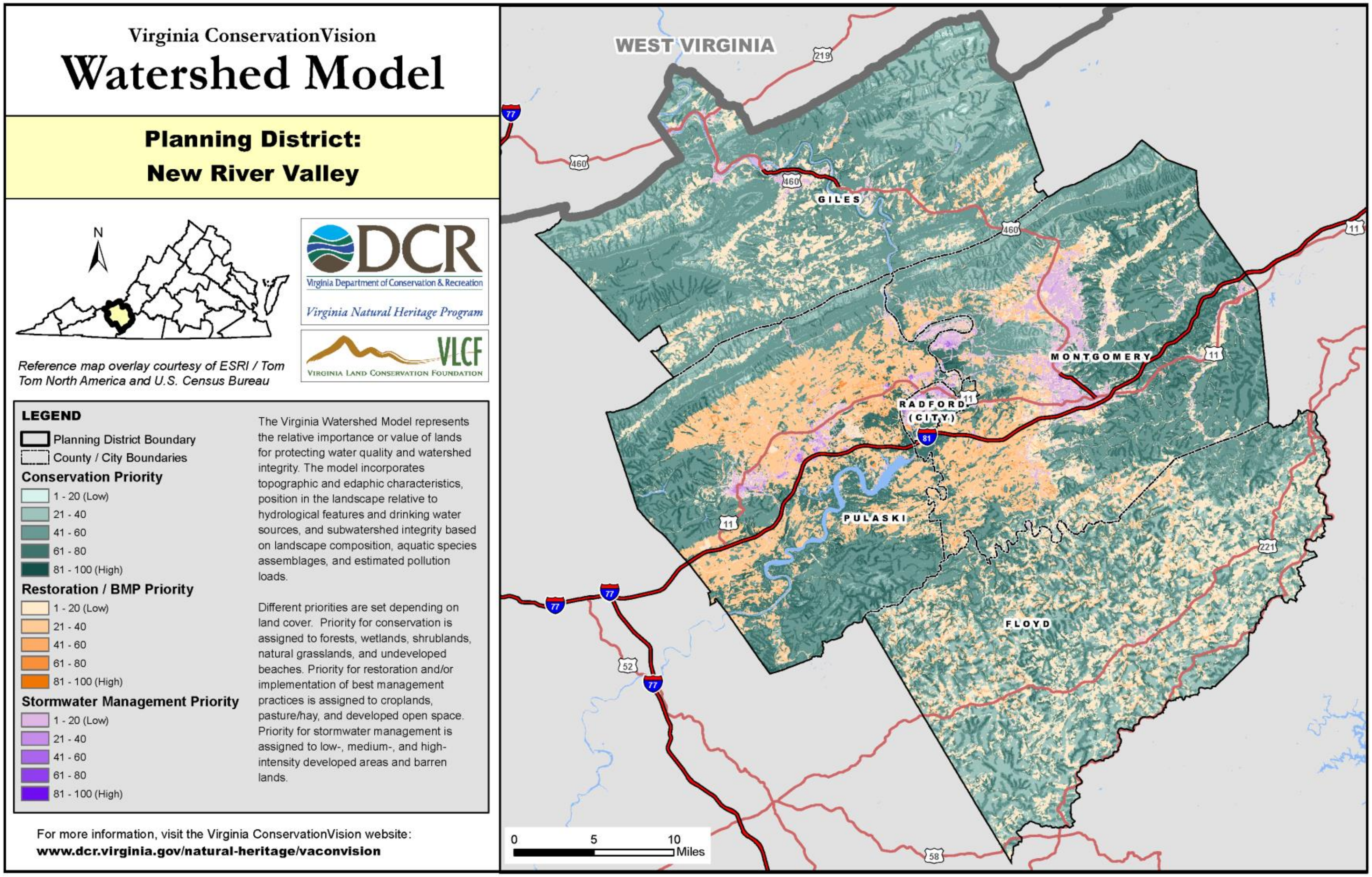
Map 12: New River Valley Planning District



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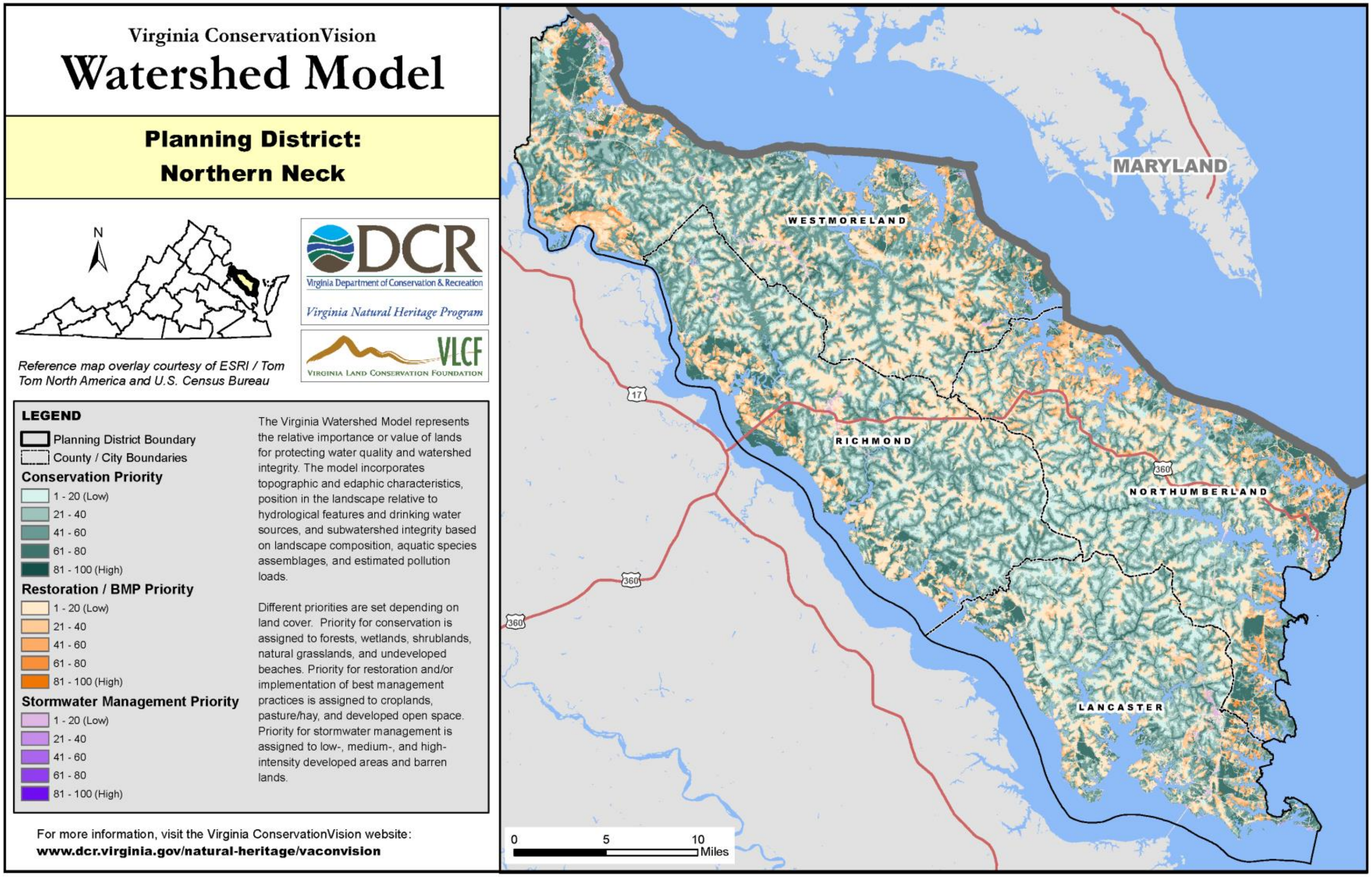
Map 13: Northern Neck Planning District



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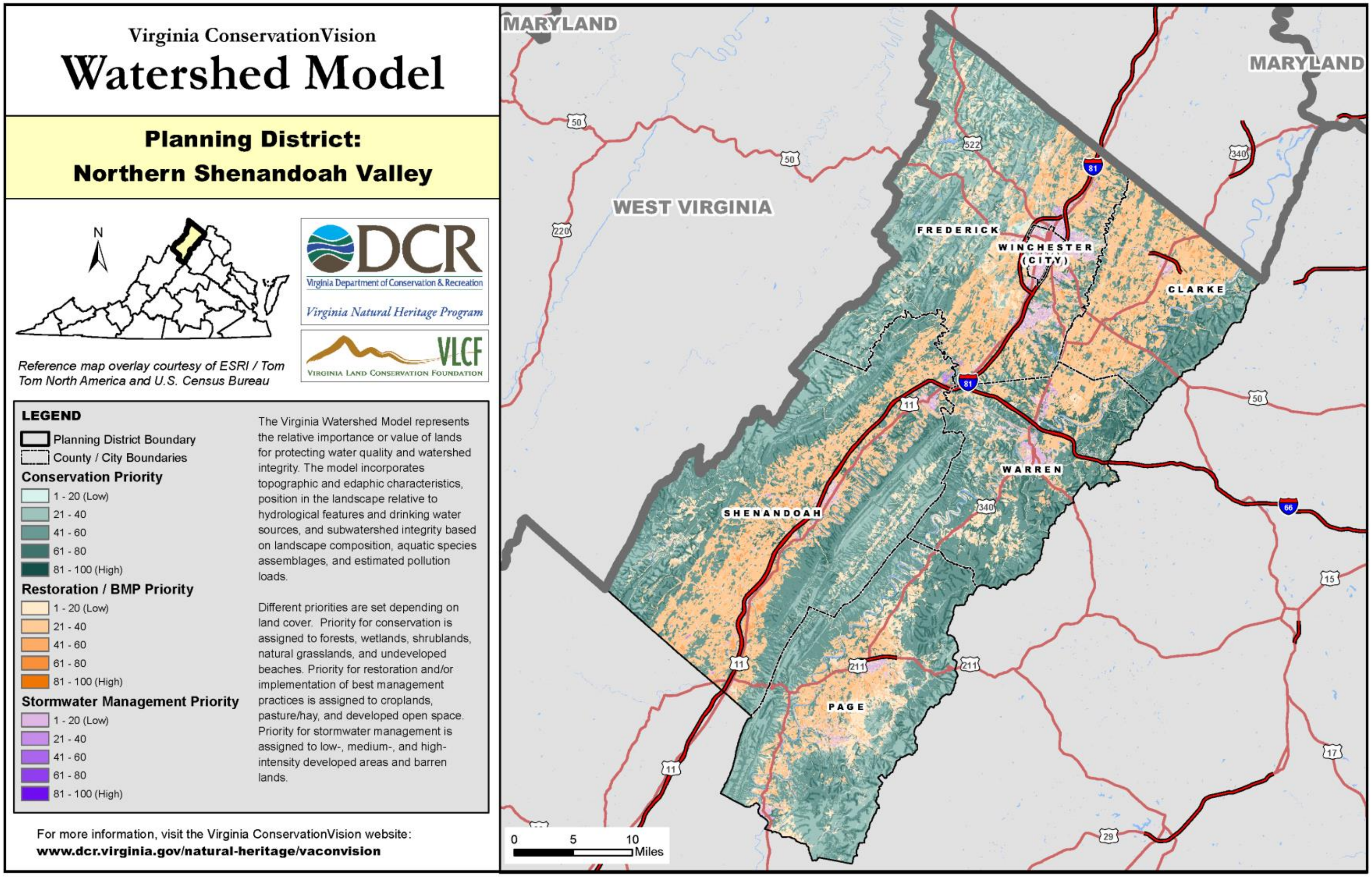
Map 14: Northern Shenandoah Valley Planning District



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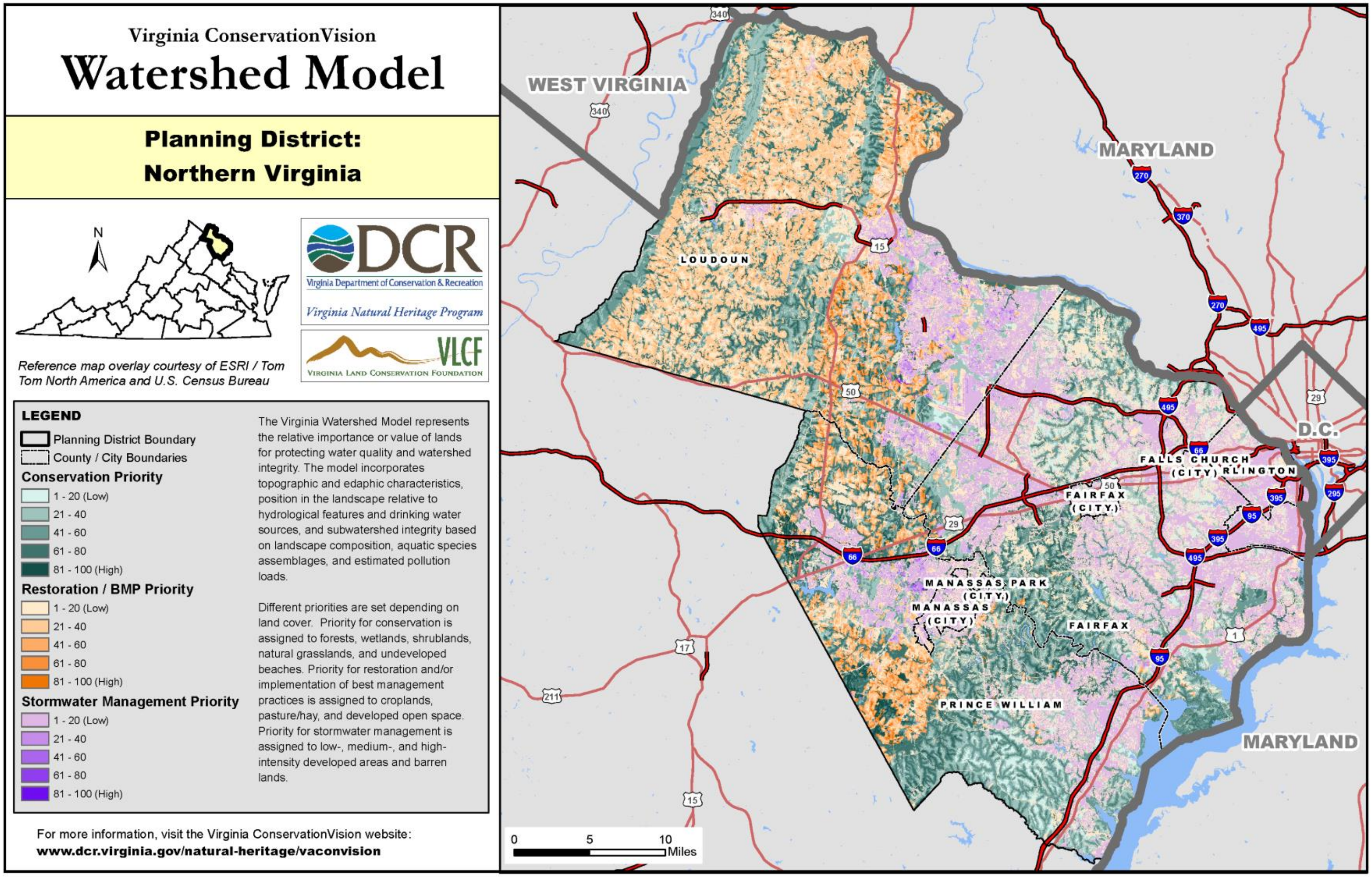
Map 15: Northern Virginia Planning District



Virginia ConservationVision

Watershed Model

Planning District:
Northern Virginia

Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

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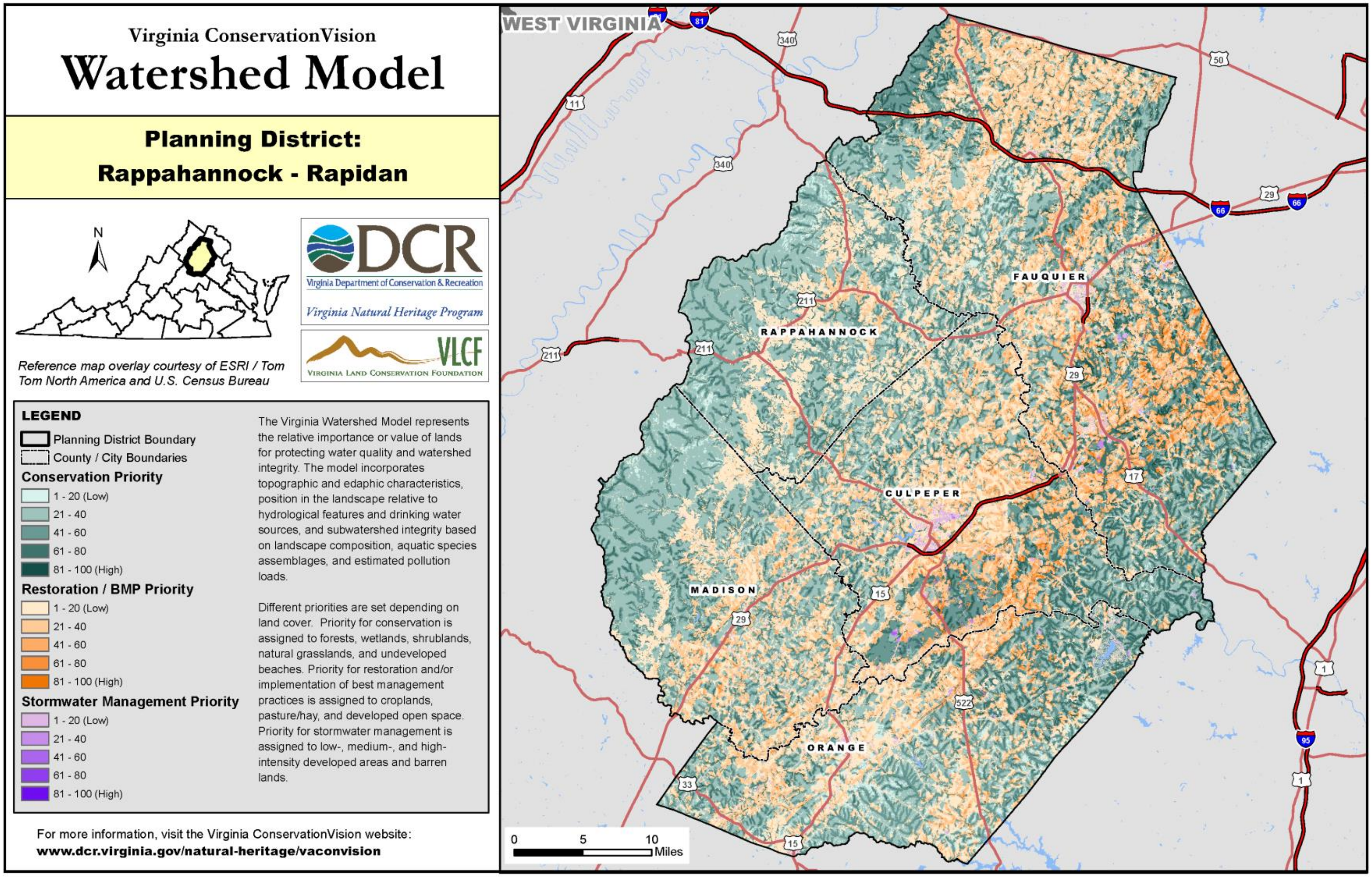
Map 16: Rappahannock - Rapidan Planning District



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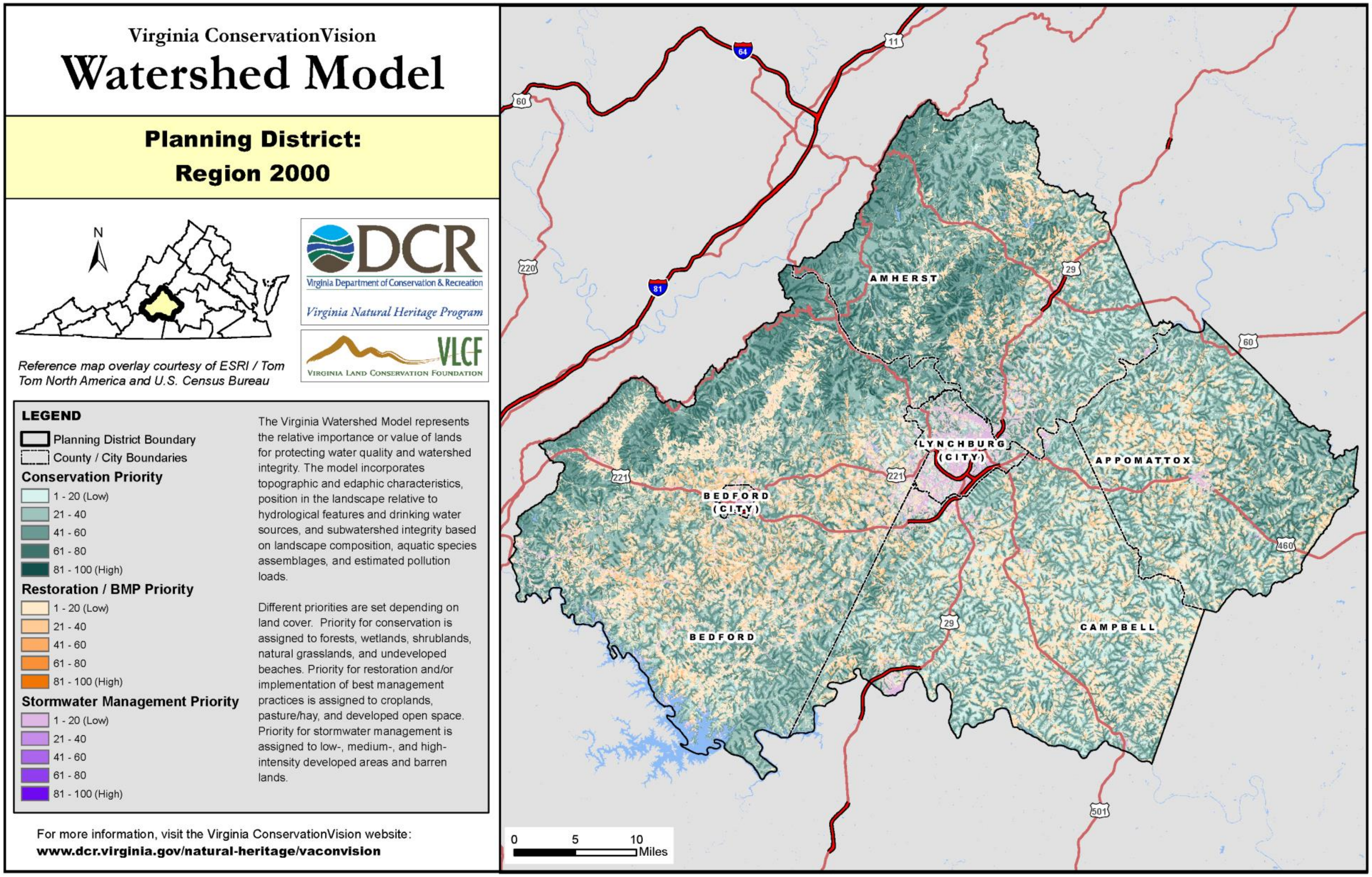
Map 17: Region 2000 Planning District



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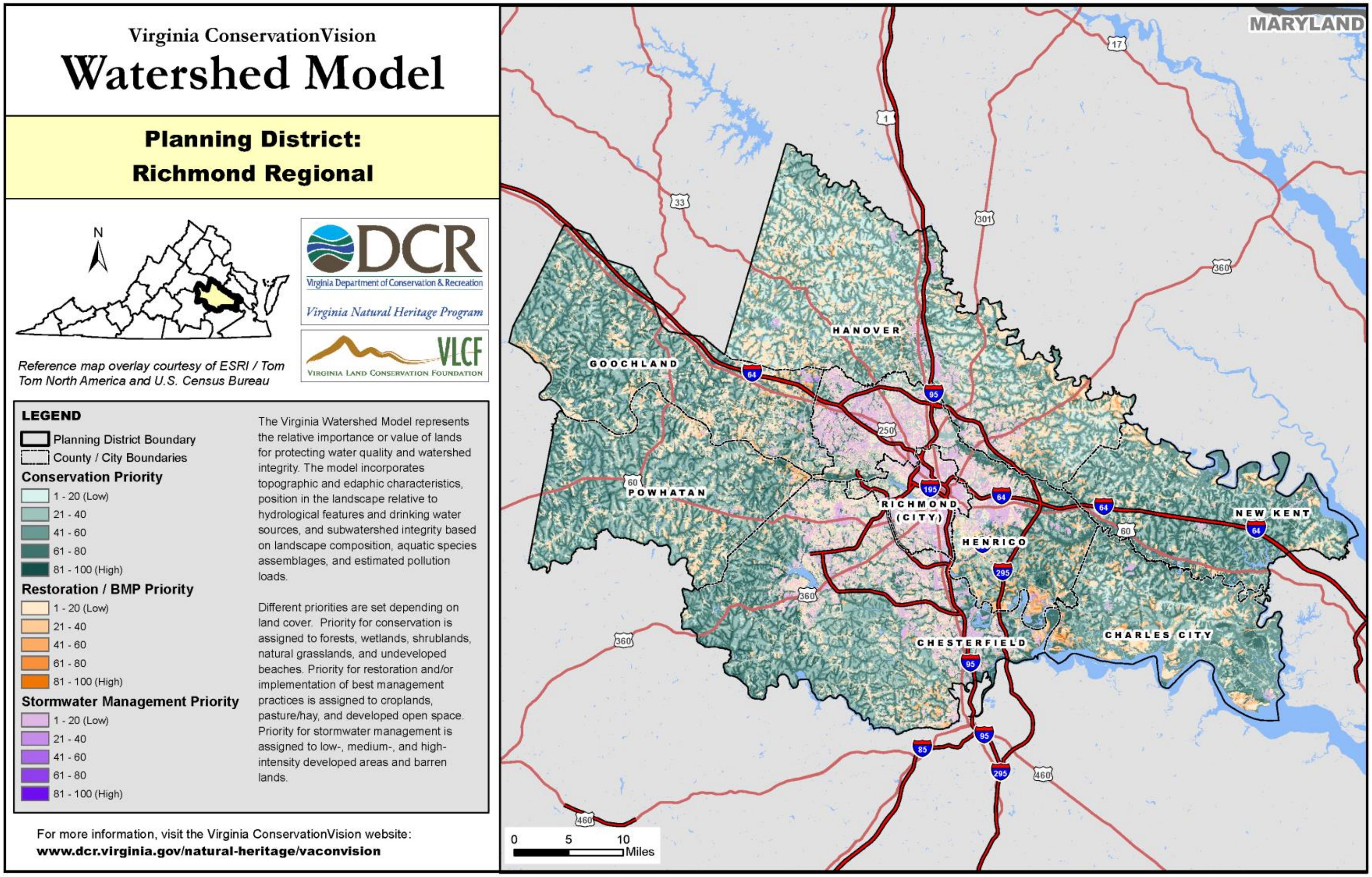
Map 18: Richmond Regional Planning District



Virginia ConservationVision

Watershed Model

Planning District: Richmond Regional

Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

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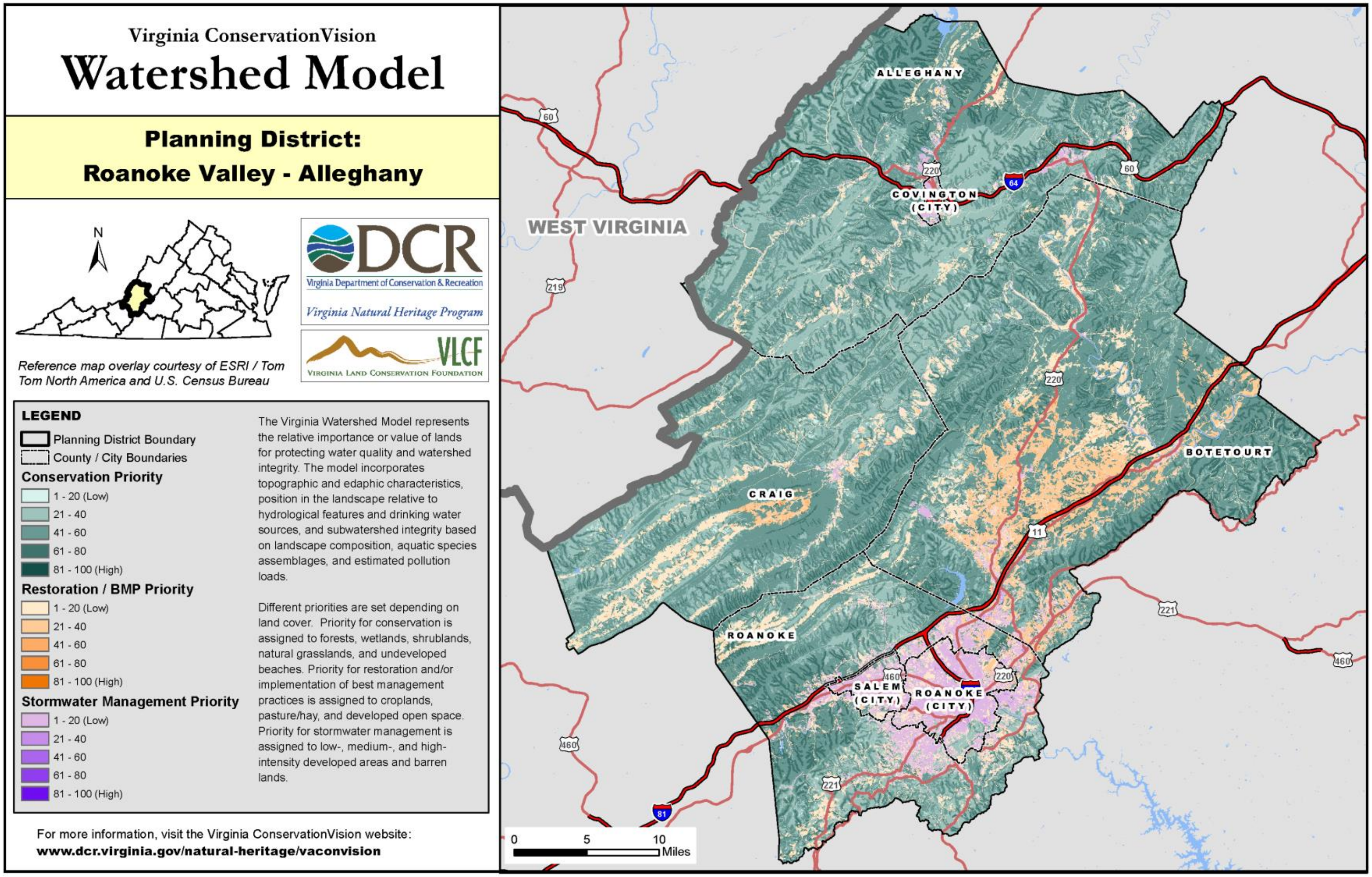
Map 19: Roanoke Valley - Alleghany Planning District



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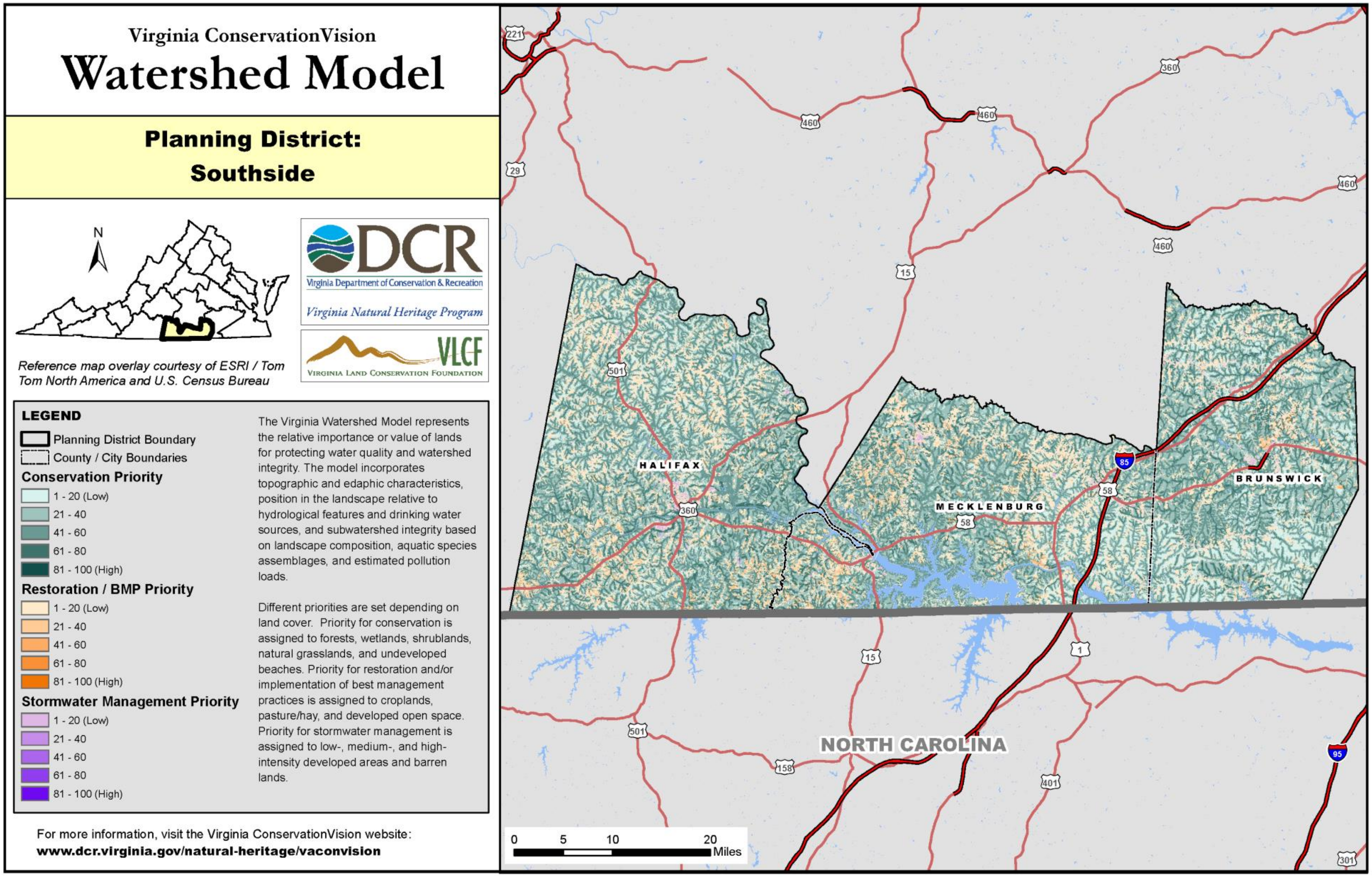
Map 20: Southside Planning District



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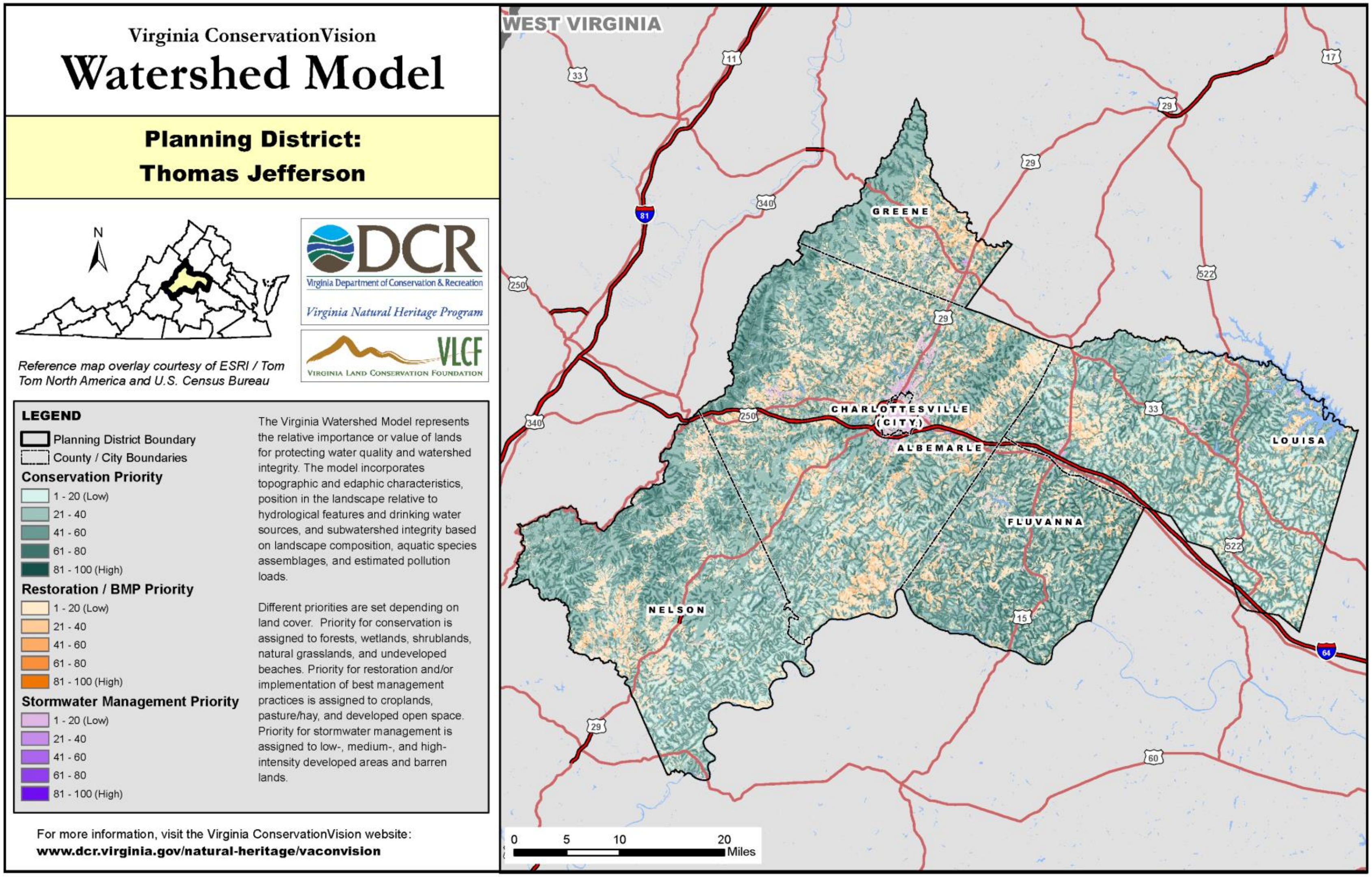
Map 21: Thomas Jefferson Planning District



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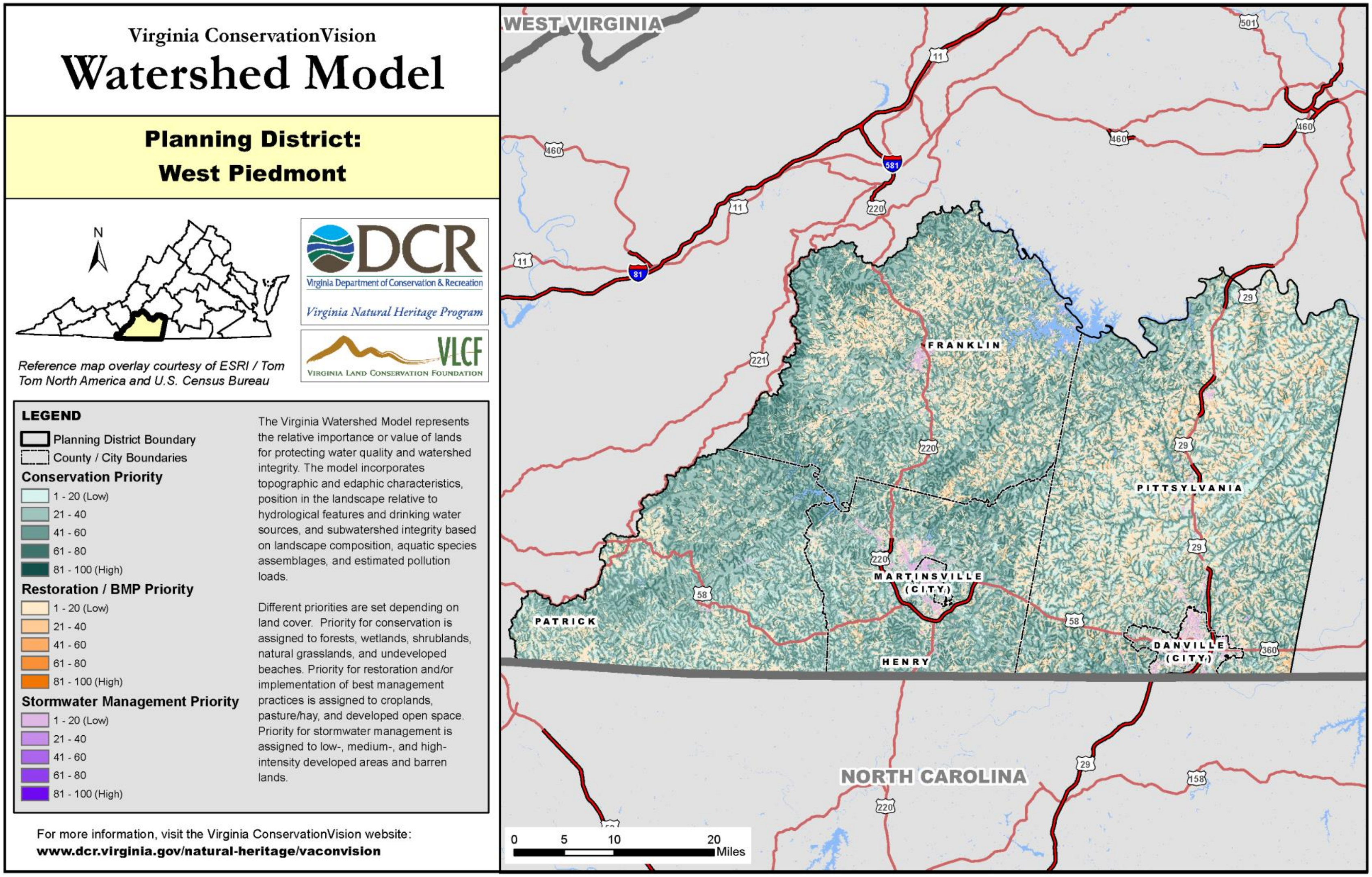
Map 22: West Piedmont Planning District



Virginia ConservationVision

Watershed Model

Planning District:
West Piedmont

Reference map overlay courtesy of ESRI / Tom Tom North America and U.S. Census Bureau

LEGEND

Planning District Boundary
County / City Boundaries

Conservation Priority
1 - 20 (Low)
21 - 40
41 - 60
61 - 80
81 - 100 (High)

Restoration / BMP Priority
1 - 20 (Low)
21 - 40
41 - 60
61 - 80
81 - 100 (High)

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21 - 40
41 - 60
61 - 80
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