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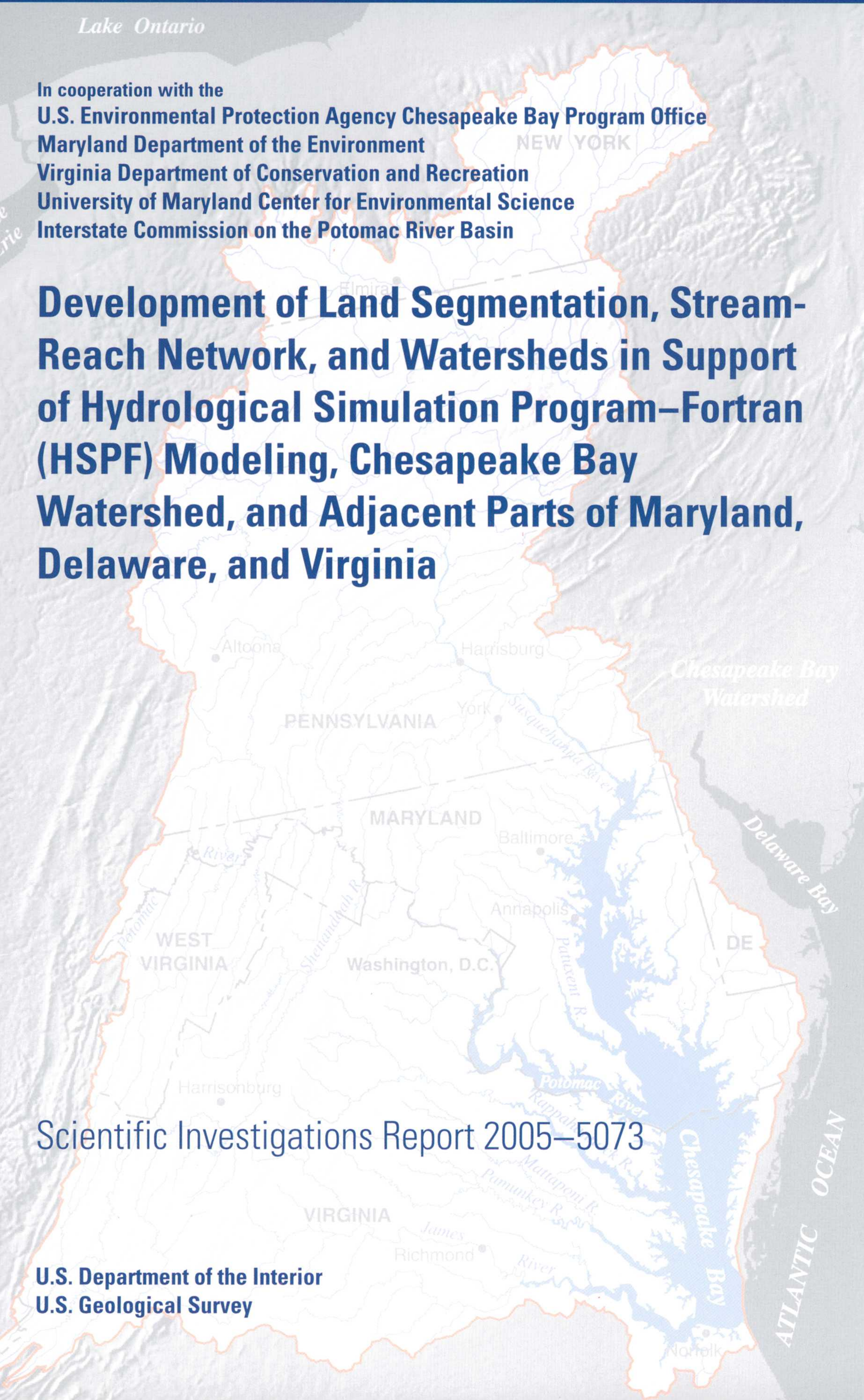
Development of Land Segmentation, Stream-Reach Network, and Watersheds in Support of Hydrological Simulation Program–Fortran (HSPF) Modeling, Chesapeake Bay Watershed, and Adjacent Parts of Maryland, Delaware, and Virginia



Scientific Investigations Report 2005–5073

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

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By Sarah K. Martucci, Jennifer L. Krstolic, and Jeff P. Raffensperger
(U.S. Geological Survey)
and
Katharine J. Hopkins
(University of Maryland Center for Environmental Science)

Prepared in cooperation with the

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

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DIRK KEMPTHORNE, Secretary

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Development of Land Segmentation, Stream-Reach Network, and Watersheds in Support of Hydrological Simulation Program–Fortran (HSPF) Modeling, Chesapeake Bay Watershed, and Adjacent Parts of Maryland, Delaware, and Virginia

By Sarah K. Martucci [1], Jennifer L. Krstolic [1], Jeff P. Raffensperger [1], and Katharine J. Hopkins [2]

Abstract

The U.S. Geological Survey, U.S. Environmental Protection Agency Chesapeake Bay Program Office, Interstate Commission on the Potomac River Basin, Maryland Department of the Environment, Virginia Department of Conservation and Recreation, and the University of Maryland Center for Environmental Science are collaborating on the Chesapeake Bay Regional Watershed Model, using Hydrological Simulation Program–FORTRAN to simulate streamflow and concentrations and loads of nutrients and sediment to Chesapeake Bay. The model will be used to provide information for resource managers. In order to establish a framework for model simulation, digital spatial datasets were created defining the discretization of the model region (including the Chesapeake Bay watershed, as well as the adjacent parts of Maryland, Delaware, and Virginia outside the watershed) into land segments, a stream-reach network, and associated watersheds.

Land segmentation was based on county boundaries represented by a 1:100,000-scale digital dataset. Fifty of the 254 counties and incorporated cities in the model region were divided on the basis of physiography and topography, producing a total of 309 land segments. The stream-reach network for the Chesapeake Bay watershed part of the model region was based on the U.S. Geological Survey Chesapeake Bay SPARROW (SPAtially Referenced Regressions On Watershed attributes) model stream-reach network. Because that network was created only for the Chesapeake Bay watershed, the rest of the model region uses a 1:500,000-scale stream-reach network. Streams with mean annual streamflow of less than 100 cubic feet per second were excluded based on attributes from the dataset. Additional changes were made to enhance the data and to allow for inclusion of stream reaches with monitoring data that were not part of the original network. Thirty-meter-resolution Digital Elevation Model data were used to delineate watersheds for each stream reach. State watershed boundaries replaced the Digital Elevation Model-derived watersheds where coincident. After a number of corrections, the watersheds were coded to indicate major and minor basin, mean annual streamflow, and each watershed's unique identifier as well as that of the downstream watershed. Land segments and watersheds were intersected to create land-watershed segments for the model.

Introduction

Excess nutrients were recognized as a major problem for the Chesapeake Bay in a 7-year U.S. Environmental Protection Agency (USEPA) study concluded in 1983 (U.S. Environmental Protection Agency, 1983). Excess nutrients stimulate algae production, which may in turn reduce light penetration in the water column, killing beds of underwater grasses and other vegetation that provide food and habitat for fauna. The oxygen balance within the estuary, mediated by photosynthesis, respiration, uptake, and decomposition, is also affected, creating appreciable volumes of low-oxygen water seasonally in deeper parts of the bay.

Following identification of the nutrient problem in the early 1980s, an agreement signed by various Chesapeake Bay watershed States (Maryland, Virginia, Pennsylvania) and the District of Columbia in conjunction with the Chesapeake Bay Commission and USEPA, led to the formation of the USEPA Chesapeake Bay Program (CBP) Office, a unique regional partnership that has led and directed the restoration of the Chesapeake Bay since 1983. In 1987, the CBP made nutrient reductions a major goal, calling for a 40-percent reduction in nitrogen and phosphorus loadings by 2000. These goals were subsequently modified, and it has been determined that the goals were only partially met (Sprague and others, 2000).

[1] U.S. Geological Survey.

[2] University of Maryland Center for Environmental Science.

A new agreement that established revised goals for bay restoration was signed in 2000, based on criteria for dissolved oxygen, chlorophyll, and water clarity levels in the tidal water of the Chesapeake Bay (U.S. Environmental Protection Agency Chesapeake Bay Program Office, 2000). Major factors that affect these levels are the transport of nutrients (primarily nitrogen and phosphorus) and sediment from the watershed to the rivers and streams that ultimately may reach the bay. Quantitative models of watershed processes have been used by the CBP and its State and Federal partners to establish connections between land-use practices, application and deposition of nutrients on the land surface, erosion of sediment and runoff of nutrient-bearing water from the land surface, and the appearance of these constituents in waters reaching the bay. Simultaneously, states in the Chesapeake Bay watershed have been involved in meeting requirements related to Total Maximum Daily Loads (TMDLs) that are mandated under the Clean Water Act. Watershed process models and other quantitative tools are a necessary aspect of the TMDL process.

The U.S. Geological Survey (USGS), the CBP, along with the Interstate Commission on the Potomac River Basin, the Maryland Department of the Environment (MDE), the Virginia Department of Conservation and Recreation, and the University of Maryland Center for Environmental Science are collaborating on the Chesapeake Bay Regional Watershed Model (CBRWM)[3]. To meet the multiple needs of the participating agencies, the model region has been extended outside of the Chesapeake Bay watershed to include the adjacent parts of Maryland, Delaware, and Virginia, as well as parts of North Carolina and Tennessee (fig. 1). A well-documented model, Hydrological Simulation Program–FORTRAN (HSPF) (Bicknell and others, 1996; Donigian and others, 1995) is being used to simulate streamflow as well as concentrations and loads of nutrients and sediment. Many modifications to the normal use of the HSPF model have been made, including adaptations to allow for time-varying land use and Best Management Practices (BMPs), flexible input-file creation, and a variety of post-processing and analytical tools (G. Shenk, U.S. Environmental Protection Agency Chesapeake Bay Program Office, written commun., 2001). The current CBRWM is more spatially refined and flexible than the previous version of the model (U.S. Environmental Protection Agency Chesapeake Bay Program Office, 1998).

A first step in model development was the discretization of the model region into individual land segments for which simulations could be performed assuming homogeneity of physical parameters, driving forces (such as precipitation), and nutrient application rates. A second step was to create a network of stream reaches and associated watersheds that could receive simulated water and chemicals from the land simulation and ultimately route them to the bay.

[3] The Chesapeake Bay Regional Watershed Model is referred to by the CBP as the Phase 5 Watershed Model, in reference to its predecessor, the Phase 4.3 Chesapeake Bay Watershed Model.

Unlike in conventional HSPF model application, it is not necessary for the simulated land segments and watersheds to have identical boundaries under the CBRWM software design (G. Shenk, U.S. Environmental Protection Agency Chesapeake Bay Program Office, written commun., 2001). The land areas created by the intersection of land segments and watersheds, referred to as "land-watershed segments," are generated within a geographic information system (GIS). A software module external to HSPF allows the model to deliver the per-acre loads for a given land-use category, multiplied by the number of acres of that land use within a land-watershed segment, to the associated stream reach (fig. 2).

Purpose and Scope

This report describes the approach and methods used to create land segments and a stream-reach network with associated watersheds for the CBRWM, including the Chesapeake Bay watershed and the adjacent parts of Maryland, Virginia, and Delaware. The methods that were used to develop spatial datasets are described, as well as a number of approaches for quality-assuring the spatial data. Finally, maps of the land segments, stream-reach networks, and watersheds are provided.

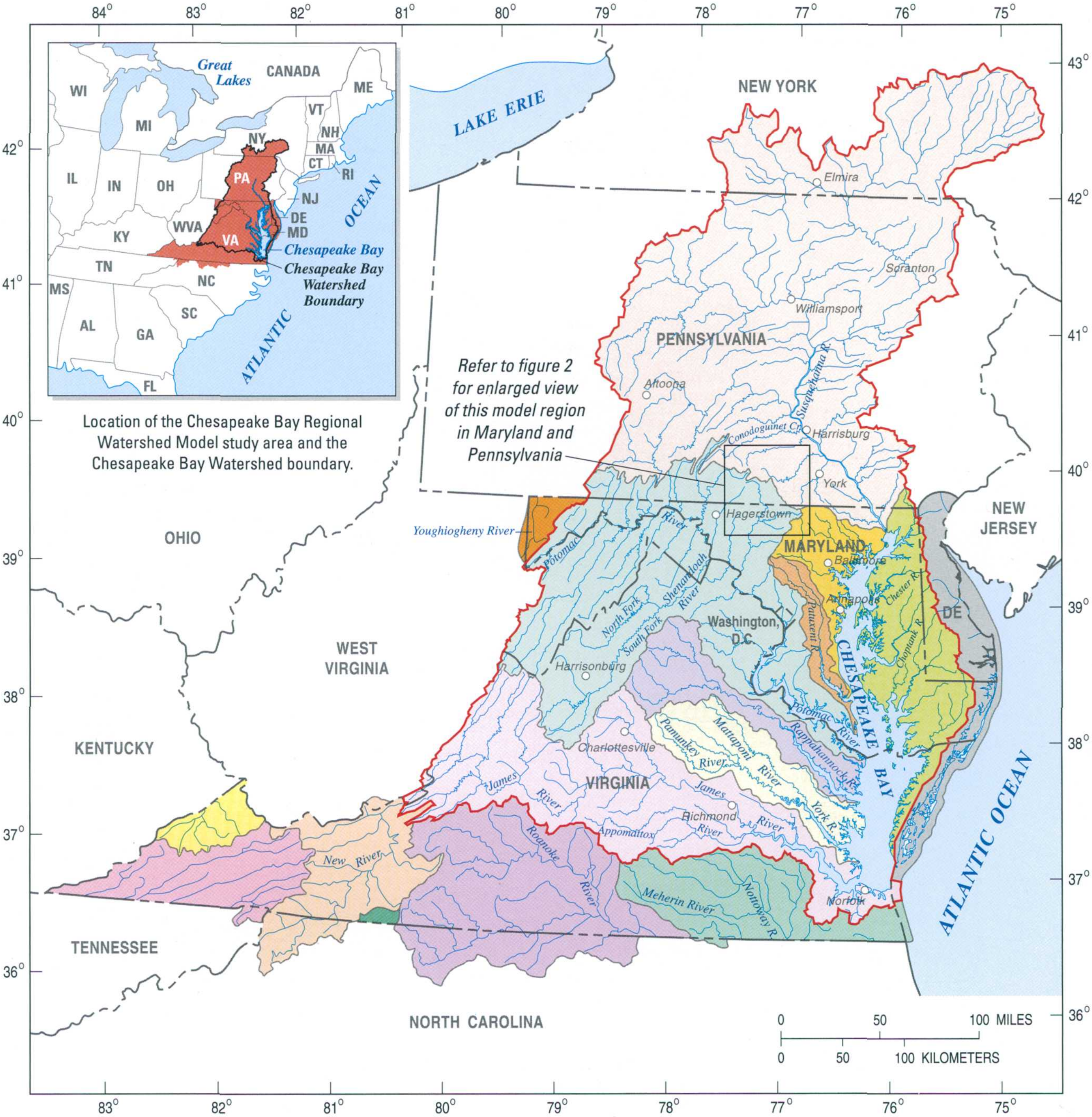
Description of Study Area

The study area for the model included the 64,000-mi^2 (square mile) Chesapeake Bay watershed, as well as the adjacent parts of the States of Maryland, Delaware, and Virginia. Additionally, various watersheds in West Virginia, Tennessee, and North Carolina were included because they contain tributaries that drain to the study area, for a total of 93,000 mi^2 of simulated drainage area (fig. 1). The watersheds of stream reaches flowing out of the study area end at state boundaries because they are not simulated for in-stream processes, but are simulated for land-surface processes.

The Chesapeake Bay watershed includes parts of New York, Pennsylvania, Maryland, Delaware, West Virginia, Virginia, and the District of Columbia. Major tributaries that drain the watershed are the Susquehanna, Potomac, and James Rivers. Smaller tributaries include the Rappahannock, Patuxent, and York Rivers (fig. 1).

The Virginia watersheds that drain outside of the Chesapeake Bay watershed include parts of the Big Sandy, Meherin, Nottoway, New, Roanoke, and Upper Tennessee River watersheds. The western Maryland watershed that drains outside of the Chesapeake Bay watershed is part of the Youghiogheny River watershed. The study area also includes the Delaware watersheds that drain to Delaware Bay, and the coastal areas of Maryland, Delaware, and Virginia that drain to the Atlantic Ocean.

The model region ranges in elevation from sea level (NAVD 88) to almost 4,000 ft (feet). The physiography is variable, and covers parts of the Coastal Plain, Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau Physiographic Provinces.



EXPLANATION

CHESAPEAKE BAY WATERSHED BOUNDARY

STREAM-REACH NETWORK

MAJOR DRAINAGE AREAS WITHIN THE CHESAPEAKE BAY WATERSHED

- SUSQUEHANNA RIVER
- WESTERN SHORE
- PATUXENT RIVER
- POTOMAC RIVER
- RAPPAHANNOCK RIVER
- YORK RIVER
- JAMES RIVER
- EASTERN SHORE

MAJOR DRAINAGE AREAS OUTSIDE OF THE CHESAPEAKE BAY WATERSHED

- DELMARVA (ATLANTIC)
- YOUGHIOGHENY RIVER
- ROANOKE RIVER
- TENNESSEE UPPER
- MEHERIN AND NOTTOWAY RIVERS
- NEW RIVER
- BIG SANDY RIVER
- YADKIN RIVER

Figure 1. The region included in the Chesapeake Bay Regional Watershed Model and the stream-reach network, highlighting major drainage areas.

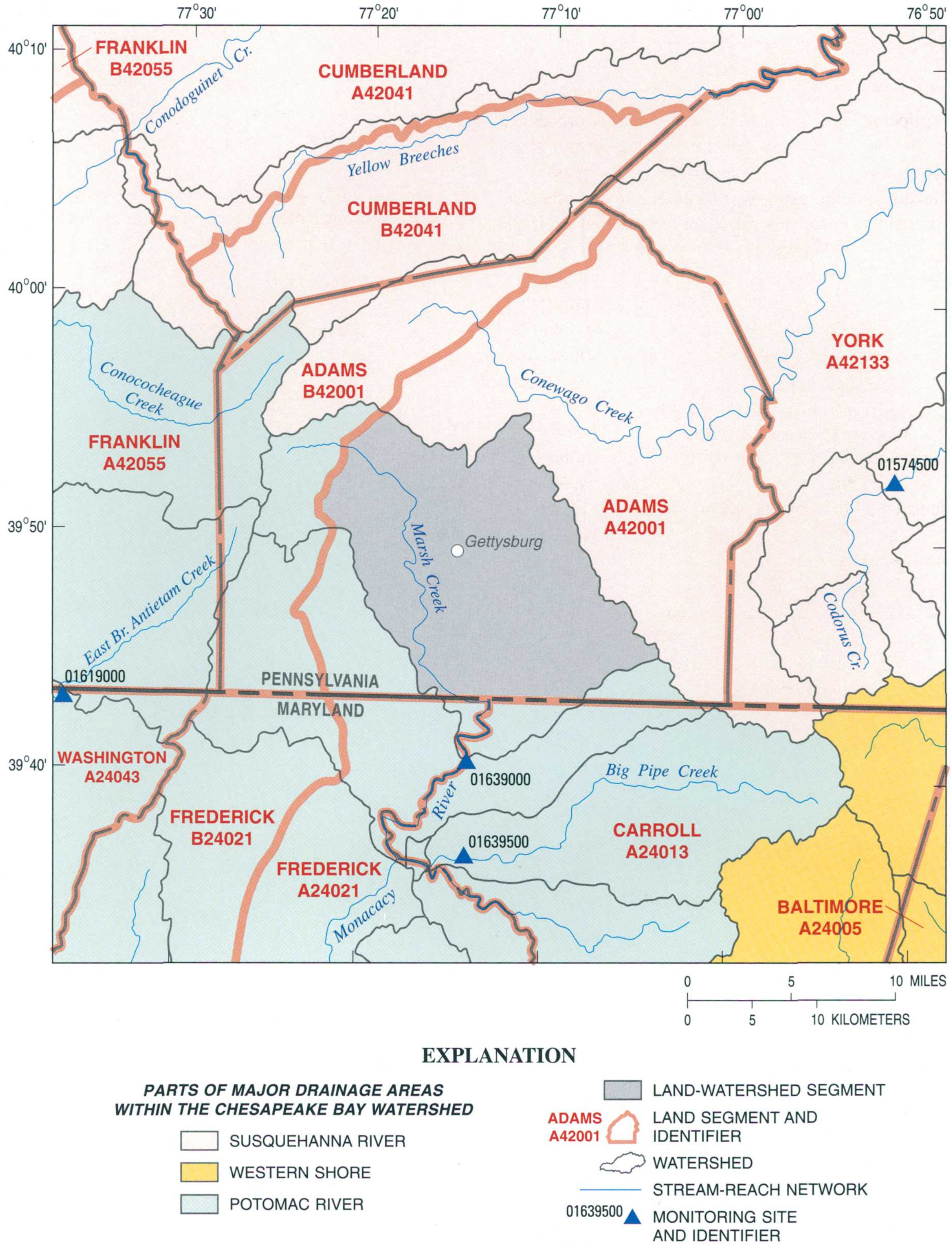


Figure 2. Part of the model region in Maryland and Pennsylvania and the relation between model land segments, watersheds, and stream reaches. (The land-watershed segment shown in gray includes the part of eastern Adams County, Pennsylvania that drains to Marsh Creek.)

Overview of the Hydrological Simulation Program–FORTRAN (HSPF)

The CBRWM uses HSPF to simulate flow, sediment transport, temperature variations, and water-quality processes over the entire hydrologic cycle. Processes controlling water flow and chemical constituent concentrations are represented at various levels of detail using HSPF (Donigian and others, 1995). Two distinct sets of processes are represented in HSPF: (1) processes that determine the fate and transport of water, sediment, and chemical constituents at or below the land surface for pervious areas, and at the land surface for impervious areas; and (2) in-stream processes that determine the fate and transport of water, sediment, and chemical constituents within stream reaches or reservoirs.

HSPF is a lumped (not spatially explicit) model that simulates water, sediment, and chemical mass balance within land areas as a series of storages with flows between the storages determined by empirical (constitutive) relations. A model region is subdivided into land segments, which are defined as areas with similar hydrologic characteristics. Within a land segment, multiple land-use types can be simulated, each using different modules and different model parameters.

Simulated chemical and sediment loads from land segments before they are transported to a stream reach are referred to as "edge-of-stream" loads. Loads are computed for a spatial unit of 1 acre. In the CBRWM approach, the areas of interest are the intersection between land segments and watersheds, referred to as "land-watershed segments" (fig. 2). To determine the total load for a land-watershed segment at each time step, the per-acre edge-of-stream load for a given land use is multiplied by the number of acres of that land use in the land-watershed segment. This process is repeated for each land use that occurs within the land-watershed segment, and the results are added to give the total load for that land-watershed segment. This load is then delivered to the associated stream reach for the second simulation step involving transport within the reach.

Land Segmentation Development

The Phase 4.3 Chesapeake Bay Watershed Model (U.S. Environmental Protection Agency Chesapeake Bay Program Office, 1998) uses land and water segments that are coincident and roughly equal to 8-digit USGS hydrologic unit codes (HUCs) (U.S. Geological Survey, 2004b). Many datasets that are used in Phase 4.3 and are also used in the CBRWM are only available by county. The CBRWM uses county boundaries as the basis for land segmentation.

A 1:100,000-scale county boundary digital dataset developed by USGS (U.S. Department of Commerce Bureau of Census, 1993) was used for the basis of the land segmentation because it is a continuous dataset and available for the entire study area. The county dataset was updated to include U.S. Census Bureau changes (U.S. Census Bureau Geography Division, 2004). Takoma Park was added to Montgomery County from Prince Georges County in Maryland, and Manassas Park annexed part of Prince William County in Virginia. Also, the cities of Clifton Forge and South Boston in Virginia were changed to town status and added to Alleghany and Halifax Counties, respectively.

In the Valley and Ridge and Blue Ridge Physiographic Provinces, orographic effects can create appreciable differences in precipitation within a county. As a result, the assumption of homogeneity of parameters and forcing functions within a land segment may not be valid. In addition, a central goal of the modeling effort is to refine spatial resolution where possible. For these reasons, physiography and topography were used to divide areas of high elevation (ridges) and low elevation (valleys) for 50 of the 254 counties within the model region. Hydrogeomorphic Regions (HGMRs) (Brakebill and Kelley, 2000), USGS 1:2,000,000-scale physiographic provinces of Virginia (U.S. Geological Survey, 1980), and National Elevation Dataset (NED) Digital Elevation Model (DEM) data (U.S. Geological Survey, 2001) were used as a guide to divide counties. This procedure produced a total of 309 land segments.

The basis for creating a unique identification system for the land segments is the 5-digit Federal Information Processing Standards (FIPS) Codes (U.S. Census Bureau Geography Division, 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; for counties that were divided, a 'B' was added; and in five cases, where counties were divided twice, a 'C' was placed before the FIPS code. The concatenation of these alphanumeric characters created unique land-segment identifiers (fig. 3) (table 1).

Stream-Reach Network Development

A stream-reach network was developed to provide the basis for watershed delineation and to provide connectivity between upstream and downstream watersheds in the study area. HSPF simulates processes within land segments and stream reaches separately and sequentially. At each time step, water flow and sediment and chemical loads for land segments are calculated. Those quantities are then provided as input to the stream-reach simulation. The stream-reach simulation processes the water, sediment, and chemicals within each stream reach, and transports them to the next reach downstream. A complete HSPF model requires definition of land segments and stream reaches, with established connections between them. Watersheds define the land draining to each reach.

The requirements for a stream-reach network for the CBRWM were: maximum spatial consistency, inclusion of stream-reach length and mean streamflow attributes, a density that would provide approximately 1,000 stream reaches in the model region, and as much consistency as possible with other

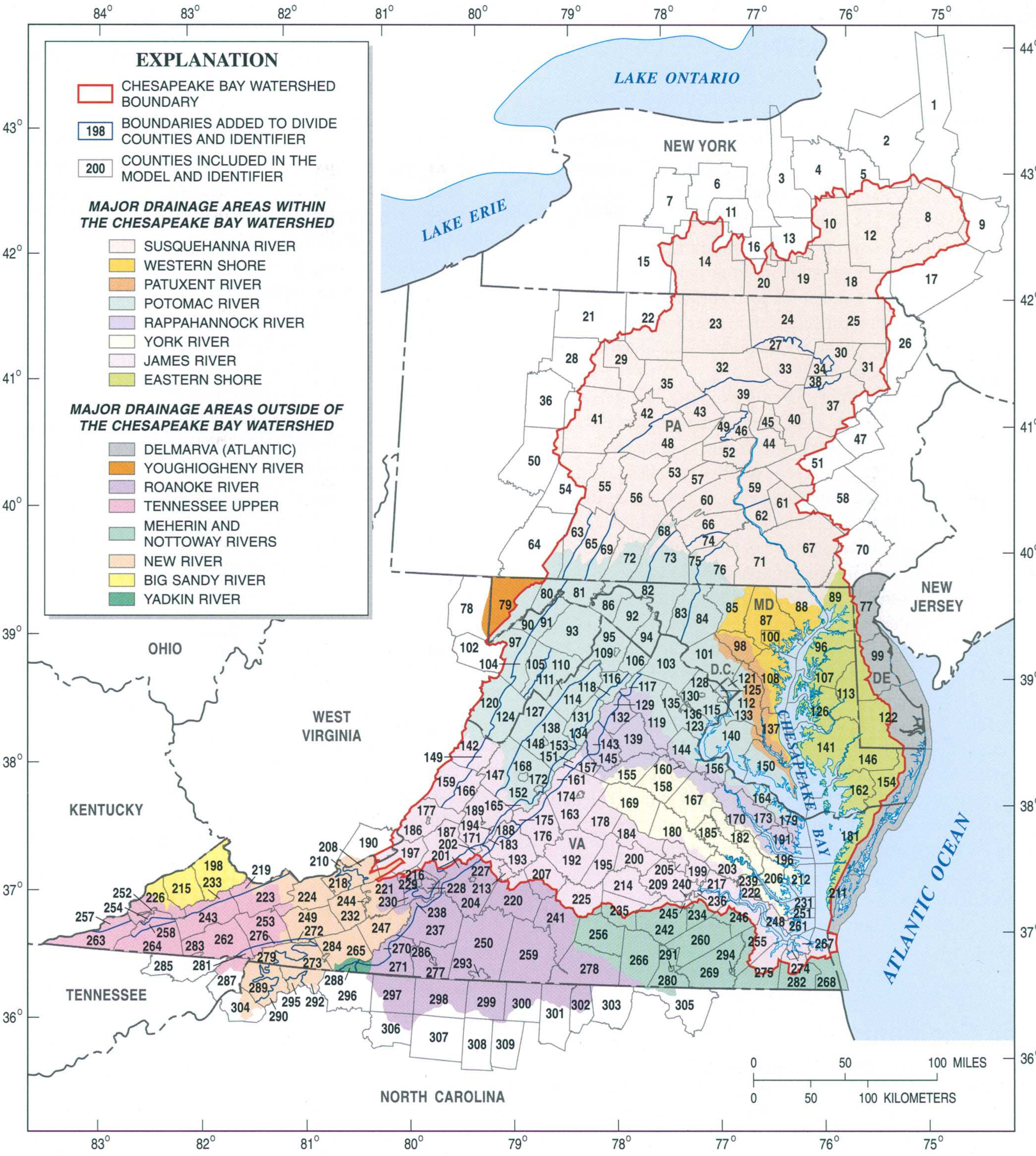


Figure 3. Land segmentation and county divisions for the Chesapeake Bay Regional Watershed Model. (Counties and county divisions have been labeled from 1 to 309. Refer to table 1 for the corresponding five-digit Federal Information Processing Standards [FIPS] codes.)

Table 1. Land segment numbers (from 1 to 309) and corresponding FIPS land segment identifiers. (Refer to figure 3).

[FIPS, Federal Information Processing Standards; land segment identifiers consist of an initial letter, 'A,' 'B,' or 'C,' indicating the subdivision of a county that has been split, and the 5-digit FIPS code. The FIPS code is unique for each state (first two digits) and county (last 3 digits).]

Land segment number	State	County/ Municipality	FIPS land segment identifier	Land segment number	State	County/ Municipality	FIPS land segment identifier
1	NY	Herkimer	A36043	**61**	PA	Lebanon	A42075
2	NY	Oneida	A36065	**62**	PA	Dauphin	B42043
3	NY	Cayuga	A36011	**63**	PA	Bedford	B42009
4	NY	Onondaga	A36067	**64**	PA	Somerset	A42111
5	NY	Madison	A36053	**65**	PA	Bedford	A42009
6	NY	Ontario	A36069	**66**	PA	Cumberland	A42041
7	NY	Livingston	A36051	**67**	PA	Lancaster	A42071
8	NY	Otsego	A36077	**68**	PA	Franklin	B42055
9	NY	Schoharie	A36095	**69**	PA	Bedford	C42009
10	NY	Cortland	A36023	**70**	PA	Chester	A42029
11	NY	Yates	A36123	**71**	PA	York	A42133
12	NY	Chenango	A36017	**72**	PA	Fulton	A42057
13	NY	Tompkins	A36109	**73**	PA	Franklin	A42055
14	NY	Steuben	A36101	**74**	PA	Cumberland	B42041
15	NY	Allegany	A36003	**75**	PA	Adams	B42001
16	NY	Schuyler	A36097	**76**	PA	Adams	A42001
17	NY	Delaware	A36025	**77**	DE	New Castle	A10003
18	NY	Broome	A36007	**78**	WV	Preston	A54077
19	NY	Tioga	A36107	**79**	MD	Garrett	A24023
20	NY	Chemung	A36015	**80**	MD	Allegany	B24001
21	PA	McKean	A42083	**81**	MD	Allegany	A24001
22	PA	Potter	A42105	**82**	MD	Washington	A24043
23	PA	Tioga	A42117	**83**	MD	Frederick	B24021
24	PA	Bradford	A42015	**84**	MD	Frederick	A24021
25	PA	Susquehanna	A42115	**85**	MD	Carroll	A24013
26	PA	Wayne	A42127	**86**	WV	Morgan	A54065
27	PA	Bradford	B42015	**87**	MD	Baltimore	A24005
28	PA	Elk	A42047	**88**	MD	Harford	A24025
29	PA	Cameron	A42023	**89**	MD	Cecil	A24015
30	PA	Wyoming	A42131	**90**	WV	Mineral	A54057
31	PA	Lackawanna	A42069	**91**	WV	Mineral	B54057
32	PA	Lycoming	A42081	**92**	WV	Berkeley	A54003
33	PA	Sullivan	A42113	**93**	WV	Hampshire	A54027
34	PA	Wyoming	B42131	**94**	WV	Jefferson	A54037
35	PA	Clinton	A42035	**95**	VA	Frederick	A51069
36	PA	Jefferson	A42065	**96**	MD	Kent	A24029
37	PA	Luzerne	A42079	**97**	WV	Grant	A54023
38	PA	Luzerne	B42079	**98**	MD	Howard	A24027
39	PA	Lycoming	B42081	**99**	DE	Kent	A10001
40	PA	Columbia	A42037	**100**	MD	Baltimore City	A24510
41	PA	Clearfield	A42033	**101**	MD	Montgomery	A24031
42	PA	Centre	B42027	**102**	WV	Tucker	A54093
43	PA	Clinton	B42035	**103**	VA	Loudoun	A51107
44	PA	Northumberland	A42097	**104**	WV	Grant	B54023
45	PA	Montour	A42093	**105**	WV	Hardy	B54031
46	PA	Union	B42119	**106**	VA	Clarke	A51043
47	PA	Carbon	A42025	**107**	MD	Queen Annes	A24035
48	PA	Centre	A42027	**108**	MD	Anne Arundel	A24003
49	PA	Union	A42119	**109**	VA	Winchester	A51840
50	PA	Indiana	A42063	**110**	WV	Hardy	A54031
51	PA	Schuylkill	A42107	**111**	VA	Shenandoah	B51171
52	PA	Snyder	A42109	**112**	MD	Prince Georges	A24033
53	PA	Mifflin	A42087	**113**	MD	Caroline	A24011
54	PA	Cambria	A42021	**114**	VA	Shenandoah	A51171
55	PA	Blair	A42013	**115**	VA	Fairfax	A51059
56	PA	Huntingdon	A42061	**116**	VA	Warren	A51187
57	PA	Juniata	A42067	**117**	VA	Fauquier	B51061
58	PA	Berks	A42011	**118**	VA	Warren	B51187
59	PA	Dauphin	A42043	**119**	VA	Fauquier	A51061
60	PA	Perry	A42099	**120**	WV	Pendleton	B54071

Table 1. Land segment numbers (from 1 to 309) and corresponding FIPS land segment identifiers. (Refer to figure 3).—Continued

[FIPS, Federal Information Processing Standards; land segment identifiers consist of an initial letter, 'A,' 'B,' or 'C,' indicating the subdivision of a county that has been split, and the 5-digit FIPS code. The FIPS code is unique for each state (first two digits) and county (last 3 digits).]

Land segment number	State	County/ Municipality	FIPS land segment identifier	Land segment number	State	County/ Municipality	FIPS land segment identifier
121	DC	District of Columbia	A11001	181	VA	Accomack	A51001
122	DE	Sussex	A10005	182	VA	King and Queen	A51097
123	VA	Prince William	A51153	183	VA	Rockbridge	B51163
124	WV	Pendleton	A54071	184	VA	Goochland	A51075
125	VA	Arlington	A51013	185	VA	King William	A51101
126	MD	Talbot	A24041	186	VA	Covington	A51580
127	VA	Rockingham	B51165	187	VA	Botetourt	A51023
128	VA	Falls Church	A51610	188	VA	Amherst	B51009
129	VA	Rappahannock	B51157	189	VA	Lexington	A51678
130	VA	Fairfax City	A51600	190	WV	Monroe	A54063
131	VA	Page	A51139	191	VA	Lancaster	A51103
132	VA	Rappahannock	A51157	192	VA	Buckingham	A51029
133	VA	Alexandria	A51510	193	VA	Amherst	A51009
134	VA	Page	B51139	194	VA	Buena Vista	A51530
135	VA	Manassas Park	A51685	195	VA	Cumberland	A51049
136	VA	Manassas	A51683	196	VA	Middlesex	A51119
137	MD	Calvert	A24009	197	VA	Craig	A51045
138	VA	Rockingham	A51165	198	VA	Buchanan	A51027
139	VA	Culpeper	A51047	199	VA	Henrico	A51087
140	MD	Charles	A24017	200	VA	Powhatan	A51145
141	MD	Dorchester	A24019	201	VA	Bedford	A51019
142	VA	Highland	A51091	202	VA	Botetourt	B51023
143	VA	Madison	B51113	203	VA	New Kent	A51127
144	VA	Stafford	A51179	204	VA	Bedford	B51019
145	VA	Madison	A51113	205	VA	Richmond	A51760
146	MD	Wicomico	A24045	206	VA	Gloucester	A51073
147	VA	Augusta	C51015	207	VA	Appomattox	A51011
148	VA	Harrisonburg	A51660	208	VA	Giles	A51071
149	VA	Highland	B51091	209	VA	Chesterfield	A51041
150	MD	St. Marys	A24037	210	VA	Giles	B51071
151	VA	Greene	B51079	211	VA	Northampton	A51131
152	VA	Augusta	A51015	212	VA	Mathews	A51115
153	VA	Rockingham	C51165	213	VA	Lynchburg	A51680
154	MD	Worcester	A24047	214	VA	Amelia	A51007
155	VA	Orange	A51137	215	VA	Dickenson	A51051
156	VA	King George	A51099	216	VA	Roanoke	A51161
157	VA	Greene	A51079	217	VA	Charles City	A51036
158	VA	Spotsylvania	A51177	218	VA	Giles	C51071
169	VA	Bath	A51017	219	VA	Tazewell	B51185
160	VA	Fredericksburg	A51630	220	VA	Campbell	A51031
161	VA	Albemarle	B51003	221	VA	Montgomery	A51121
162	MD	Somerset	A24039	222	VA	James City	A51095
163	VA	Albemarle	A51003	223	VA	Tazewell	A51185
164	VA	Westmoreland	A51193	224	VA	Bland	A51021
165	VA	Augusta	B51015	225	VA	Prince Edward	A51147
166	VA	Bath	B51017	226	VA	Wise	A51195
167	VA	Caroline	A51033	227	VA	Bedford	A51515
168	VA	Staunton	A51790	228	VA	Roanoke	A51770
169	VA	Louisa	A51109	229	VA	Salem	A51775
170	VA	Essex	A51057	230	VA	Roanoke	B51161
171	VA	Rockbridge	A51163	231	VA	York	A51199
172	VA	Waynesboro	A51820	232	VA	Pulaski	A51155
173	VA	Richmond	A51159	233	VA	Russell	B51167
174	VA	Charlottesville	A51540	234	VA	Prince George	A51149
175	VA	Nelson	B51125	235	VA	Nottoway	A51135
176	VA	Nelson	A51125	236	VA	Hopewell	A51670
177	VA	Alleghany	A51005	237	VA	Franklin	A51067
178	VA	Fluvanna	A51065	238	VA	Franklin	B51067
179	VA	Northumberland	A51133	239	VA	Williamsburg	A51830
180	VA	Hanover	A51085	240	VA	Colonial Heights	A51570

Table 1. Land segment numbers (from 1 to 309) and corresponding FIPS land segment identifiers. (Refer to figure 3).—Continued

[FIPS, Federal Information Processing Standards; land segment identifiers consist of an initial letter, 'A,' 'B,' or 'C,' indicating the subdivision of a county that has been split, and the 5-digit FIPS code. The FIPS code is unique for each state (first two digits) and county (last 3 digits).]

Land segment number	State	County/ Municipality	FIPS land segment identifier	Land segment number	State	County/ Municipality	FIPS land segment identifier
241	VA	Charlotte	A51037	**276**	VA	Smyth	B51173
242	VA	Dinwiddie	A51053	**277**	VA	Henry	A51089
243	VA	Russell	A51167	**278**	VA	Mecklenburg	A51117
244	VA	Radford	A51750	**279**	VA	Grayson	B51077
245	VA	Petersburg	A51730	**280**	VA	Greensville	A51081
246	VA	Surry	A51181	**281**	VA	Washington	B51191
247	VA	Floyd	A51063	**282**	VA	Chesapeake	A51550
248	VA	Newport News	A51700	**283**	VA	Bristol	A51520
249	VA	Wythe	A51197	**284**	VA	Galax	A51640
250	VA	Pittsylvania	A51143	**285**	TN	Sullivan	A47163
251	VA	Poquoson	A51735	**286**	VA	Martinsville	A51690
252	VA	Norton	A51720	**287**	TN	Johnson	A47091
253	VA	Smyth	A51173	**288**	VA	Carroll	B51035
254	VA	Scott	C51169	**289**	NC	Ashe	A37009
255	VA	Isle of Wight	A51093	**290**	NC	Ashe	B37009
256	VA	Lunenburg	A51111	**291**	VA	Emporia	A51595
257	VA	Lee	B51105	**292**	NC	Alleghany	B37005
258	VA	Scott	B51169	**293**	VA	Danville	A51590
259	VA	Halifax	A51083	**294**	VA	Franklin	A51620
260	VA	Sussex	A51183	**295**	NC	Alleghany	A37005
261	VA	Hampton	A51650	**296**	NC	Surry	A37171
262	VA	Washington	A51191	**297**	NC	Stokes	A37169
263	VA	Lee	A51105	**298**	NC	Rockingham	A37157
264	VA	Scott	A51169	**299**	NC	Caswell	A37033
265	VA	Carroll	A51035	**300**	NC	Person	A37145
266	VA	Brunswick	A51025	**301**	NC	Granville	A37077
267	VA	Norfolk	A51710	**302**	NC	Vance	A37181
268	VA	Virginia Beach	A51810	**303**	NC	Warren	A37185
269	VA	Southampton	A51175	**304**	NC	Watauga	A37189
270	VA	Patrick	B51141	**305**	NC	Northampton	A37131
271	VA	Patrick	A51141	**306**	NC	Forsyth	A37067
272	VA	Wythe	B51197	**307**	NC	Guilford	A37081
273	VA	Grayson	A51077	**308**	NC	Alamance	A37001
274	VA	Portsmouth	A51740	**309**	NC	Orange	A37135
275	VA	Suffolk	A51800				

[1] U.S. Census Bureau Geography Division, 2003.

regional models, especially the Chesapeake Bay SPARROW (SPAtially Referenced Regressions On Watershed attributes) model (Preston and Brakebill, 1999). The first step in developing a stream-reach network was to compile information about available digital stream-reach datasets to determine if they met these requirements.

National digital stream-reach network datasets are available at the 1:100,000 scale [River Reach File 3 (RF3) (U.S. Environmental Protection Agency, 1994)] and 1:500,000 scale [Enhanced River Reach File 1 (ERF1) (Alexander and others, 1999; U.S. Environmental Protection Agency, 1996)]. RF3 is more spatially detailed than ERF1, however, the stream density in both datasets is not consistent across the region. RF3 does not have necessary attributes; therefore, it was not used as the basis for the model stream-reach network. ERF1 contains the attributes of stream-reach length and mean streamflow that are not contained in RF3, but is less accurate than RF3. For this reason, it was not used as the basis for the model stream-reach network throughout the entire model region either.

A stream-reach network for the Chesapeake Bay watershed was developed for the SPARROW model (Preston and Brakebill, 1999) using synthetic stream reaches derived from 30-m (meter) DEM data; attributes from ERF1 were associated with the SPARROW stream reaches (Brakebill and others, 2001). The SPARROW stream-reach network meets most of the requirements for the CBRWM stream-reach network, except that it does not cover the entire model region. Therefore, it was used as the basis for the stream-reach network for the Chesapeake Bay watershed part of the model region; the rest of the model region is based on the ERF1 stream reaches (fig. 1). Both datasets have the attributes needed for the model (stream-reach length and mean streamflow), and are of similar scale.

A number of changes were made to the combined SPARROW/ERF1 stream-reach network for use in the CBRWM to satisfy the remaining requirements of spatial consistency while providing approximately 1,000 reaches in the model region. Because of the stream density, using the SPARROW stream-reach network would have created over 1,400 watersheds within the Chesapeake Bay watershed alone, far more than could be reasonably simulated. To reduce the number of watersheds, an attribute quantifying the mean streamflow was used to eliminate reaches with mean streamflow less than 100 ft^3/s (cubic feet per second). This process also created a consistent criterion for stream density across the different digital datasets.

Additional changes were made to allow for inclusion of stream reaches that were not part of the original network. Some stream reaches, which were originally excluded because of mean streamflow less than 100 ft^3/s, were re-added to the network if a monitoring site with adequate streamflow or water-quality data could be associated with the stream reach. If a stream reach that was not part of the SPARROW or ERF1 stream-reach network included a monitoring site, the appropriate RF3 stream reach was added.

Nutrient, sediment, and streamflow-monitoring data are essential to the calibration of a watershed model. Information on sites with available monitoring data was used to modify the stream-reach network design, as described previously. The goal in site selection was to include as many sites as possible with a streamflow record meeting specified criteria (described below), or sufficient water-quality data for model calibration.

The USGS National Water Information System Web Site (NWISWeb) (http://waterdata.usgs.gov/nwis) was used to retrieve a list of USGS streamgaging stations in Maryland, Delaware, the District of Columbia, New York, Pennsylvania, Virginia, West Virginia, and North Carolina with mean-daily streamflow data from October 1, 1984 through December 31, 2000. The latitudes and longitudes of the stations and the station identification numbers from NWISWeb were used to create a spatial dataset. Stations outside the study area were removed from the dataset. NWISWeb data also were used to determine whether the stations had at least 8 years of total streamflow data within this period. Analysis of graphs of the streamflow data allowed stations that did not have at least 8 years of streamflow data to be removed from the dataset.

In most cases, USGS streamgaging stations were only used if they could be associated with the model stream-reach network. Two stations that were not on a stream reach in the network were included because of their relatively large drainage areas (comparable in size to other simulated watersheds); the corresponding reaches were added to the network based on RF3. Three other stations were included that were on reaches with mean streamflow less than 100 ft^3/s because of the quantity of water-quality data available for those stations. Sixteen stations close to the bay that were on stream reaches without another station downstream were included even if they had a mean streamflow of less than 100 ft^3/s. A total of 292 USGS streamgaging stations that met the criteria for inclusion were eventually identified.

In the Potomac River watershed, 12 MDE TMDL sites were added because of the quantity of water-quality data available. Their associated stream reaches were then re-added to the network from the SPARROW stream-reach network, if available, or from RF3. The total number of sites in the study area with streamflow- and/or water-quality monitoring data used for model calibration is 304 (plate 1).

Watershed Delineation

In this report, the term "watershed" is used to represent the area of land draining to a stream reach. A stream reach consists of a length of stream with two endpoints–an endpoint may be the tidal estuary, a confluence within the stream-reach network, a reservoir, a monitoring site, the headwater of a stream, or in a few cases, a point corresponding to a state watershed boundary. Drainage areas are defined using surface topography, and it is assumed (as in HSPF in general) that the surface-water divides and ground-water divides are coincident.

Separate watersheds are needed for all stream reaches being modeled.

A 30-m-resolution flow-direction raster dataset was generated from the NED DEM (with a vertical resolution in decimal-meters) and used to delineate watersheds for each stream reach. This dataset was not available when the SPARROW stream-reach network was created. That network was created from preliminary NED data with a vertical resolution of integer-meters, which caused some problems when creating watersheds because stream reaches were derived from the older dataset, and flow direction was derived from the newer dataset. Similar problems were encountered for the stream-reach network outside the Chesapeake Bay watershed, because the stream-reach network for this area was created from ERF1 stream reaches. Because the ERF1 stream reaches were not delineated from a DEM, there were additional discrepancies in the watershed boundaries. The methods used to address these discrepancies are discussed in the Quality Assurance of Watershed Boundaries section.

The CBRWM has multiple objectives, and was designed by various Federal, State, and local agencies. In order to meet some of the objectives, the watershed boundaries available from the states were used in place of the DEM watershed boundaries where they coincided (Hoffman and Kernan, 1996; Maryland Department of Natural Resources, 1998; U.S. Department of Agriculture Natural Resources Conservation Service, 1998; U.S. Department of Agriculture Natural Resources Conservation Service Tennessee, 2000; U.S. Environmental Protection Agency Chesapeake Bay Program Office, 1999; Upper Susquehanna Coalition and others, 2002; Virginia Department of Conservation and Recreation - DSWC, 1995; H. Mirsajadi, Delaware Department of Natural Resources and Environmental Control, written commun., 2005). State watersheds were used in areas outside the Chesapeake Bay watershed where DEMs had not been used to create watersheds. The DEM watershed boundaries were used at monitoring sites and at all other stream-reach endpoints where no state watershed boundaries existed.

Watershed boundaries also were created for reservoir outlets. There are 42 reservoirs in the model region that are simulated; these were selected on the basis of size, purpose, or use as a county or city water supply. If a monitoring site was located 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 based on RF3 and 1:24,000-scale Digital Raster Graphics (DRG) (U.S. Geological Survey, 2004a). Where large reservoirs spanned several watersheds, those watersheds were combined into one.

A number of short stream reaches were formed because of the distance between confluences or the location of monitoring sites. As a result, a number of small watersheds were produced. Because of possible numerical stability issues, excessive computational effort, and the difficulty in capturing processes accurately at a small scale within a regional model, small watersheds that represented 5 percent or less of the upstream drainage area were incorporated into an adjacent watershed.

Each watershed has 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 region. There are 672 watersheds with simulated reaches that drain to a simulated downstream reach. There are 66 watersheds with simulated reaches that drain directly to the Chesapeake Bay or a tidal stream reach that is not simulated; they have a DSID equal to one. There are 324 watersheds that do not include a simulated reach; these watersheds have a DSID equal to zero. Many of these are the result of subdivision to facilitate the linking of the watershed model output to the CBP water-quality model; the boundaries for this subdivision are based on state watershed boundaries. Watersheds with a DSID equal to zero are in tidal areas, drain directly (through subsurface discharge or ephemeral surface runoff) to tidal stream reaches or the estuary, or drain to areas outside of the study area and are truncated at state boundaries.

A number of watershed divides within the District of Columbia were adjusted to account for Combined Sewer Overflows (T. Spano, Metropolitan Washington Council of Governments, written commun., 2005). In most areas with sewer systems that combine storm runoff with wastewater before treatment, these systems may overflow without treatment when storm runoff exceeds their capacity. These overflows are generally not measured and their drainage areas may be different from those that are defined or delineated topographically. The affected area was given a DSID of four (plate 1). The total number of watersheds in the model region is 1,063.

Each watershed within the entire Chesapeake Bay watershed is associated with a two-letter code identifying its major and minor basin (table 2); watersheds outside the Chesapeake Bay watershed were given a two-letter code identifying the major basin. The relative size of the stream reach and volume of water transported is represented by a 1-digit numerical value calculated from the mean streamflow value in the ERF1 dataset. This value is calculated as $3[log(mean\ streamflow)] - 5$ and is rounded to the nearest positive integer. The value ranges from zero to 9. For reaches that have a mean streamflow value of zero or 99999 (unknown value), a value of zero was assigned.

The major and minor basin codes, stream-reach size based on 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 stream reach size equal to 2, a UNIQID of 1100 and a DSID of 1130.

Quality Assurance of Watershed Boundaries

To ensure the creation of an acceptable digital watershed boundary dataset for the model region, extensive quality assurance was performed. This quality assurance was a complex

Table 2. Two-letter code identifying basins used in the creation of the watershed identifiers for the Chesapeake Bay Regional Watershed Model.

	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 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 Maury River confluence
JL	Lower James River, below Maury River confluence, above Richmond, Virginia
JA	Appomattox River
JB	James River below Richmond, Virginia, not including Appomattox River
	York River Basin
YP	Pamunkey River
YM	Mattaponi River
YL	York River below Mattaponi and Pamunkey confluence, including 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 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 Choptank River
	Areas Outside of Chesapeake Bay Watershed
GY	Part of Youghiogheny River
DE	Delmarva (Atlantic)
TU	Part of Upper Tennessee River
BS	Part of Big Sandy River
NR	Part of New River
OD	Dan River, tributary of Roanoke River
OR	Part of Roanoke River, not including Dan River
MN	Meherin and Nottoway Rivers

process, involving multiple data sources from six states. The quality-assurance process involved comparing data sources, checking individual watersheds to ensure they were representative of the actual drainage areas, and ensuring that the watersheds met all criteria specified.

Watershed boundaries derived from DEMs were used where state watershed boundaries were not available, as was the case at most monitoring sites. The stream reaches and watersheds were created from different DEM sources, preliminary low-resolution NED, and higher-resolution NED, respectively. One inaccuracy resulted from incorrect delineation of stream channels, which placed them outside of topographic low points. Subsequently, watershed boundaries delineated from the high-resolution NED would follow a parallel path to the streams. These boundaries were corrected by manual delineation and digitizing using 1:24,000-scale DRGs and the RF3 stream-reach network as guides for the topology and dendritic patterns.

Another inaccuracy was discovered regarding the representation of stream confluences. The stream-reach network is composed of line segments of zero width, so it does not take into account variations in actual stream width. This simplified representation of streams sometimes caused the intersections of streams to be represented far downstream of the actual confluences, which produced inaccurate watershed boundaries near these confluences. These boundaries also were corrected by manual delineation and digitizing using 1:24,000-scale DRGs and the RF3 stream-reach network as guides for the topology and dendritic patterns.

Intersection of Land Segments and Watersheds

In the CBRWM, the land simulation and the river simulation are run separately. In order to link the two simulations, the common area between land segments and watersheds needed to be determined. The land segments and watersheds were combined to create a new spatial dataset, referred to as "land-watershed segments." In the CBRWM, nutrient and sediment loads from land-watershed segments are delivered to the associated stream reach.

Scale differences in datasets between the watershed boundaries and the land-segment boundaries created many small areas where the two boundaries repeatedly intersected. Along some ridges, for example, where a watershed boundary and a county boundary are intended to be coincident, many areas that do not need to be represented individually in the model were created. These areas are anomalies that are related to scale, and are not true land-watershed segments. A number of different size thresholds were examined for separating out these anomalies. The best spatial dataset resulted when areas less than 100 acres were merged into adjacent polygons, after the intersection of watersheds and land-segment boundaries.

The land-watershed segments are used to connect the land simulation with the river simulation. In order to distinguish between tidal water and inland surface-water bodies, the tidal shoreline was added to the land-watershed segmentation dataset. Watershed boundaries, the stream-reach network, and monitoring sites are shown in plate 1.

Summary

The U.S. Geological Survey, U.S. Environmental Protection Agency Chesapeake Bay Program Office, Interstate Commission on the Potomac River Basin, Maryland Department of the Environment, Virginia Department of Conservation and Recreation, and the University of Maryland Center for Environmental Science are collaborating on the Chesapeake Bay Regional Watershed Model, which will provide a quantitative tool for understanding nutrient and sediment transport and for managing resources in the region, including the Chesapeake Bay watershed, as well as the adjacent parts of Maryland, Delaware, and Virginia outside of the watershed. Excess nutrients and sediment affect the oxygen balance within the estuary, creating appreciable volumes of low-oxygen water seasonally in deeper parts of the bay. The first step in developing the model was the creation of digital spatial datasets describing the discretization of the model region into land segments, the creation of a stream-reach network, and the delineation of associated watersheds.

The study area for the model (93,000 square miles) includes the Chesapeake Bay watershed and adjacent parts of Maryland, Delaware, and Virginia, as well as various watersheds in West Virginia, Tennessee, and North Carolina that were included because they contain tributaries that drain to the study area. Land segmentation was based on a 1:100,000-scale county boundary digital dataset. Fifty of the 254 counties in the model region were divided once or twice on the basis of physiography and topography, producing a total of 309 land segments.

The U.S. Geological Survey Chesapeake Bay SPARROW model stream-reach network was used as the basis for the stream-reach network for the Chesapeake Bay watershed part of the model region. Because that network was created only for the Chesapeake Bay watershed, a 1:500,000-scale stream-reach network was used as the basis for the rest of the model region. To reduce the number of stream reaches modeled, most stream reaches with mean streamflow of less than 100 cubic feet per second were excluded. A small number of stream reaches that were not part of the original network were included in order to capture locations that had monitoring stations, were close to the bay, or were otherwise hydrologically important.

A 30-meter-resolution Digital Elevation Model was used to delineate watersheds for each stream reach. A quality-assurance process was followed for the delineated watersheds that involved comparing different data sources, checking individual watersheds to ensure they were representative of the actual drainage areas, and checking accuracy of watershed boundaries near stream confluences. After incorporating state

watershed boundaries and making a number of corrections, the watersheds were coded to indicate major and minor basin, mean streamflow, and each watershed's unique identifier as well as that of the downstream watershed. The land segments and watersheds were intersected to create land-watershed segments. These spatial data will be used in support of the Chesapeake Bay Regional Watershed Model.

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References Cited

Alexander, R.B., Brakebill, J.W., Brew, R.E., and Smith, R.A., 1999, Enhanced river reach file 1.2 (ERF1): U.S. Geological Survey Open-File Report 99-457, accessed November 16, 2004, at *http://water.usgs.gov/lookup/getspatial?erf1*

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., and Donigian, A.S., Jr., 1996, Hydrological Simulation Program–FORTRAN user's manual for Release 11: Athens, Georgia, U.S. Environmental Protection Agency, 755 p.

Brakebill, J.W., and Kelley, S.K., 2000, Hydrogeomorphic Regions in the Chesapeake Bay Watershed, Version 1: U.S. Geological Survey Open-File Report 00-424, accessed November 16, 2004, at *http://water.usgs.gov/lookup/getspatial?hgmr*

Brakebill, J.W., Preston, S.D., and Martucci, S.K., 2001, Digital data used to relate nutrient inputs to water quality in the Chesapeake Bay Watershed, version 2.0: Baltimore, Maryland: U.S. Geological Survey Open-File Report 01–251, 17 p.

Donigian, A.S., Jr., Bicknell, B.R., and Imhoff, J.C., 1995, Hydrological Simulation Program–FORTRAN (HSPF), *in* Singh, V.P., ed., Computer models of watershed hydrology: Highlands Ranch, Colorado, Water Resources Publications, p. 395–442.

Hoffman, S.A., and Kernan, J.T., 1996, Digital drainage basin boundaries of named streams in Pennsylvania: U.S. Geological Survey Open-File Report 96–354, accessed January 28, 2005, at *http://pa.water.usgs.gov/pa_digit.v2.html*

Maryland Department of Natural Resources, 1998, swshed12-Maryland's Third Order Watershed: Maryland Department of Natural Resources, accessed January 25, 2005, at *ftp://dnrftp.dnr.state.md.us/Public/SpatialData/Watershed/WShedBndry/swshed12.htm*

Preston, S.D., and Brakebill, J.W., 1999, Application of spatially referenced regression modeling for the evaluation of total nitrogen loading in the Chesapeake Bay Watershed: U.S. Geological Survey Water-Resources Investigations Report 99–4054, 12 p.

Sprague, L.A., Langland, M.J., Yochum, S.E., Edwards, R.E., Blomquist, J.D., Phillips, S.W., Shenk, G.W., and Preston, S.D., 2000, Factors affecting nutrient trends in major rivers of the Chesapeake Bay Watershed: U.S. Geological Survey Water-Resources Investigations Report 00–4218, 98 p.

U.S. Census Bureau Geography Division, 2003, Federal Information Processing Standards (FIPS) codes, accessed January 11, 2005, at *http://www.census.gov/geo/www/fips/fips.html*

U.S. Census Bureau Geography Division, 2004, Significant changes to counties and county equivalent entities: 1970–present, accessed November 19, 2004, at *http://www.census.gov/geo/www/tiger/ctychng.html*

U.S. Department of Agriculture Natural Resources Conservation Service, 1998, Hydrologic Units–North Carolina Subbasins: USDA Natural Resources Conservation Service, accessed March 3, 2005, at *http://cgia.cgia.state.nc.us:80/cgdb/huncsb.html*

U.S. Department of Agriculture Natural Resources Conservation Service, Tennessee, 2000, Watersheds (12 Digit HUC), 1st ed.: USDA Natural Resources Conservation Service, accessed March 3, 2005, at *http://www.tngis.org/watershed.html*

U.S. Department of Commerce Bureau of Census, 1993, 1:100,000-scale counties of the United States, Ed. 1.1: U.S. Geological Survey, accessed November 16, 2004, at *http://water.usgs.gov/lookup/getspatial?county100*

U.S. Environmental Protection Agency, 1983, Chesapeake Bay: A framework for action: Philadelphia, Pennsylvania, U.S. Environmental Protection Agency, 186 p.

U.S. Environmental Protection Agency, 1994, The USEPA Reach File version 3.0 alpha release (RF3-Alpha) technical reference, accessed November 16, 2004, at *http://www.epa.gov/waters/doc/techref.html*

U.S. Environmental Protection Agency, 1996, USEPA Reach File version 1.0 (RF1) for the conterminous United States (CONUS), accessed November 16, 2004, at *http://www.epa.gov/waters/doc/rf1_meta.html#Identification*

U.S. Environmental Protection Agency Chesapeake Bay Program Office, 1998, Chesapeake Bay Watershed model application and calculation of nutrient and sediment loadings, Appendix I: Model operations manual: Annapolis, Maryland, Chesapeake Bay Program, 102 p.

U.S. Environmental Protection Agency Chesapeake Bay Program Office, 1999, Chesapeake Bay Hydrologic Units, accessed January 27, 2005, at *ftp://ftp.chesapeakebay.net/pub/Geographic/MidAtlantic/Watersheds/Huc11/*

U.S. Environmental Protection Agency Chesapeake Bay Program Office, 2000, CHESAPEAKE 2000, accessed November 15, 2004, at *http://www.chesapeakebay.net/agreement.htm*

U.S. Geological Survey, 1980, Physiographic Provinces of Virginia: prov2m_ugs, GIS polygon coverage, 1:2,000,000 scale.

U.S. Geological Survey, 2001, National Elevation Dataset, accessed November 16, 2004, at *http://ned.usgs.gov/*

U.S. Geological Survey, 2004a, Digital Raster Graphics, accessed January 11, 2005, at *http://topomaps.usgs.gov/drg/*

U.S. Geological Survey, 2004b, Hydrologic Unit Maps, accessed January 11, 2005, at *http://water.usgs.gov/GIS/huc.html*

Upper Susquehanna Coalition, U.S. Geological Survey, U.S. Department of Agriculture, and Natural Resources Conservation Service, 2002, 11 digit hydrologic unit code-watershed boundaries for Upper Susquehanna River Watershed: Upper Susquehanna Coalition, accessed January 27, 2005, at *http://www.u-s-c.org/html/GIS_Data.htm*

Virginia Department of Conservation and Recreation-DSWC, 1995, Virginia's 14 digit hydrologic unit boundaries, 2nd ed.: Virginia Department of Conservation and Recreation–DSWC, 2004.

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