SECTION LAND AND RIVER SEGMENTATION

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SECTION 3. LAND AND RIVER SEGMENTATION

3.1 Introduction to Land and River Segmentation

Phase 5.3 Community Watershed Model simulates both land and river processes. River reaches receive simulated flows, nutrients, and sediment from the land simulation and ultimately transport them to the Bay. The framework for the Phase 5.3 Community Watershed Model is based on jointly applying two types of segmentation to the model domain: (1) county-based, *land-segments,* and *(2) river segments,* which primarily are the watersheds associated with the river reach network, although many river reaches draining directly into the Bay have no reaches associated with them (Martucci et al. 2006). If the intersection of land and river segments is included, the process of developing model segmentation for the Phase 5.3 Community Watershed Model involved the following three steps.

The first step in model development was dividing the model domain into individual land-segments for which simulations could be performed. Key features, such as crop types and associated nutrient application rates, are available only at the county-level scale for the 21 years of model simulation in the entire model domain. The county-level agricultural census, available every 5 years, was used for agricultural county-level data.

The spatial limitations of the agricultural data set limited the land segmentation to be based on county boundaries represented by a 1:100,000-scale digital data set. Of the 254 counties and incorporated cities in the model domain, 50 were further divided on the basis of physiography and topography, producing a total of 309 land-segments. This subdivision improved the simulation of meteorological variables in counties with highly variable topography.

The second step was to create a network of river reaches and their associated watersheds, or river-segments. The river-segments for the Chesapeake Bay watershed part of the model domain are largely based on the USGS Chesapeake Bay SPARROW model river reach segmentation (Preston and Brakebill 1999). A decision rule established during the Phase 5.3 Model development was to simulate river reaches with discharges of 100 cubic feet per second (cfs) or greater. The areas of drainage to those simulated river reaches were the river-segments. Exceptions were made to the 100-cfs cutoff rule for some river reaches that had useful monitoring data but were less than 100 cfs, which were included as river-segments in some cases. The Phase 5.3 land-segments and river-segments are shown in Figure 3-1. The change in spatial scale from the segmentation of the previous phase of the model (Phase 4.3) to the current Phase 5.3 scale segmentation is shown in Figure 3-2.

For the portions of the Phase 5.3 model domain outside the Chesapeake watershed the SPARROW Model was unavailable and so a 1:500,000-scale river reach network was used. As discussed in Section 1 (Figure 1-1), the Phase 5.3 domain was expanded to include the entire states of Virginia, Delaware, and Maryland. About 56% of the entire

Phase 5.3 domain is the Chesapeake watershed and about 44% of the domain is outside the Chesapeake watershed.

Thirty-meter-resolution Digital Elevation Model (DEM) data derived from digitized USGS maps were used to delineate watersheds for each river-segment. State watershed boundaries replaced the DEM-derived watersheds where both data were coincident. After a number of corrections, the river-segments were coded to indicate major (1^{st} coded letter) and minor (2^{nd} coded letter) basins, mean annual flow, and each river-segment's unique identifier, as well as that of the downstream river-segment. Sections 3.3 and 3.4 discuss the development of river segmentation in more detail.

The third step intersected land-segments and river-segments to create *land-river segments* allowing flow and loads from the land simulation to be routed properly to the river simulation. For example, a river-segment might intersect two or more land segments. In such a case, the flow and loads from each of the land-segments would be routed to the river segment as a proportion that each land use in the land-segments contributed to the river-segment. The intersection of land-segments and river segments is discussed in more detail in Section 3.4.2.

The complete spatial delineation information on the Phase 5.3 land-segments, river-segments and land-river segments is at the Chesapeake Community Modeling Program's (CCMP) Phase 5.3 data library on the Web at
http://ches.communitymodeling.org/models/CBPhase5/datalibrary.php.

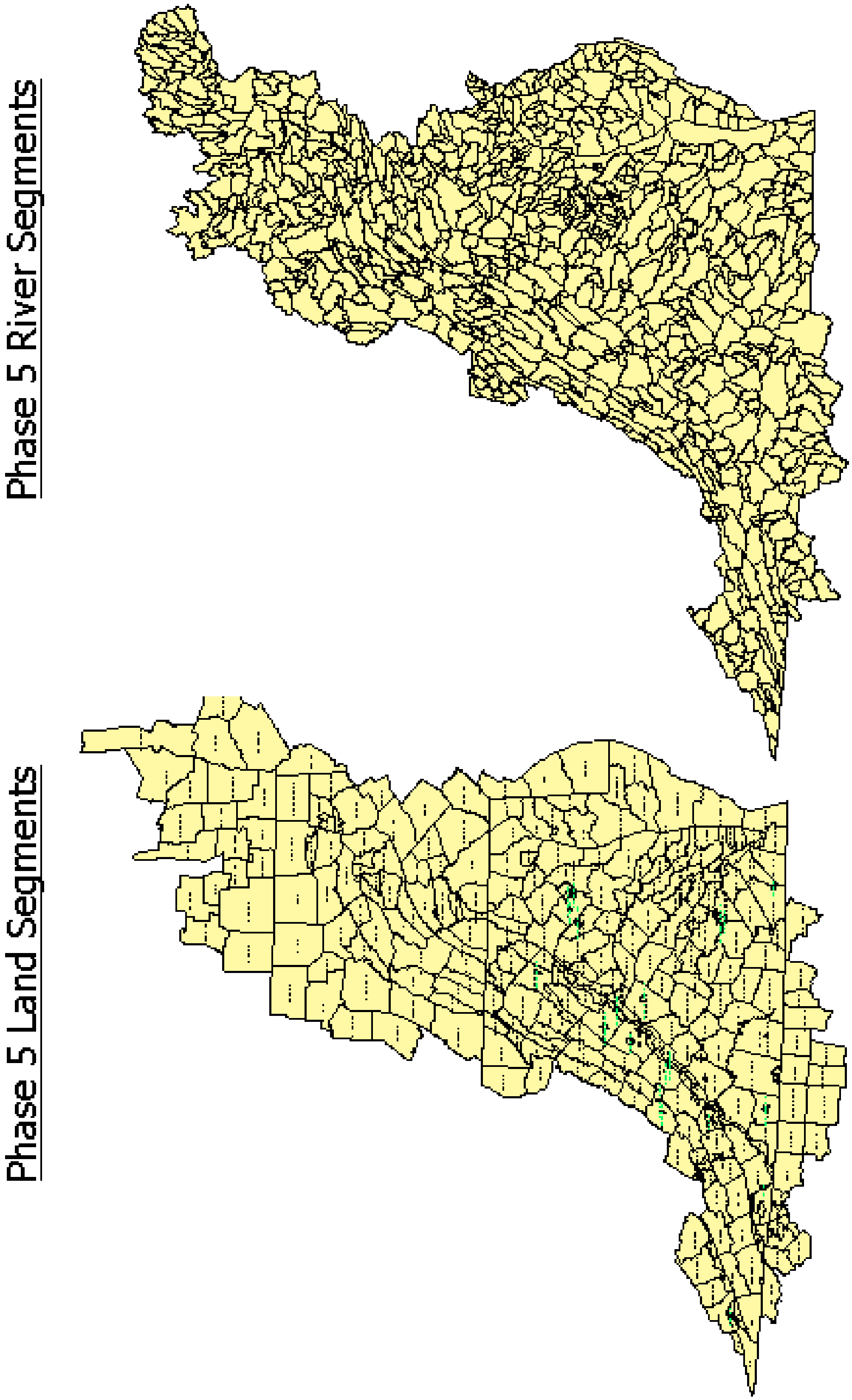


Figure 3-1. Phase 5.3 land-segments and river-segments.

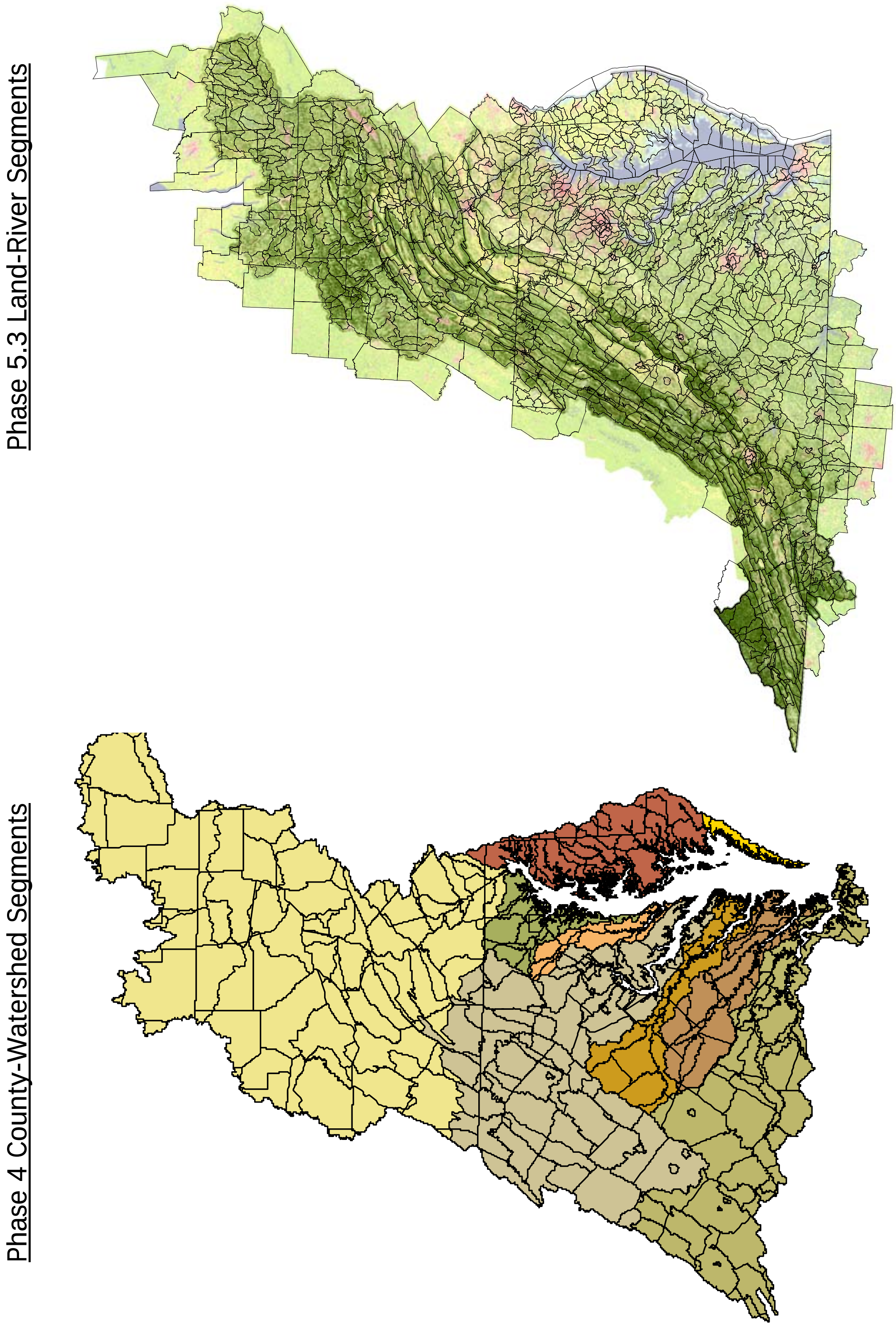


Figure 3-2. The change in spatial scale from the finest segmentation of the previous Phase 4.3 Model to the current finest Phase 5.3 scale of land-river-segments.

3.2 Land Segmentation Development

A 1:100,000-scale county boundary digital data set published by USGS (USGS 1993) was used as the basis of the land segmentation. It is a spatially continuous data set available for the entire model domain. The county data set was also updated to include U.S. Census Bureau changes (U.S. Census Bureau 2004).

In the Valley and Ridge and Blue Ridge physiographic provinces, orographic effects can create significant influence on precipitation patterns within a county. To deal with such orographic effects, physiography and topography were used as guides to divide areas of high elevation (ridges) and low elevation (valleys) for 50 of the 254 counties within the model region. That division also tended to separate the forested mountain ridges that are generally farther from the rivers from the agriculture and developed land on the valley floors and that are closer to the rivers. Hydrogeomorphic Regions (HGMRs) (Brakebill and Kelley 2000), USGS 1:2,000,000-scale Physiographic Provinces of Virginia (USGS 1980), and National Elevation Dataset (NED) DEM data (USGS 2001) were used as a guide to divide counties. Doing so produced a total of 309 land-segments.

The creation of a unique identification system for the land-segments relied on the 5-digit Federal Information Processing Standards (FIPS) codes (U.S. Census Bureau 2003). The FIPS code is unique for each state (first 2 digits) and county (last 3 digits). For all counties, an *A* was placed at the beginning of the FIPS code; and for counties that were divided, a *B* was used; and in five cases, where counties were divided twice, a *C* was placed before the FIPS code. The concatenation of the alphanumeric characters created unique land-segment identifiers (Table 3-1 and Figure 3-3). An excerpt of Table 3-1 is shown below, and the full table is available by clicking the following hyperlink: Table 3-1 (full table).

Table 3-1. Counties in the Phase 5.3 Community Watershed Model.

FIPSAB	County	State
A10001	Kent	DE
A10003	New Castle	DE
A10005	Sussex	DE
A11001	Dist Of Columbia	DC
A24001	Allegany	MD
A24003	Anne Arundel	MD
A24005	Baltimore	MD
A24009	Calvert	MD
A24011	Caroline	MD
A24013	Carroll	MD
A24015	Cecil	MD
A24017	Charles	MD
A24019	Dorchester	MD
A24021	Frederick	MD
A24023	Garrett	MD
A24025	Harford	MD
A24027	Howard	MD
A24029	Kent	MD
A24031	Montgomery	MD
A24033	Prince Georges	MD
A24037	St Marys	MD
A24039	Somerset	MD
A24041	Talbot	MD
A24043	Washington	MD
A24045	Wicomico	MD
A24047	Worcester	MD
A24510	Baltimore	MD
A36003	Allegany	NY
A36007	Broome	NY
A36011	Cayuga	NY
A36015	Chemung	NY
A36017	Chenango	NY
A36023	Cortland	NY
A36025	Delaware	NY
A36043	Herkimer	NY
A36051	Livingston	NY
A36053	Madison	NY
A36065	Oneida	NY
A36067	Onondaga	NY
A36069	Ontario	NY
A36077	Otsego	NY
A36095	Schoharie	NY
A36097	Schuyler	NY
A36101	Steuben	NY
A36107	Tioga	NY
A36109	Tompkins	NY

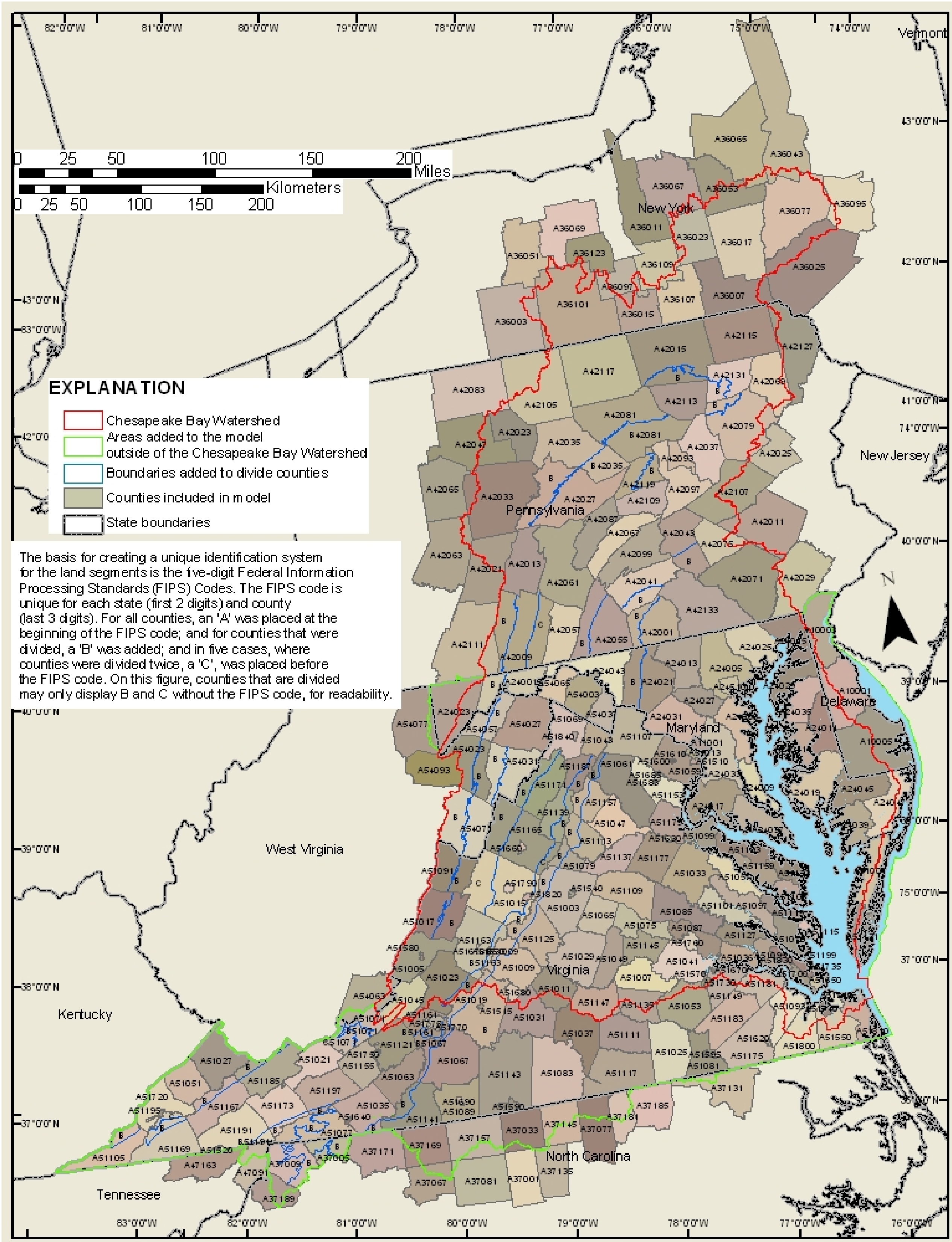


Figure 3-3. Land-segmentation and county divisions for the Phase 5.3 Watershed Model.

3.3 River-Segment Development

A river reach is a section of a river or reservoir that is simulated as a single unit. The term *river-segment* is used to represent the area of land immediately draining to a river reach. The Phase 5.3 Watershed Model simulates processes within land-segments and river reaches separately and sequentially. At each time step, the water flow, sediment, and nutrient loads for land-segments are calculated. Those quantities are then provided as input to the river reach simulation proportional to the land use in the watershed containing the river-segment. The river reach simulation processes the water, sediment, and nutrients within each river reach and transports them to the next reach downstream. River-segments define the model land uses connected to each river reach represented in the model. However, it should be noted that that the segments do not include the simulation of the reaches of the small streams (1st to 3rd order streams) that are tributary to the simulated river reach.

The objectives for the river-reach network were (1) to achieve a density of about 1,000 river reaches in the model region, as this was considered to be at the limit of effective operational runtimes of the simulation, (2) to have consistency with the Chesapeake Bay SPARROW model (Preston and Brakebill 1999), and (3) to maximize the calibration data available from river monitoring stations (Sprague et al. 2000). Applying the objectives yielded 1,063 river-segments in the model region.

3.3.1 Monitoring Site Selection

Increasing the number of calibration stations and observed data for calibration was a key Phase 5.3 goal. The USGS National Water Information System Web site (NWISWeb) was used to retrieve a list of USGS river gaging stations in Maryland, Delaware, the District of Columbia (DC), New York, Pennsylvania, Virginia, West Virginia, and North Carolina with mean-daily riverflow data from October 1, 1984, through December 31, 2002 (USGS 2007). The latitude and longitude of the stations and the station identification number from NWISWeb were used to create a spatial data set. The NWISWeb data were also used to determine whether the stations had at least 8 years of total streamflow data in that period. A total of 292 USGS river gaging stations met the criteria for inclusion in the calibration data set.

In the Potomac River watershed, 12 Maryland Department of Environment TMDL sites were added because water quality monitoring data was explicitly collected at these sites for use in calibrating the Phase 5 Model. Therefore, a total number of 304 sites were in the study area with streamflow or water-quality monitoring data or both, and were used for model calibration as listed in Table 3-2. An excerpt of Table 3-2 is shown below, and the full table is available by clicking the following hyperlink:
Table 3-2 (full table).

Table 3-2. Monitoring sites used in Phase 5.3 Community Watershed Model calibration.

Station ID	Location	CATCODE2	Tributary team basin
03207800	Levisa Fork at Big Rock, VA	BS3_8330_0000	Outside CB Basin - Big Sandy River
03208500	Russell Fork at Haysi, VA	BS4_8440_8441	Outside CB Basin - Big Sandy River
03208950	Cranes Nest River Near Clintwood, VA	BS4_8540_8441	Outside CB Basin - Big Sandy River
03209000	Pound River Below Flannagan Dam Near Haysi, VA	BS4_8540_8441	Outside CB Basin - Big Sandy River
01483700	St Jones River at Dover, DE	DE0_3790_0000	Outside CB Basin - Delmarva Peninsula
01484100	Beaverdam Branch at Houston, DE	DE0_4231_0001	Outside CB Basin - Delmarva Peninsula
01487000	Nanticoke River Near Bridgeville, DE	EL0_4562_0001	DE, Nanticoke & Broad Creek
01485500	Nassawango Creek Near Snow Hill, MD	EL1_5430_0001	MD, East Shore, Lower
01488500	Marshyhope Creek Near Adamsville, DE	EL2_4400_4590	DE, Marshyhope Creek
01485000	Pocomoke River Near Willards, MD	EL2_5270_0001	MD, East Shore, Lower

3.4 River-Segment Delineation

A river reach consists of a length of river with two endpoints. A reach endpoint can be the tidal estuary; a confluence within the river reach network; a reservoir; a monitoring site; the headwater of a stream; or a point corresponding to a state watershed boundary in a few cases. A 30-meter resolution, flow-direction raster data set generated from the NEDDEM (National Elevation Dataset Digital Elevation Model), which has a vertical resolution in decimal-meters, was used to delineate watersheds for each river reach. Drainage areas are defined using surface topography, and it is generally assumed in the HSPF (Bicknell et al. 1997; 2001; Donigian et al. 1984; Johanson et al. 1980) framework that the surface water divides and groundwater divides are coincident. Separate watersheds are needed for all river reaches being modeled. Figures 3-5 to 3-22 show all the Phase 5.3 river-segments and associated monitoring stations.

Phase 5.3 is designed to meet multiple objectives—among them, the assessment of nutrient and sediment loads within a large-scale regional Chesapeake Bay Program TMDL and fine-scale local TMDLs. To meet those objectives, the river-segment boundaries available from the states were used in place of the DEM river-segment boundaries where they coincided (Chesapeake Bay Program 1998; Hoffman and Kernan 1996; Maryland Department of Natural Resources 1998; Upper Susquehanna Coalition, U.S. Geological Survey, and others 2002; Virginia Department of Conservation and Recreation—DSWC 1995). Using a segmentation scheme that fit both TMDL program scales allowed the Phase 5.3 Model to be used for both the large-scale Chesapeake TMDL and for finer-scale state TMDLs

Watershed boundaries also were created for reservoir outlets. The Phase 5.3 Model simulates 42 reservoirs in its domain. If a monitoring site was downstream of a reservoir, watershed boundaries were generated from the DEM. For the remaining reservoirs, either state watershed boundaries were used or watershed boundaries were manually delineated and digitized on the basis of RF3 and 1:24,000-scale Digital Raster Graphics (DRG) (USGS 2004a; 2004b; USEPA 1994; USEPA 1996). Where large reservoirs spanned several smaller watersheds, those watersheds were combined into one.

A number of very small river-segments were formed because of the unusual geometries relating to the distance between stream confluences or the location of monitoring sites.

Because of potential numerical instability brought on by the one-hour time step coupled with a very small watershed, excessive computational effort, and the difficulty in capturing processes accurately at a very small scale in a regional model, small river-segments that represented 5 percent or less of the upstream drainage area were incorporated into an adjacent river-segment.

Each river-segment was given a unique 4-digit identifier (UNIQID) and a downstream identifier (DSID) that is the UNIQID of the downstream adjacent watershed. The UNIQIDs were generated so that they increase from north to south within the model domain. There are 672 river-segments with simulated reaches that drain to a simulated downstream reach. There are 66 river-segments with simulated reaches that drain directly to the Chesapeake Bay; they have a DSID equal to one. There are 324 river-segments that are either adjacent to tidal waters or are outside the Chesapeake watershed which are without a simulated reach; they have a DSID equal to zero (0000).

In most areas with sewer systems that combine storm runoff with wastewater before treatment, the systems can overflow without treatment when storm runoff exceeds their capacity. A number of watershed divides in DC were adjusted to account for these combined sewer overflows (CSOs). The CSO area of DC was given a DSID of four (0004). Outside of DC, estimates of areas contributing to CSO discharges were treated as a distinct land use.

Each river-segment in the Chesapeake Bay watershed is associated with a two-letter code identifying its major and minor basin (Table 3-3); watersheds outside the Chesapeake Bay watershed were given a two-letter code identifying the major basin. The relative size of the river reach and volume of water transported was represented by a one-digit numerical value calculated from the mean streamflow value (using units of cubic feet per second) in the Enhanced River Reach File (ERF1) data set (Alexander et al. 1999). That value is calculated as:

$$3[\log_{10}(\textit{mean streamflow in cfs})] - 5$$

and is rounded to the nearest positive integer. The value ranges from 0 to 9.

The major and minor basin codes, river reach size on the basis of streamflow, UNIQID, and DSID were combined to create a unique 13-character identifier for every watershed in the study area (Plate 1). The identifier SW2_1100_1130, for example, refers to Susquehanna River Basin, West Branch, with a river reach size equal to 2, a UNIQID of 1100 and a DSID of 1130.

3.4.1 Quality Assurance of Watershed Boundaries

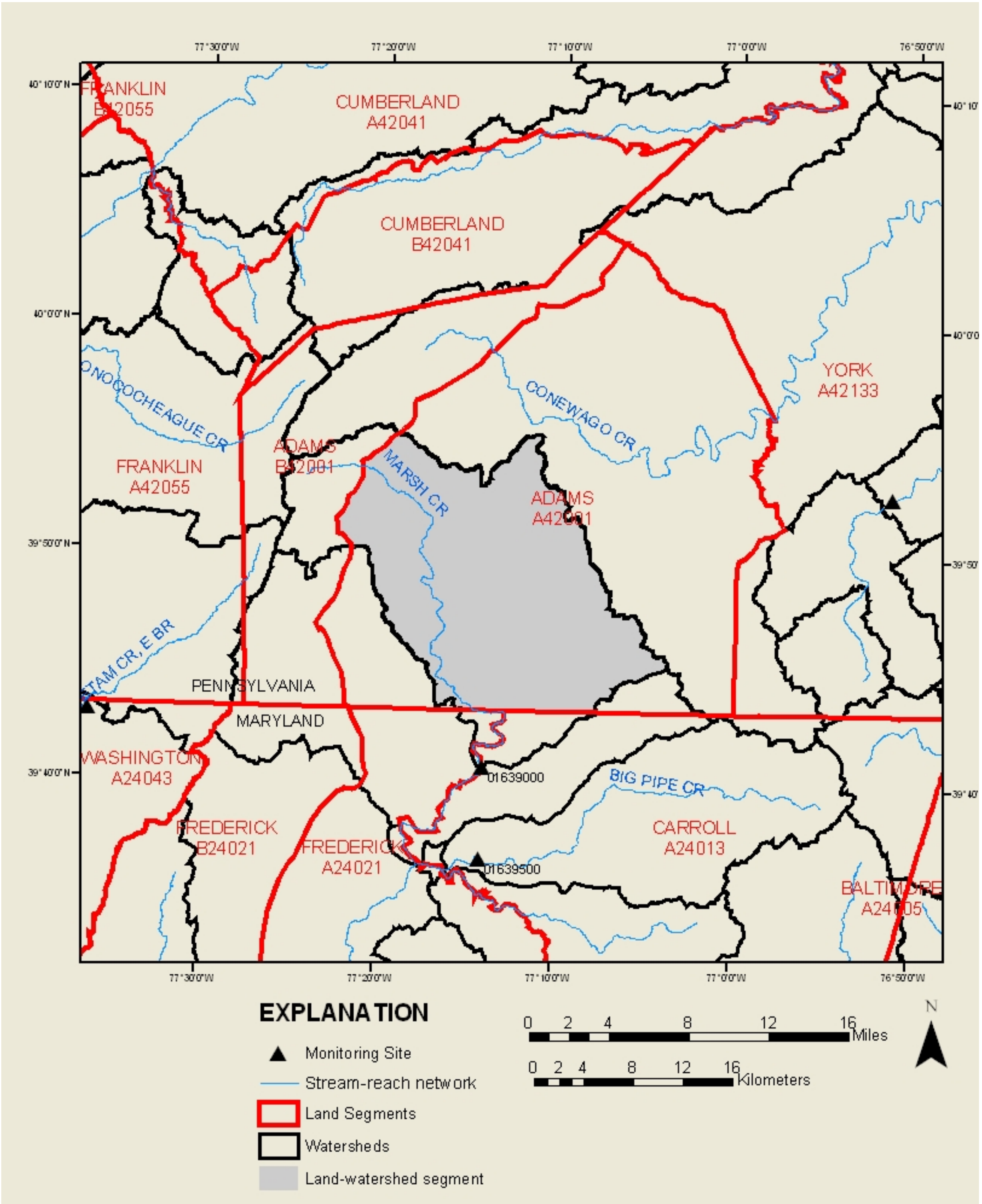
To ensure an acceptable segmentation for the entire model domain, extensive quality assurance evaluations were performed. The approach involved the six watershed states and Washington, DC performing a review and the states examining multiple data sources. The quality assurance process included (1) comparing data sources, (2) checking individual watersheds to ensure that they were representative of the actual drainage areas, and (3) ensuring that the segments met the specified criteria.

Table 3-3. Major (1st letter) and minor (2nd letter) basin codes used to define watershed identifiers for the Chesapeake Bay Regional Watershed Model

Code	Description
Chesapeake Bay Watershed	
Susquehanna River Basin	
SU	Upper Susquehanna River, above confluence with West Branch
SW	Susquehanna River, West Branch
SJ	Juniata River
SL	Lower Susquehanna River below West Branch confluence not including the Juniata River
Potomac River Basin	
PU	Upper Potomac River, above Shenandoah confluence
PS	Shenandoah River
PM	Middle Potomac River, including Monocacy River below Shenandoah confluence, above Chain Bridge
PL	Lower Potomac River, below Chain Bridge
James River Basin	
JU	Upper James River, above the Maury River confluence
JL	Lower James River, below the Maury River confluence, above Richmond, Virginia
JA	Appomattox River
JB	James River, below Richmond, Virginia, not including the Appomattox River
York River Basin	
YP	Pamunkey River
YM	Mattaponi River
YL	York River, below Mattaponi and Pamunkey confluence, including the Piankatank River
Rappahannock River Basin	
RU	Upper Rappahannock River
RL	Lower Rappahannock River
Patuxent River Basin	
XU	Patuxent River above Bowie, Maryland
XL	Patuxent River below Bowie, Maryland
Western Shore of Chesapeake Bay	
WL	Lower Western shore
WM	Middle Western shore, including the Patapsco and Back Rivers
WU	Upper Western shore
Eastern Shore of Chesapeake Bay	
EU	Upper Eastern Shore
EL	Lower Eastern Shore
EM	Middle Eastern Shore, including the Choptank River
Regions Outside the Chesapeake Bay Watershed	
GY	Part of the Youghiogheny River
DE	Delmarva Peninsula, outside the Chesapeake Bay watershed
TU	Part of the Upper Tennessee River
BS	Part of the Big Sandy River
NR	Part of the New River
OD	Dan River, tributary of the Roanoke River
OR	Part of Roanoke River, not including the Dan River
MN	Meherin and Nottoway rivers

3.4.2 Intersection of Land-Segments and River-Segments

In Phase 5.3, the land simulation and the river simulation are run separately. To link the two simulations, the common area between land-segments and river-segments needed to be determined. The land-segments and river-segments were combined to create a new spatial data set, referred to as *land-river-segments*. In Phase 5.3, nutrient and sediment loads from land-river-segments are delivered to the associated river reach in a way represented in Figure 3-4. To determine the total load for a land-river-segment at each time step, the load for each land use is multiplied by the number of acres of that land use in the land-river-segment. That load is then delivered to the associated river reach for the second simulation step involving transport within the reach.



Note: The land-river-segment shown in gray includes the portion of eastern Adams County that drains to Marsh Creek.

Figure 3-4. An example of the relation between model land-segments, river-segments, and land-river-segments here shown for Marsh Creek in Adams County, Pennsylvania and its surrounding region.

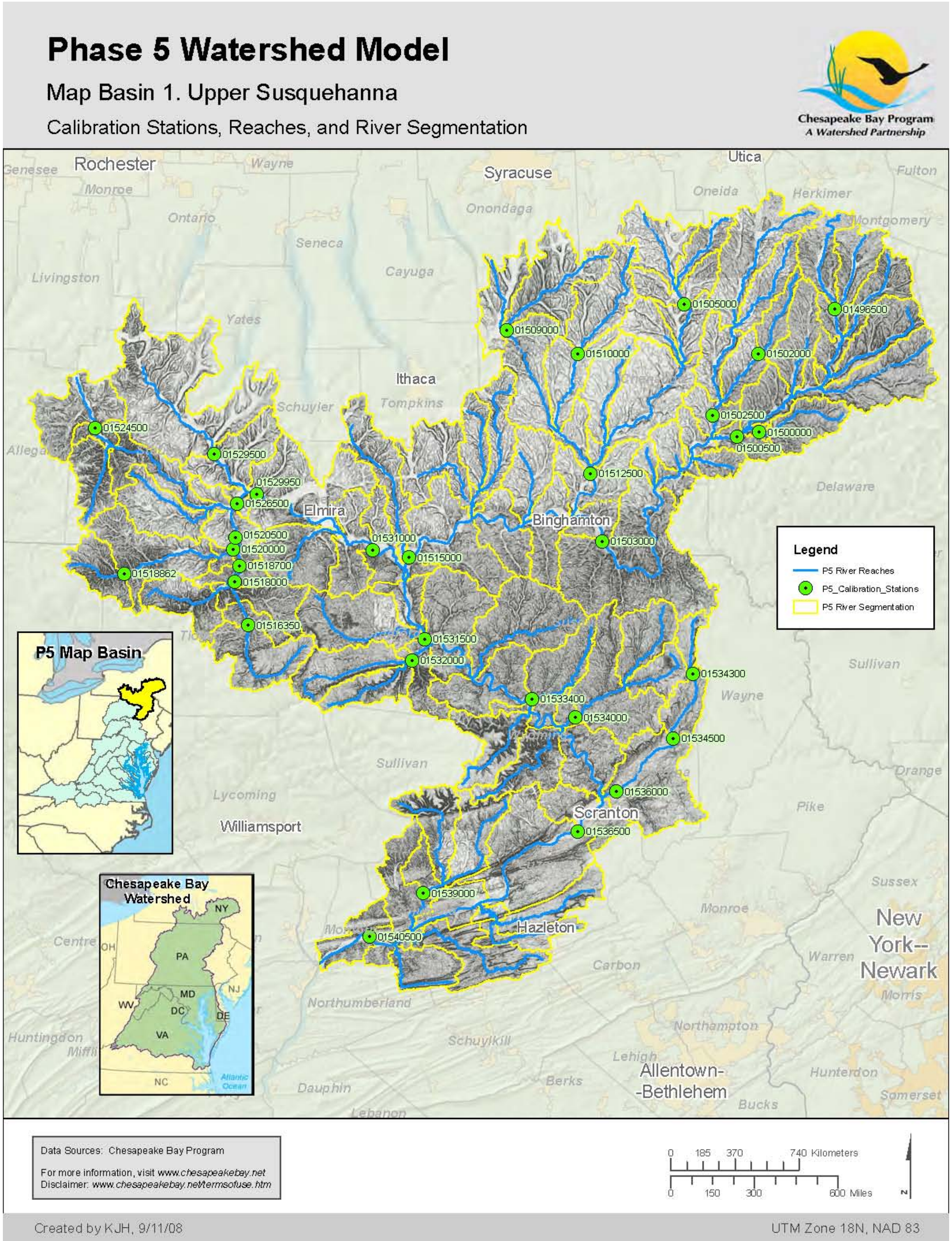


Figure 3-5. Upper Susquehanna River watershed above the confluence with the West Branch River showing Phase 5.3 Model segments and calibration stations.

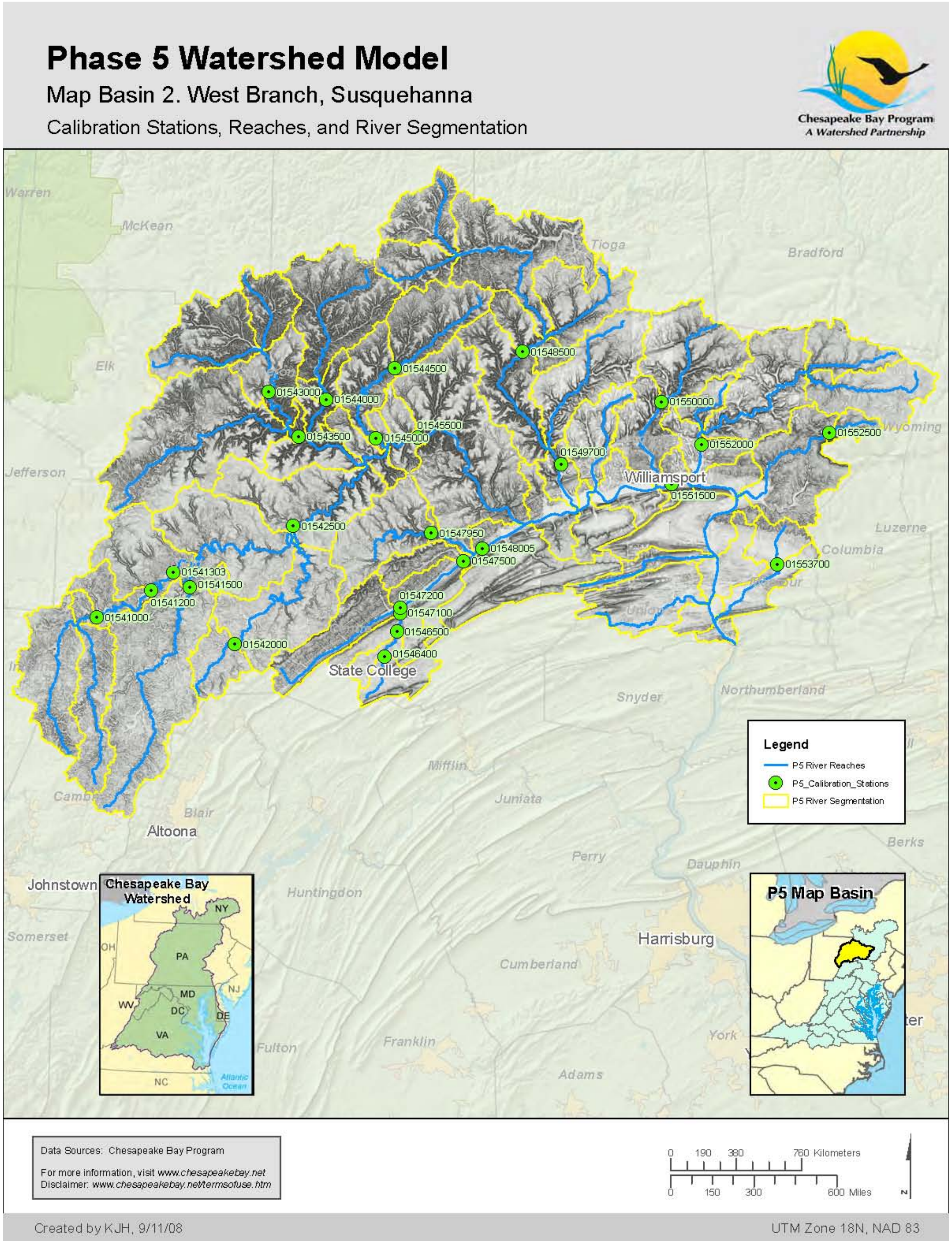


Figure 3-6. Susquehanna West Branch River watershed showing Phase 5.3 Model segments and calibration stations.

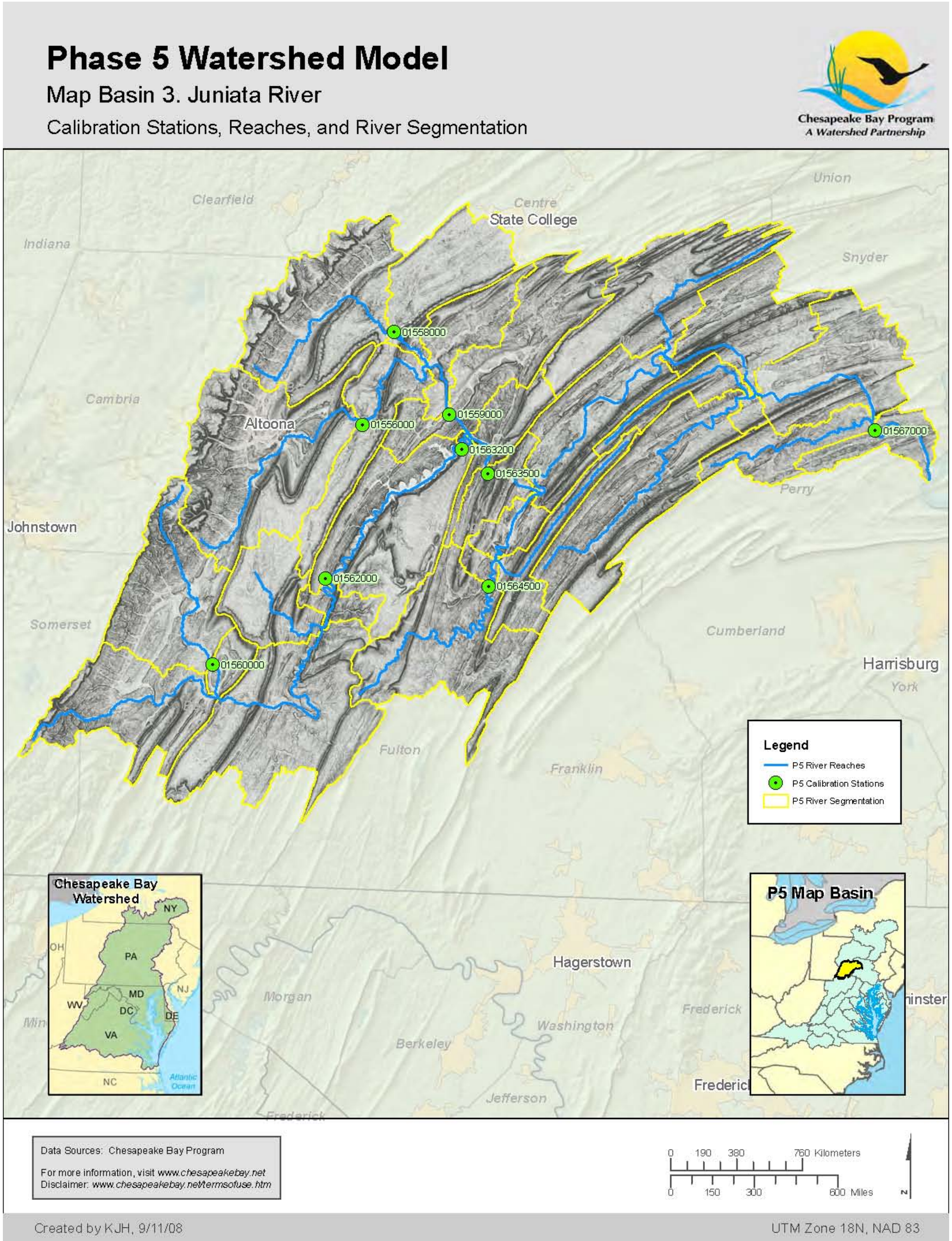


Figure 3-7. Juniata River watershed showing Phase 5.3 Model segments and calibration stations.

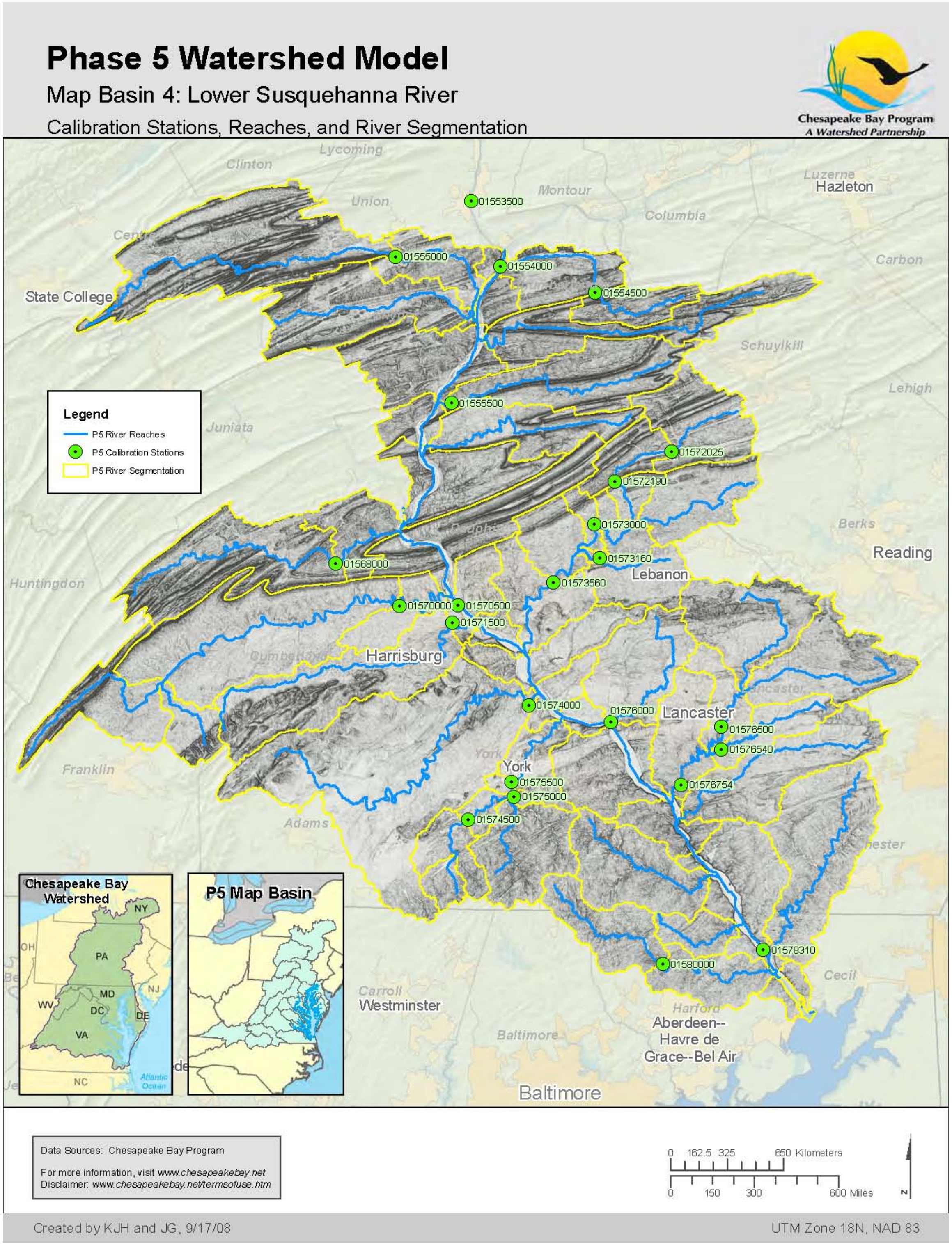


Figure 3-8. Lower Susquehanna River watershed below the West Branch River confluence (not including the Juniata River) showing Phase 5.3 Model segments and calibration stations.

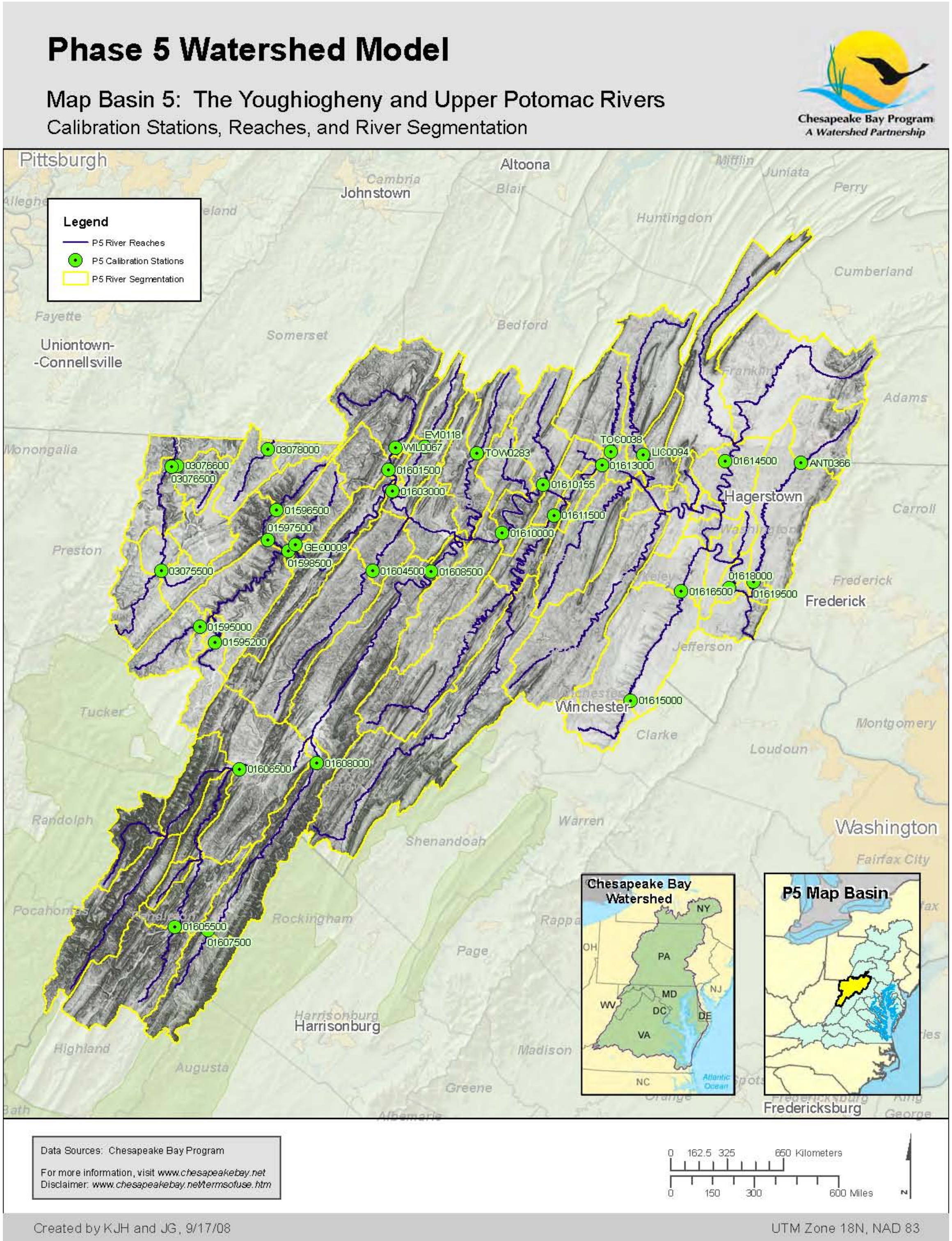


Figure 3-9.Upper Potomac River watershed above the Shenandoah confluence showing Phase 5.3 Model segments and calibration stations.

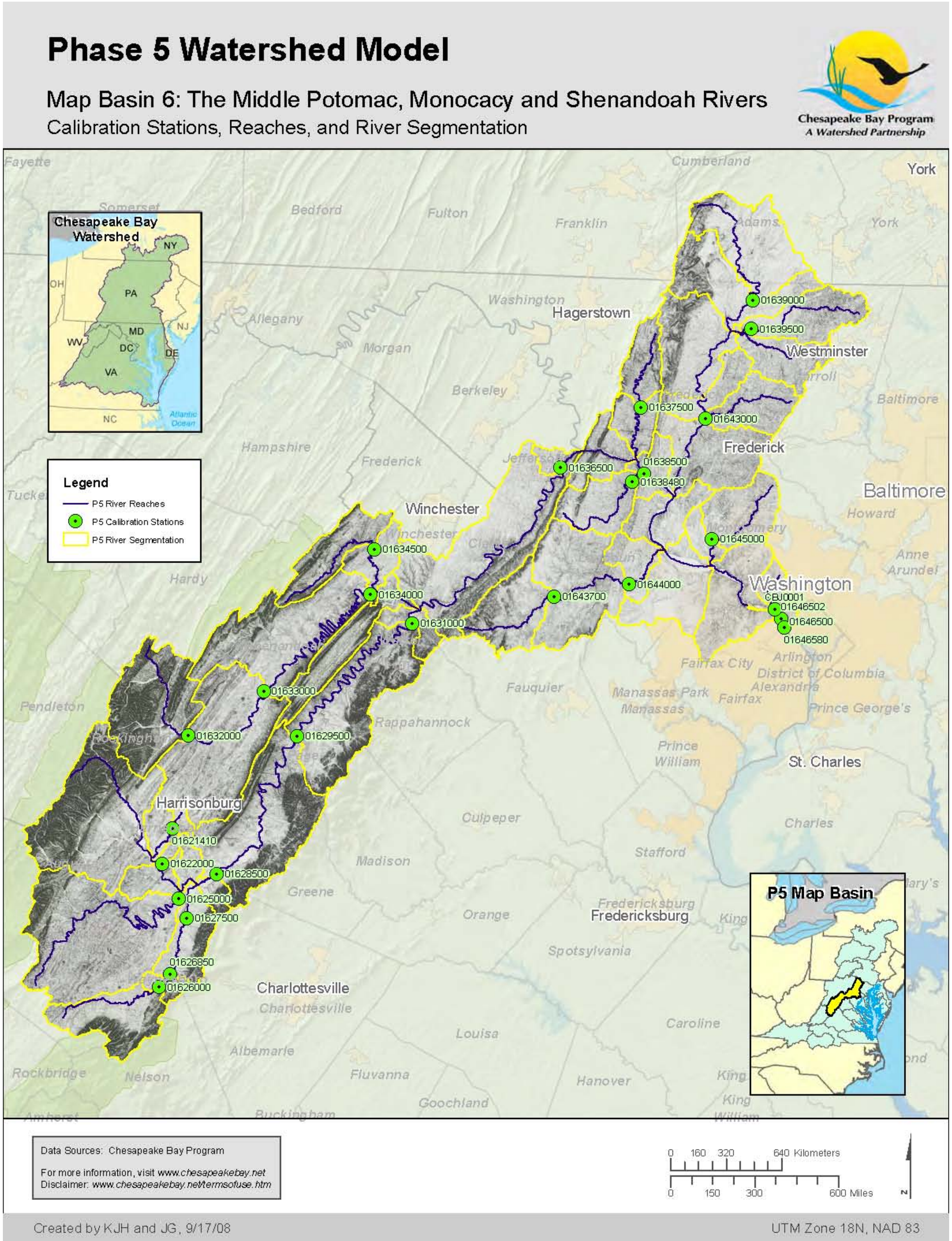


Figure 3-10. The Middle Potomac, Monocacy, and Shenandoah River watersheds showing Phase 5.3 Model segments and calibration stations.

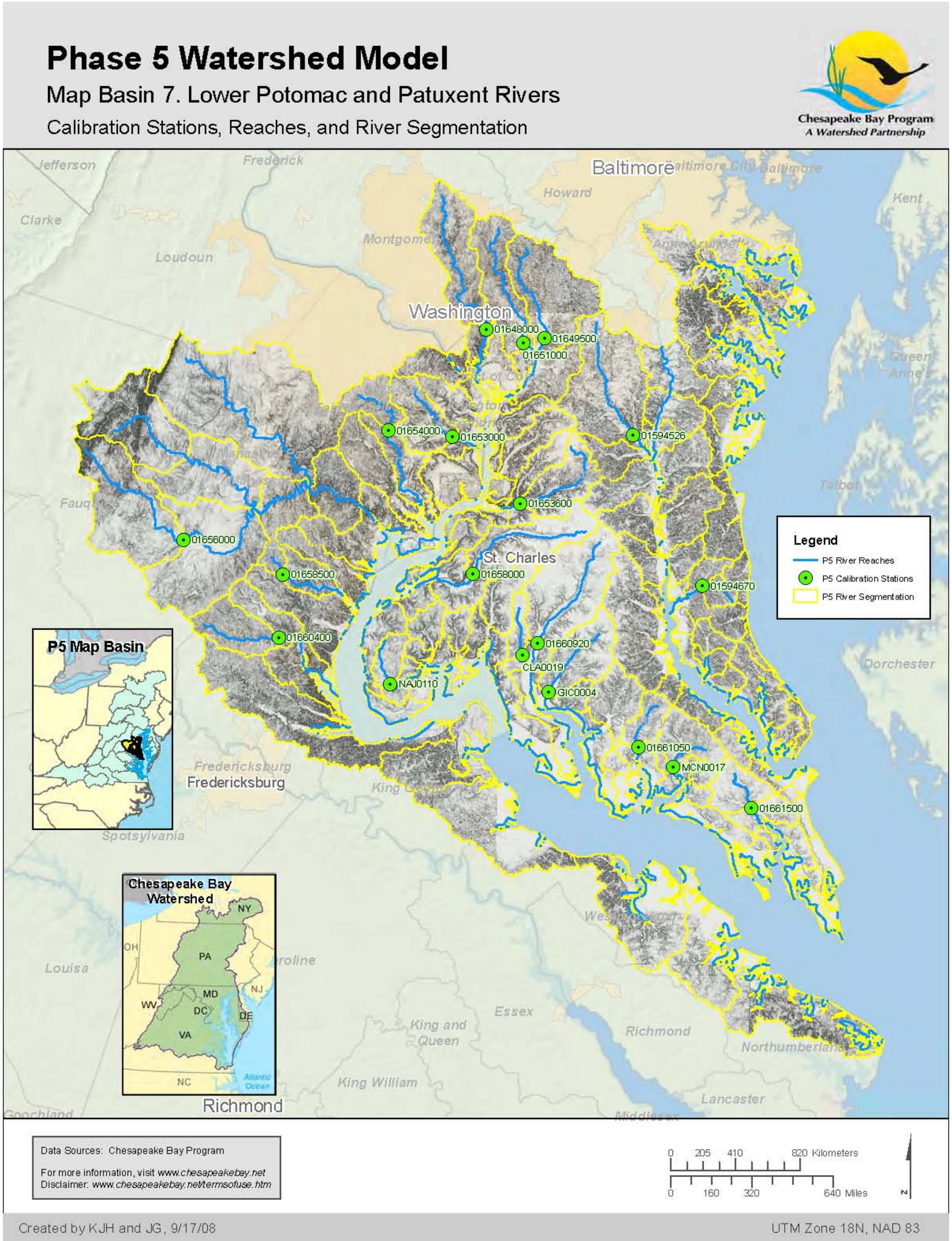


Figure 3-11. Lower Potomac and Patuxent River watersheds showing Phase 5.3 Model segments and calibration stations.

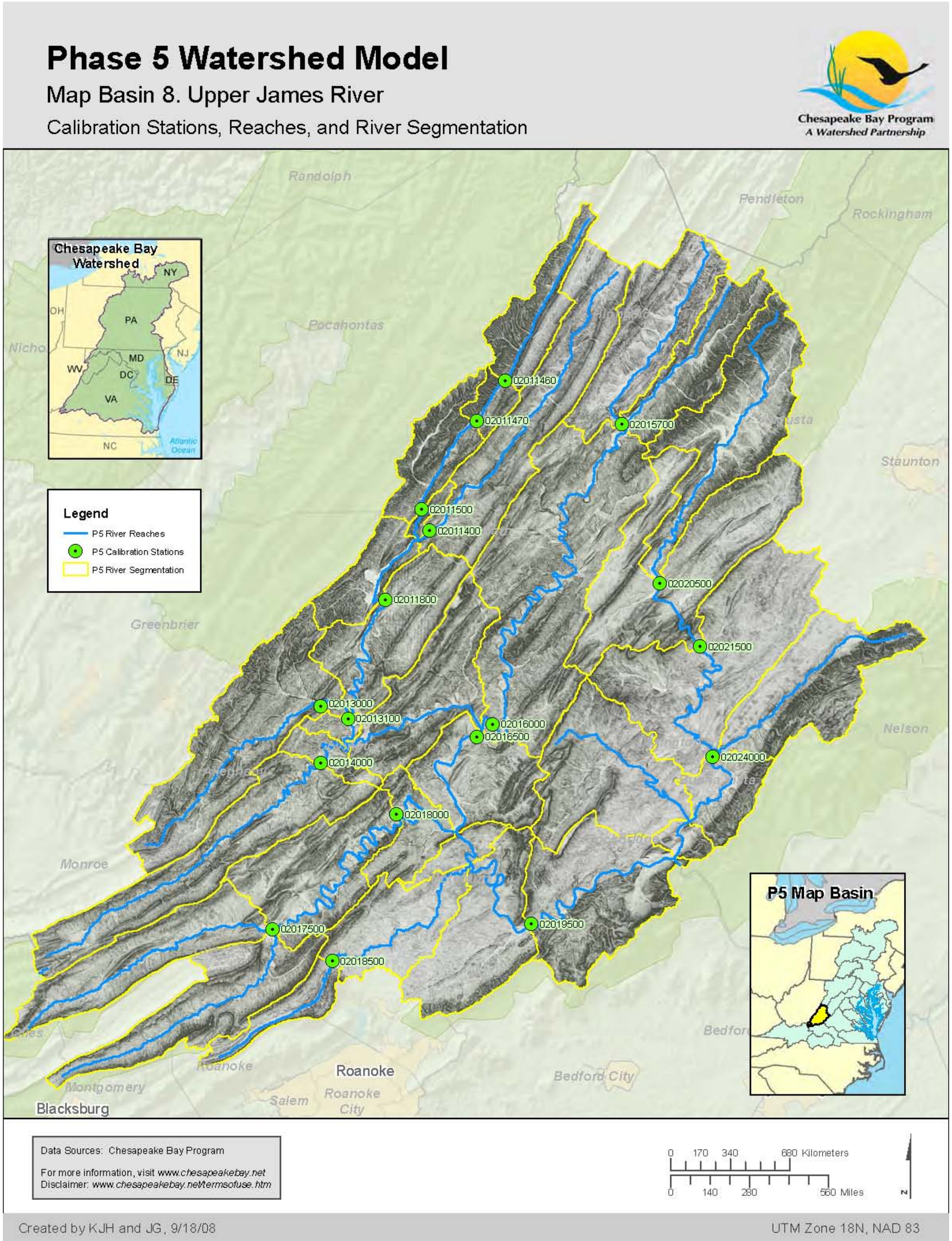


Figure 3-12. Upper James River watershed above the Maury River confluence showing Phase 5.3 Model segments and calibration stations.

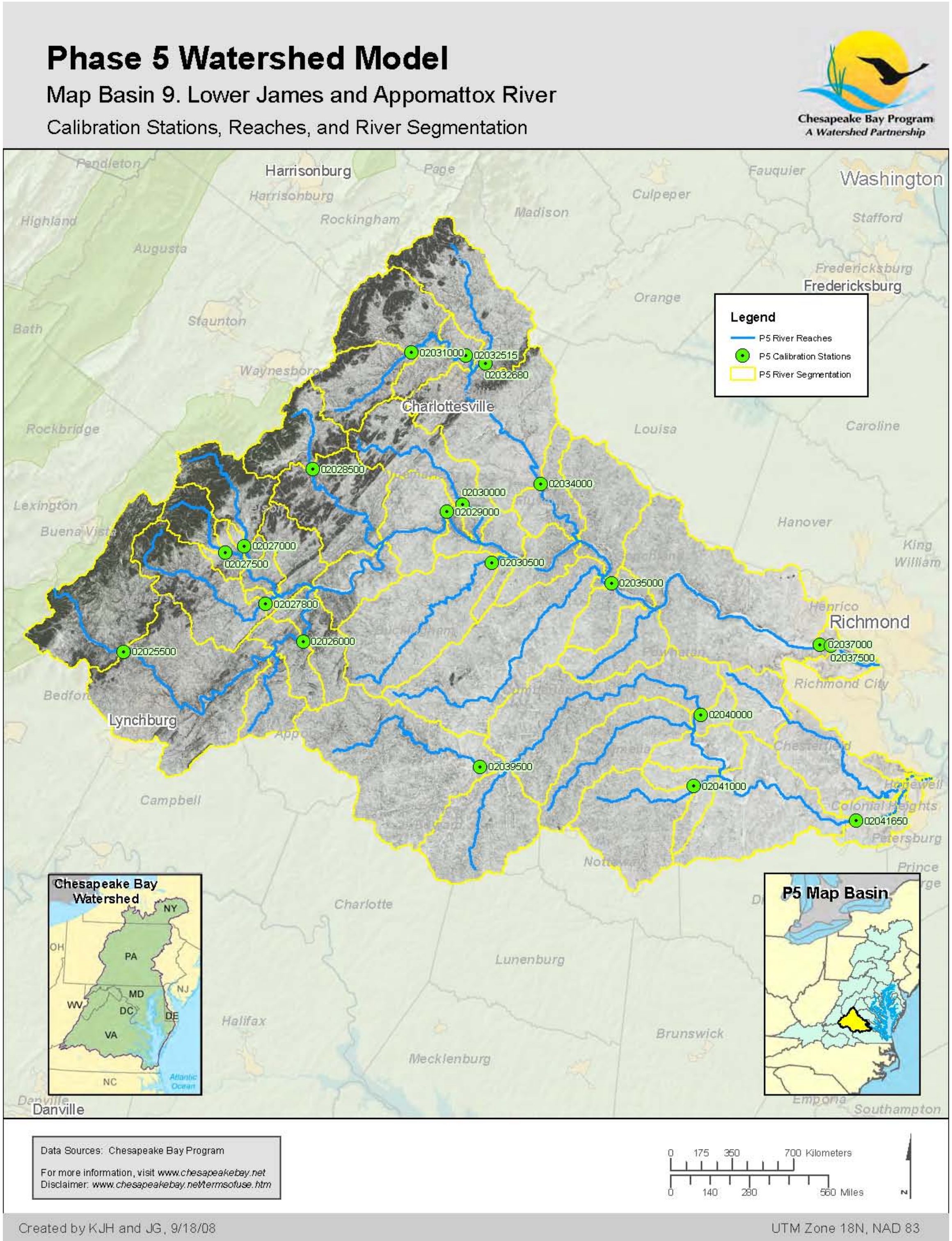


Figure 3-13. Lower James and Appomattox River watersheds showing Phase 5.3 Model segments and calibration stations.

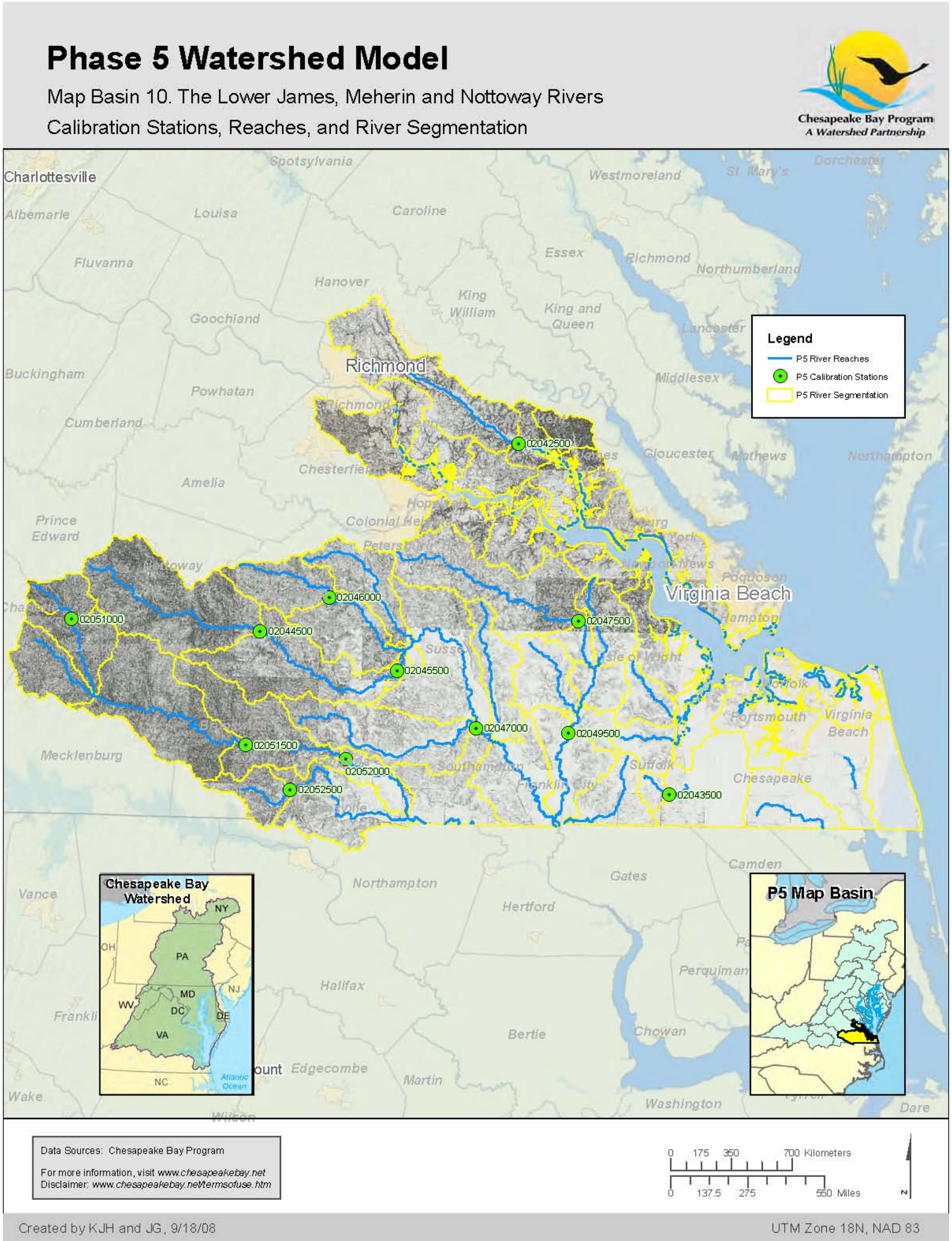


Figure 3-14. Lower James, Merherin, and Nottoway River watersheds showing Phase 5.3 Model segments and calibration stations.

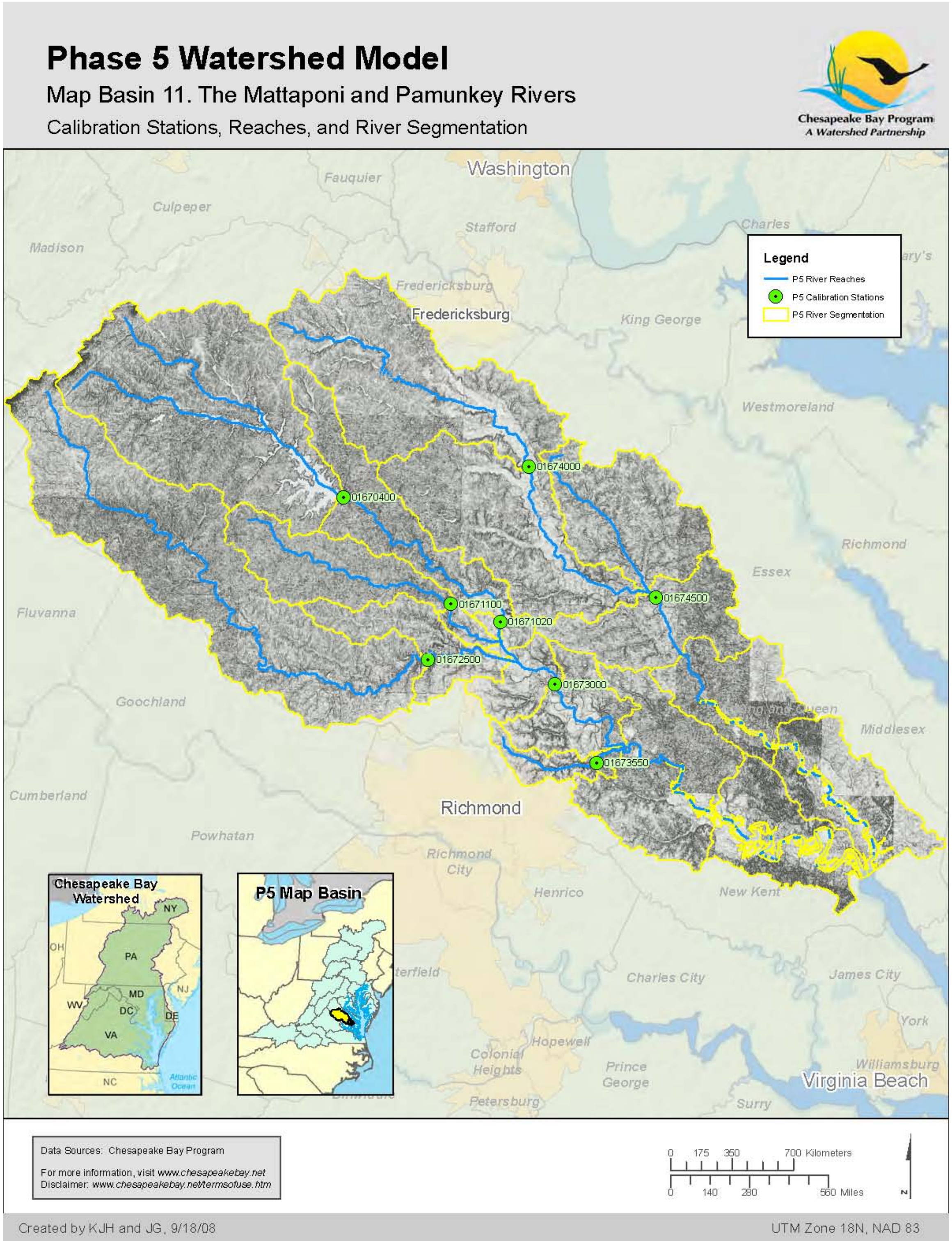


Figure 3-15. Mattaponi and Pamunkey River watersheds showing Phase 5.3 Model segments and calibration stations.

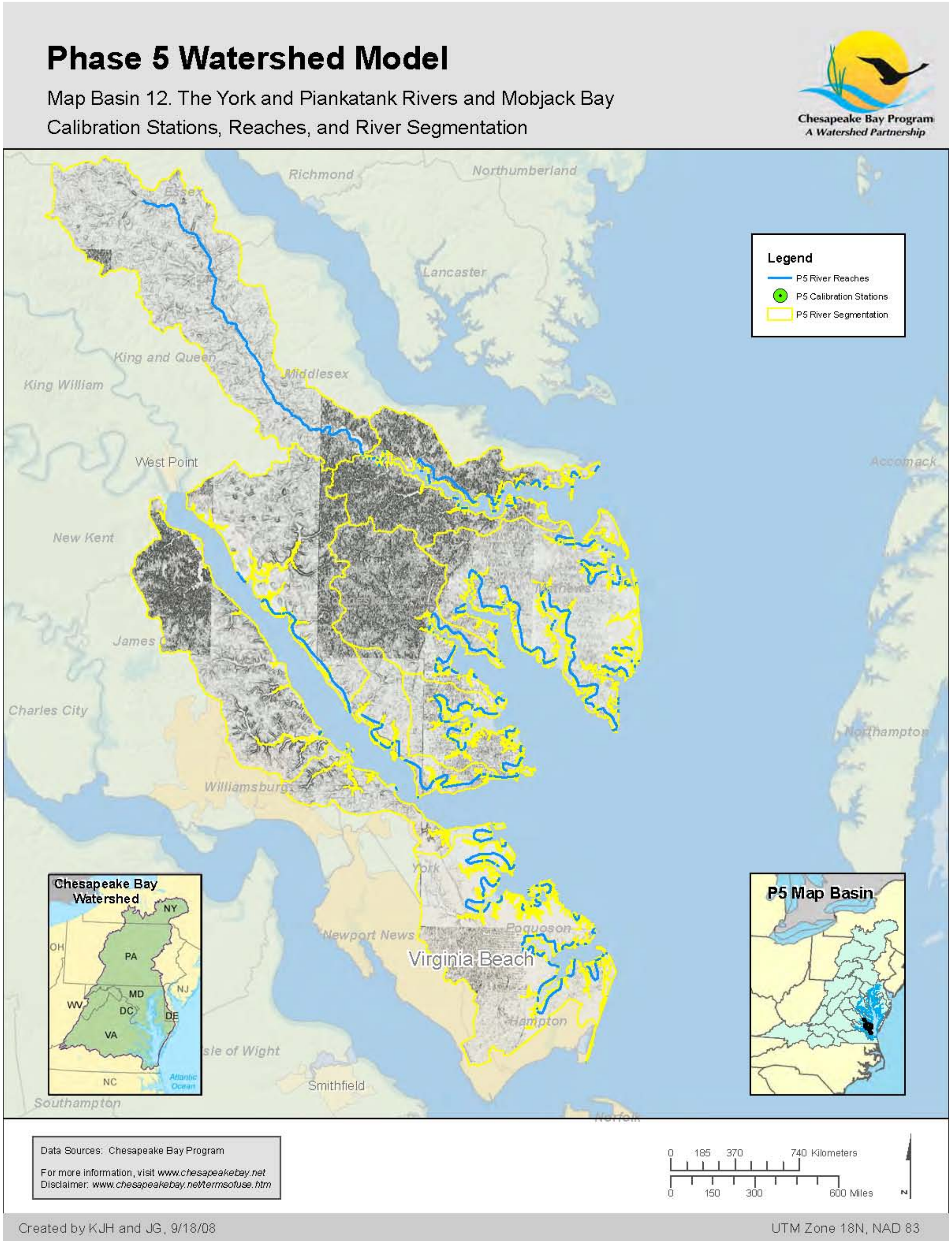


Figure 3-16. York and Piakatank River watersheds and Mobjack Bay showing Phase 5.3 Model segments and calibration stations.

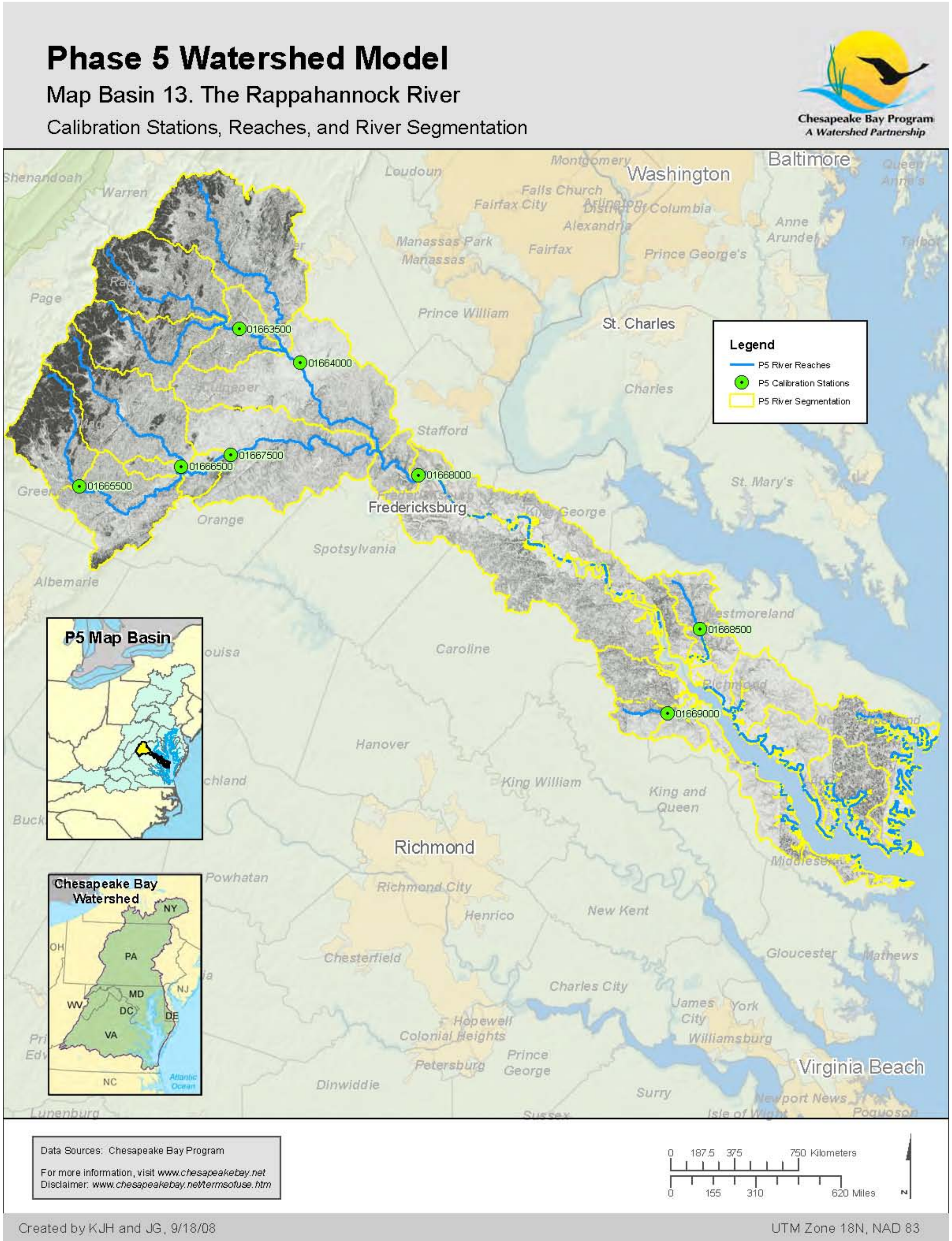


Figure 3-17. Rappahannock River watershed showing Phase 5.3 Model segments and calibration stations.

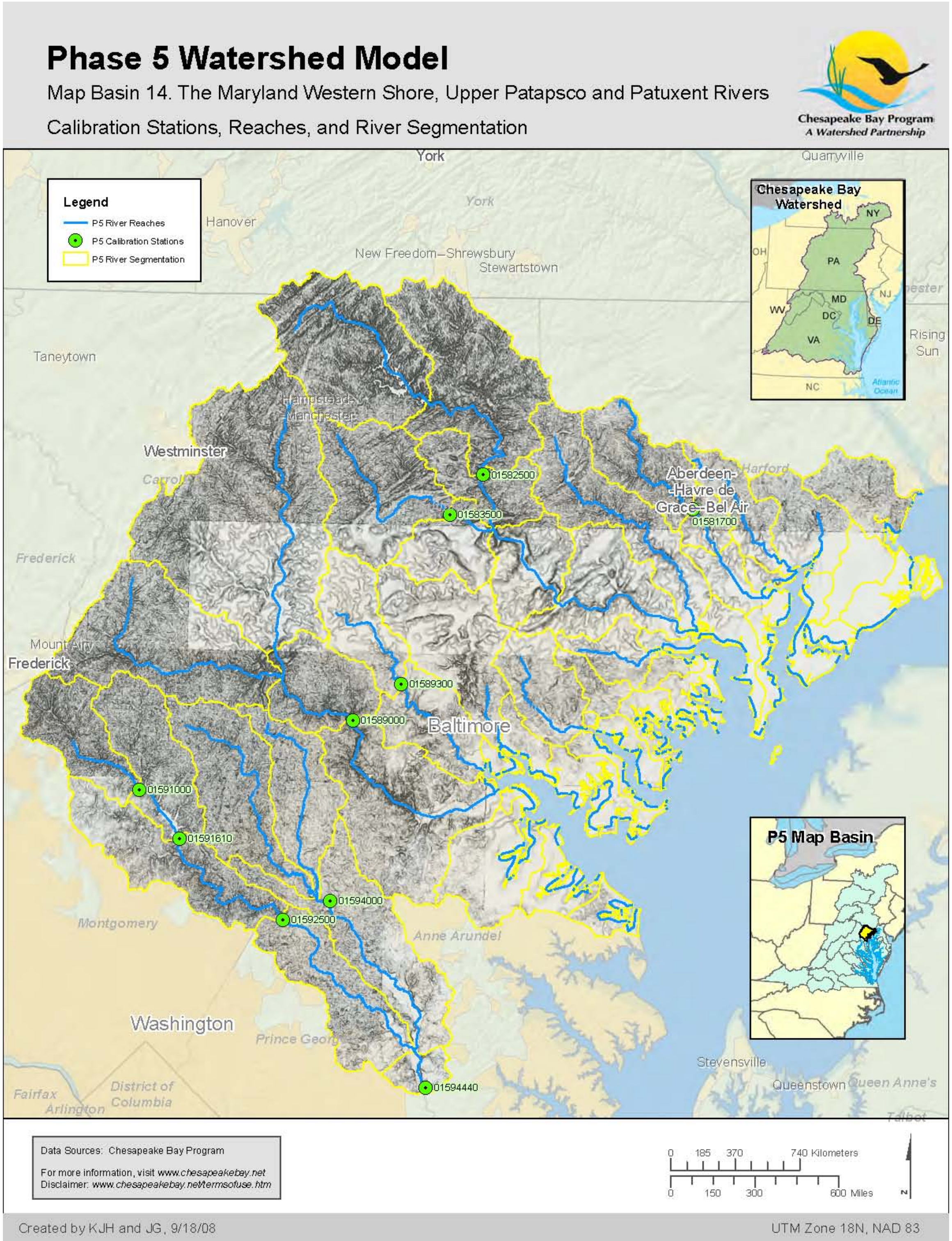


Figure 3-18. Maryland Western Shore, Patapsco and Patuxent River watersheds showing Phase 5.3 Model segments and calibration stations.

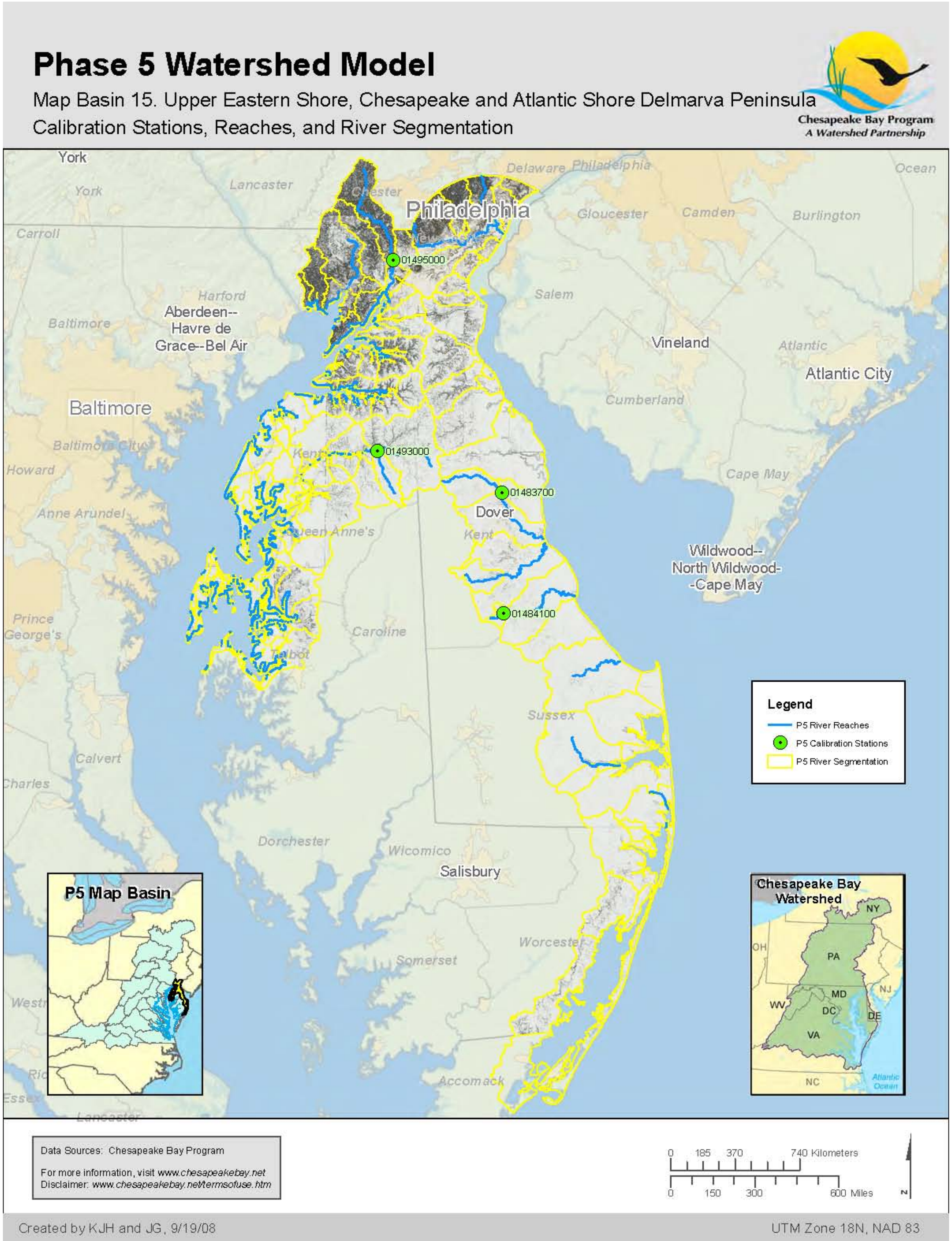


Figure 3-19. Upper Eastern Shore, Chesapeake, and Atlantic Shore Delmarva watersheds showing Phase 5.3 Model segments and calibration stations.

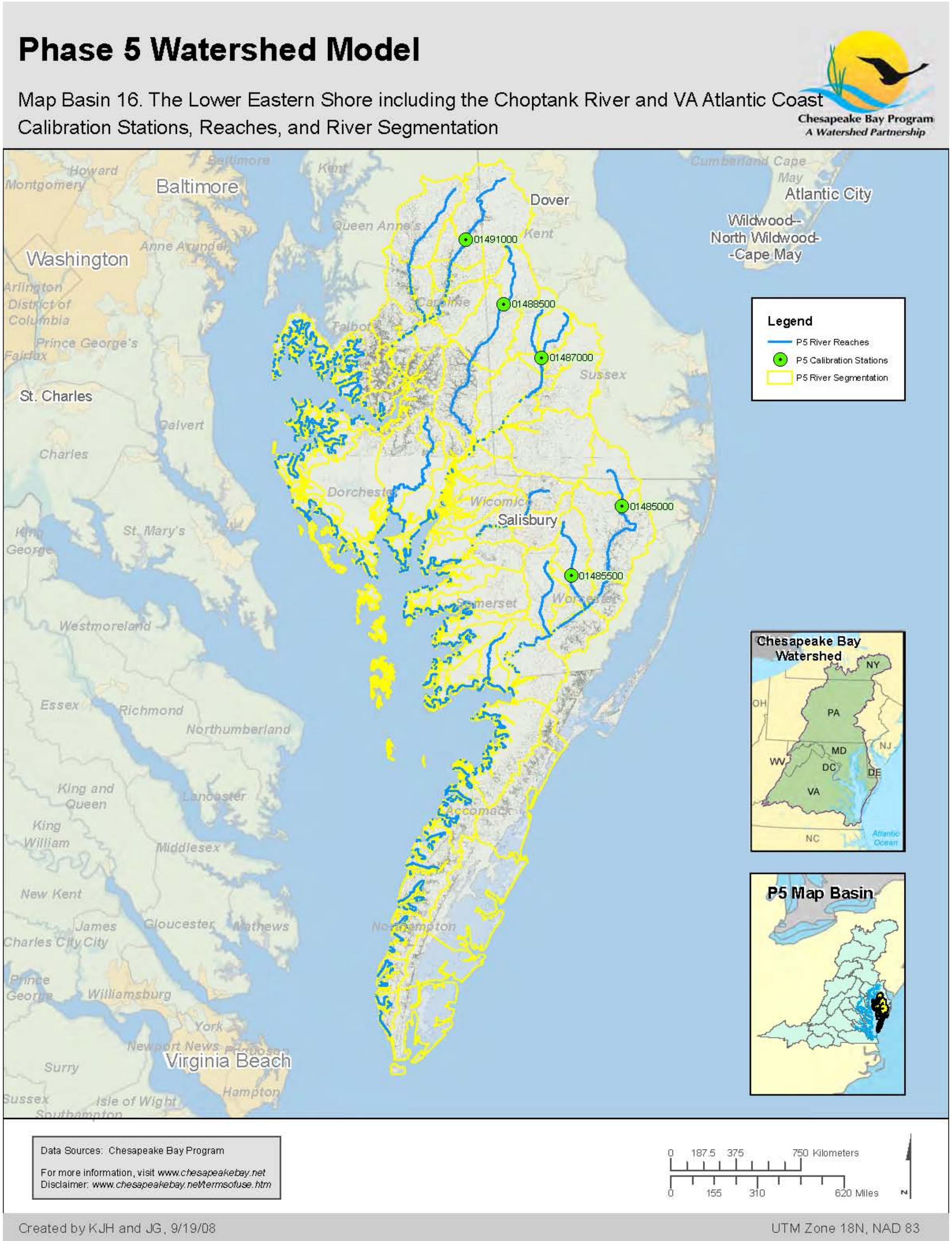


Figure 3-20. Lower Eastern Shore, including Choptank River and Virginia Atlantic Coast watersheds showing Phase 5.3 Model segments and calibration stations.

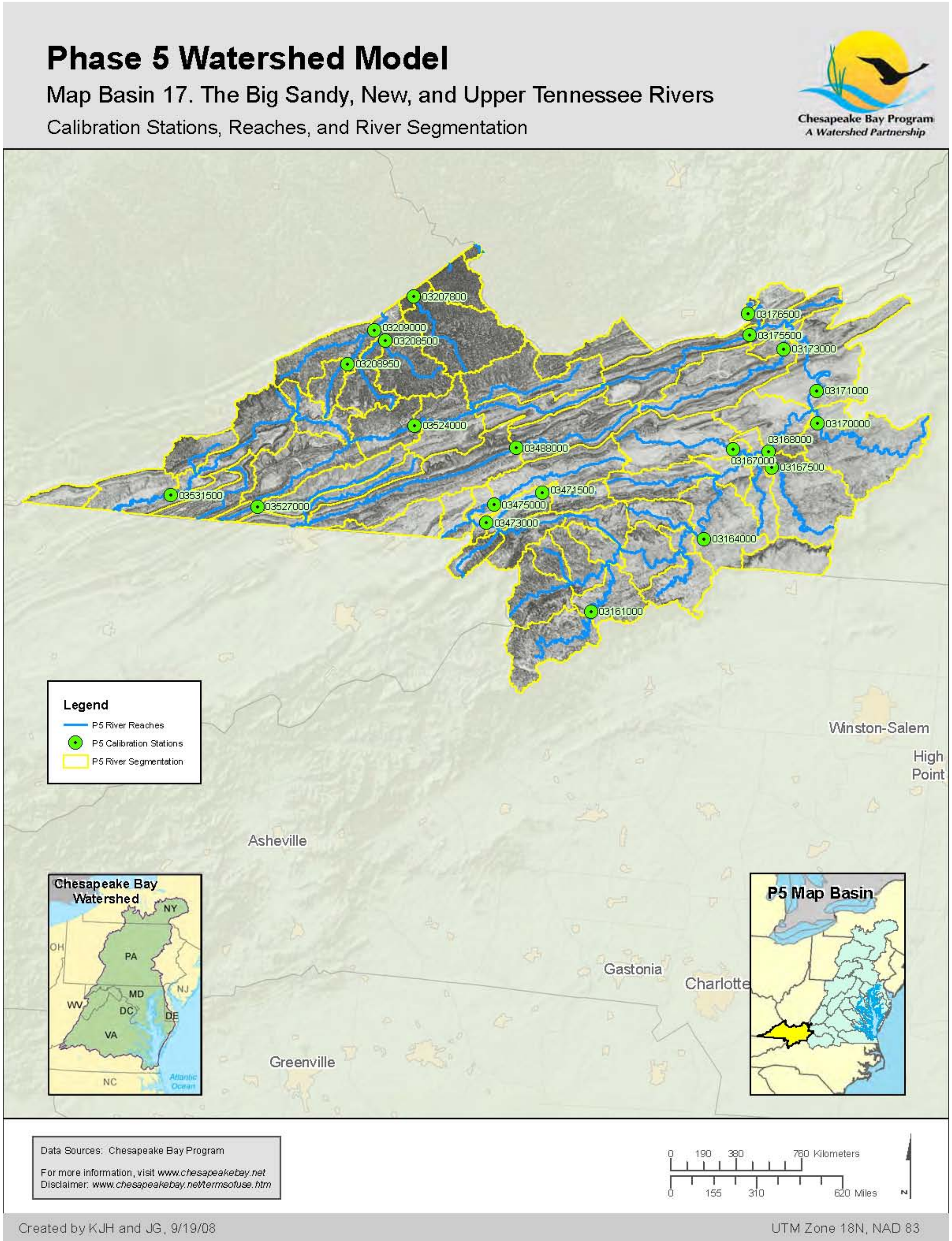


Figure 3-21. The Big Sandy, New, and Upper Tennessee River watersheds showing Phase 5.3 Model segments and calibration stations.

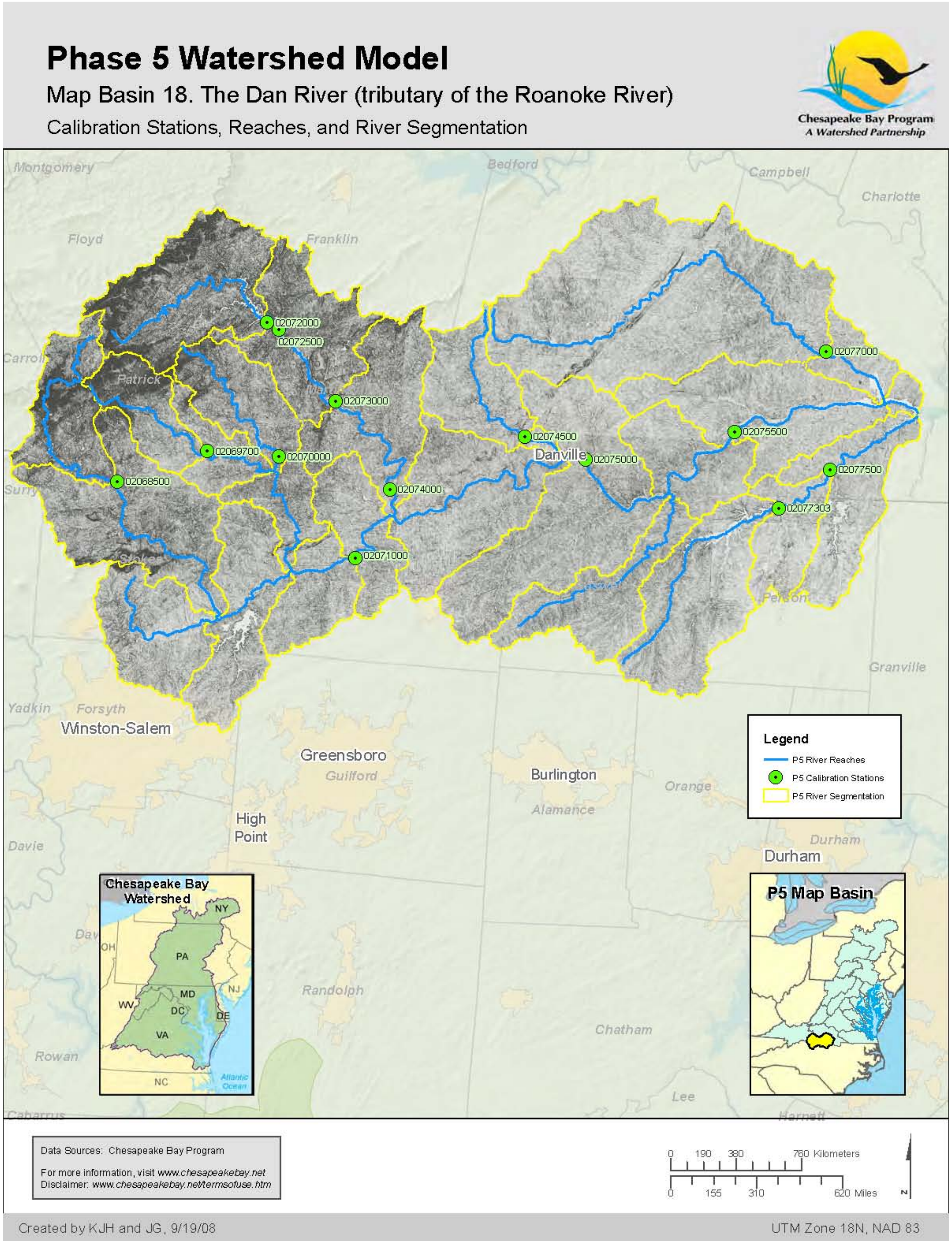


Figure 3-22. The Dan River watershed showing Phase 5.3 Model segments and calibration stations.

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