A Procedure for the Preliminary Assessment of

Water Supply Availability

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(ABSTRACT)

Of the factors that determine development potential in a given geographic area, the availability of water for residential, commercial, and industrial purposes is a primary indication of prospective growth. Governmental bodies at the regional, state and federal levels often need to identify water supply availability in order to identify growth potential.

To address this need, a procedure for the preliminary assessment of water supply availability has been developed that can potentially be applied to any geographic area in the United States. The procedure uses the USGS demand cataloging unit as the basic planning area, with supply estimates from streamflow parameters at USGS gage locations and demand estimates from USGS demand reports. By comparing known supply and demand estimates in a base year, an overview of water supply availability in the region can be determined.

With supply and demand data in a base year, projections of future water supply availability can then be made. Detailed projection of future water demand must account for changes in the amount of water use activities and the rates of water use within those activities, but a simplified procedure is applied here. Total offstream water use is averaged over the population in the base year to determine per-capita offstream use, which is assumed to remain constant in the future in this preliminary assessment procedure. Population is then projected and demand is forecast as a function of the projected population. The supply quantity is projected assuming each flow parameter derived from the historical record will remain constant in the future year. By comparing projected supply and demand estimates, water supply availability in future years can be anticipated in the planning area.

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1. Introduction

> "Water works for all of us in industry, power generation, mining, navigation, fisheries, farming and ranching, and in fulfilling municipal domestic needs. By accepting our place in the water cycle, we will secure a promising social and economic future for the generations that will follow us."[1]

Since the dawn of the city of Ur along the Tigris and Euphrates, water availability has driven the location of human population. Ancient Egypt settled nearly entirely along the banks of the Nile where water was readily available to sustain the trade, travel, food and other needs of the Egyptian civilization. As the evolving city began to attract larger populations and more industry, the human need for water to supply municipal and industrial needs rose as well. As human needs have risen and withdrawals from natural environments continue to increase, methodologies to characterize the interaction of human needs with natural water supplies have become increasingly important. Assessment of water supply availability must mirror the complexity of the interaction of water and humans if it is to be conducted with accuracy. However, need exists for preliminary assessments that are less data intensive and provide an overview of water supply availability across broad geographic areas.

The following report provides a discussion of the process for preliminary assessment of water supply availability. Chapter 2 identifies the general procedure and discusses the concepts and the assumptions associated with the development of the procedure. Chapter 3 illustrates the application of the procedure by demonstrating its use in the analysis of water supply availability in the Upper Roanoke planning area in

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[1] Robinson, S., D. Nelson, S. Higgins and M. Brody. "Water: A Gift of Nature." KC Publications, Inc., 1993, p. 47.

Virginia. Chapter 4 utilizes the general procedure in the specific context of 27 planning areas in the Commonwealth of Virginia. At the end of Chapter 4 are two case studies that discuss local issues across the Shenandoah River basin and between the municipalities in the Roanoke Valley. Chapter 5 summarizes the findings of the study and makes recommendations for related research in the future. The appendices include the data collected for the preliminary assessment of water supply availability in the Commonwealth of Virginia. The appendices include specific hydrologic unit data for small water sheds in Virginia by planning area, Arcview-GIS plates of Virginia's river basins and the study planning areas, USGS gage location and derived flow condition data by planning area, comprehensive supply estimates and projections by planning area, full population estimates and projections by planning area, complete USGS demand data by planning area in 1995, detailed total demand projections by planning area, water supply availability with and without instream demand, and a guide to published Virginia water supply information.

2. Procedure for Preliminary Assessment of Water Supply Availability

2.1 Introduction

The procedure for the preliminary assessment of water supply availability involves four steps: (1) defining planning area boundaries, (2) estimating supply in the base year and projecting likely supply in future years, (3) estimating demand in the base year and projecting likely demand in future years, and (4) comparing the water supply and demand estimates and projections. The procedure for preliminary assessment may serve as a framework study to provide a general understanding of potential water supply deficits and surpluses. Simplifying the water supply assessment allows elimination of details necessary when a comprehensive analysis of water supply availability is conducted.

2.1.1 The Hydrologic Cycle and the Water Balance

In the long term, the amount of water that can be removed from a natural watercourse or other source of supply cannot exceed the amount of water that will be replenished by the natural water cycle. Water does not disappear from the hydrologic cycle when it is borrowed from its natural course, but diversions of water do alter natural environments and the amount of water available in each environment. In order to assess the relationship between supply and demand, it is important to understand the natural cycle of water, the amount of water available for human development, and the amount of water presently used by human activities. The hydrologic cycle represents the interaction of water among all its phases on, above and below the Earth's surface. The water balance is a tool used to quantify hydrologic inputs to a particular area, transformations of water among the various components of the hydrologic cycle within the chosen area, human and environmental uses of water within the area, and outflow of water from the area.

2.1.1.1 The Hydrologic Cycle

> "The basic components of the hydrologic cycle include precipitation, evaporation, evapotranspiration, infiltration, overland flow, streamflow, and groundwater flow. The movement of water through various phases of the hydrologic cycle is erratic in time and space, giving rise to extremes of flood or drought."[2]

The hydrologic cycle characterizes the interaction of water stored as a gas in the atmosphere with water as a liquid on and below the land surface and with water as a solid in glaciers and snow accumulations (see Figure 2.1). It is distributed as follows:

Table 2.1: Abundance of water on a global scale.[3]

Oceans	97.2%
Ice caps and glaciers	2.14%
Fresh Groundwater	0.61%
Fresh Surface water	0.009%
Soil moisture	0.005%
Atmosphere	0.001%

Although local hydrologic and climatic conditions affect the relative abundance of each phase of water, the total water is fixed in the closed system model of the global water cycle. The closed system cyclical model recognizes that water is a renewable resource that simply changes phase within the processes of the water cycle.[4]

Continued exchange among the gaseous, liquid and solid water creates the kinetic equilibrium that determines the climatic conditions of our planet. The water contained in

[2] Bedient, P.B. and W.C. Huber. "Hydrology and Floodplain Analysis." Addison-Wesley Publishing, 1992, p.6.
[3] Fetter, C.W. "Applied Hydrogeology." Prentice-Hall, 1994, p.4. Adopted from figure 1.3.

the atmosphere as a vapor (.001% of the world's water) is evaporated from the land, the oceans, and other surface water bodies, transpired from vegetation, and sublimed from snow and glacier formations. The amount of liquid water confined to surface water bodies (97.209% of the world's water) is a function of the precipitation that results from the condensation of vapors stored in the atmosphere. The amount of water frozen in glaciers and icecaps (2.14% of the world's water) is a function of the global temperature and climate structure. In order to better manage fresh surface water (.009% of the world's water) and fresh groundwater (.61% of the world's water) in future years, it is important to understand its role in the natural environment.

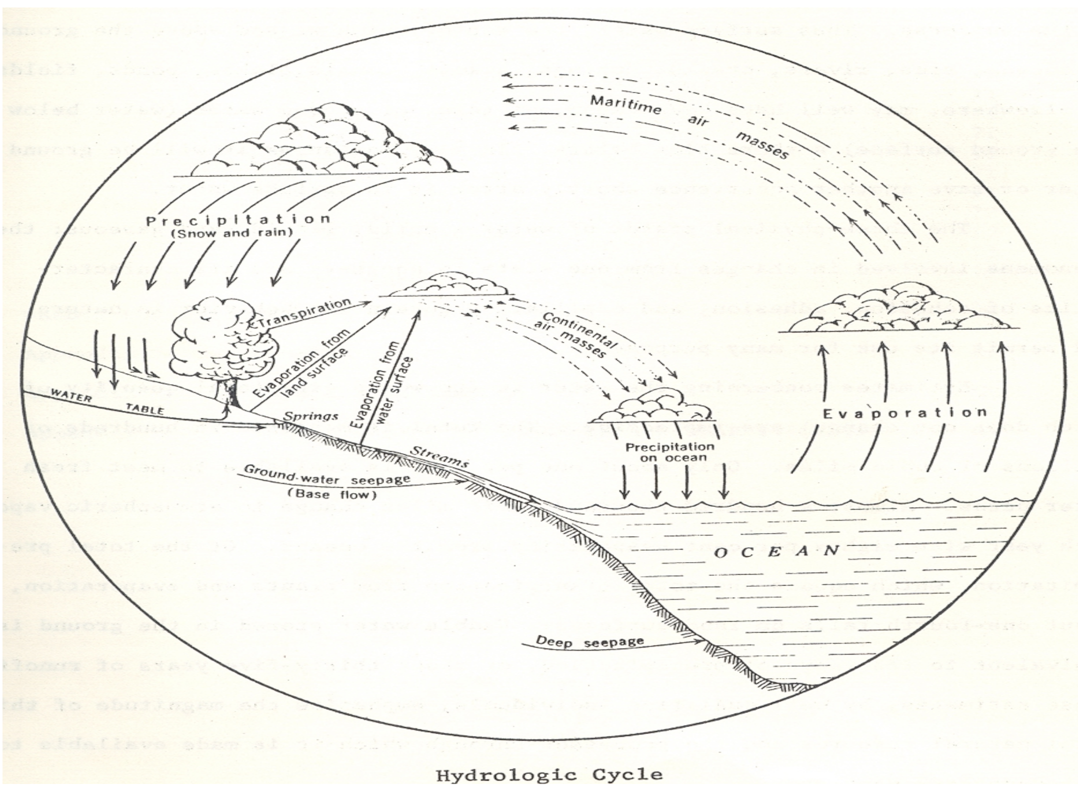

Figure 2.1: Virginia Division of Water Resources' representation of the hydrologic cycle.[5]

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[4] Id.
[5] Virginia Division of Water Resources. "Notes on Surface Water in Virginia." Virginia Department of Conservation and Economic Development, December, 1960, p.2.

2.1.1.2 The Water Balance

> "Many of society's fundamental needs call for the diversion of water from its natural cycle. The water has to be 'borrowed' for a time before it finally makes its way back to the watercourse."[6]

The water balance (sometimes referred to as the water budget) as illustrated in Figure 2.2 describes inflows to a geographic area from the various components of the hydrologic cycle, transformations among these components, human water use within the area, and outflows from the area through various hydrologic processes and artificial conveyance facilities. Since the water balance involves the quantification of human interactions with the hydrologic system, it is a useful mechanism for analyzing the status of water use and the potential for future development at a particular time. Although water balance calculations can be used to show changes in the global or regional water vapor-liquid-solid equilibrium[7], the water balance generally attempts to describe the interaction between natural hydrologic processes and human water supply and demand activities within a specified geographic area. By accounting for the water yielded by the climatic environment in the study region and the water needed to sustain human development, the water balance is an important tool that can be used to assess current and future water supply availability.

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[6] Falkenmark, M. and G. Lindh. "Water for a Starving World." Westview Press, 1976, p.12.
[7] Wei, H. and C. Fu. "Study of the sensitivity of a regional model in response to land cover change over Northern China" in *Hydrological Processes*, v.12, no.13-14, Oct-Nov 1998, p. 2249-2265.

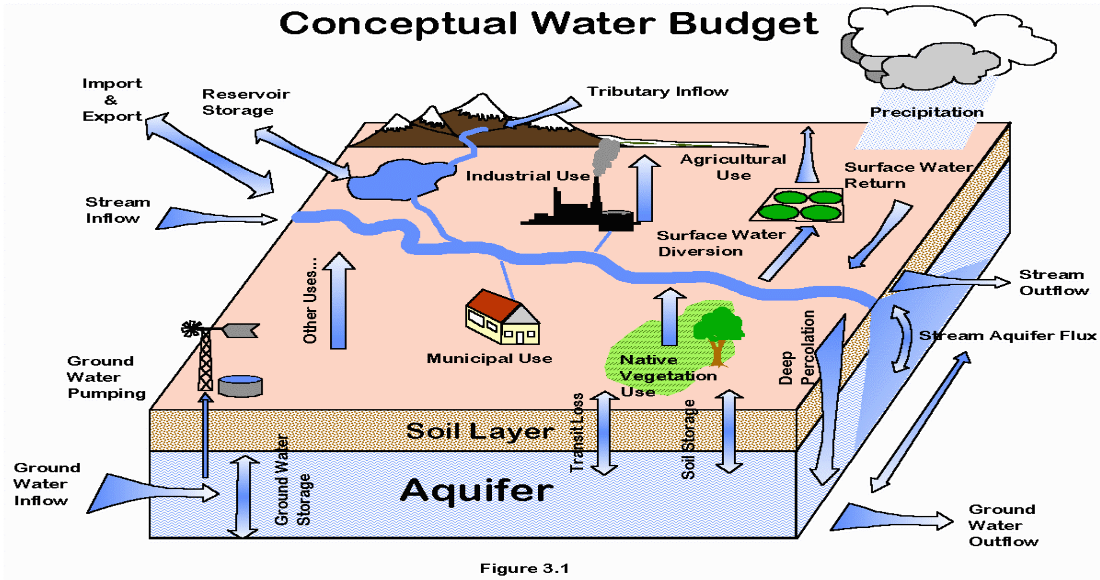

Figure 2.2: The Colorado Department of Natural Resources' representation of the water balance.[8]

Every water balance includes descriptions of natural and artificial inflows and outflows of water resources; the scope of the area under consideration defines the range and complexity of the inflows and outflows considered in the water balance. The operator of a local surface water system may only look at the effects of water withdrawals immediately surrounding the site of the stream withdrawal. The water balance in the small scope of the solitary surface water user may include only the water existing naturally in the watercourse, adjacent withdrawals upstream and downstream, and the amount of treated wastewater returned to the water body. The local groundwater supplier may be concerned only with competing wells, local aquifer storage capacity, and any recharge zones, natural or artificial, within the capture zone of the well. Such small scope provides a limited set of variables that eliminate the complexity of larger frames of reference.

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[8] "Conceptual Water Budget." Colorado Department of Natural Resources. http://water.state.co.us/maps.htm.

Generally, as the scope increases, the components of the water balance that must be included increases. For instance, the county water resource manager is responsible for all the supply systems inside the county boundary. The set of variables is compounded by introducing a need to analyze not only the availability of water for the solitary user but also effects of multiple users upon each other. The variables that must be evaluated by a comprehensive state plan maybe even more complex. A state planner must consider not only the components of the water balance at the single user and county levels, but the effects of the accumulation of the withdrawals on the state as a whole.

2.2 Planning Area Designation

The choice of the planning area boundary is the first step in determining water supply availability. Choice of an inappropriate planning area increases the difficulty of establishing supply and demand estimates. The United States Geological Survey (USGS) reports water demand by county and by demand cataloging unit.[9] Planning areas based on political boundaries, such as Soil and Water Conservation Districts (SWCDs) and state planning districts (SPDs), may seem appropriate and worth consideration. However, assessment seems most feasible within hydrologic boundaries because supply estimates may be developed for an area with similar hydrologic characteristics. The USGS demand cataloging unit is the recommended choice because it is a boundary defined by hydrologic features that has corresponding demand estimates.

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[9] "Water Use in the United States." US Geological Survey, July 16, 1998. http://water.usgs.gov/watuse.

Although the USGS demand cataloging unit boundaries are drawn coincidental to hydrologic boundaries, the division of larger Regions, Subregions, and Accounting Units into Cataloging Units does not include considerations that may be significant to water supply analysis. For instance, if a cataloging unit contains a reservoir system, then the USGS places the boundary downstream from the reservoir in all cases. Downstream of the reservoir was chosen "because the headwaters can vary considerably over a period of time whereas the outlet of the impoundment is usually a fixed point."[10] Regardless of the validity of the rationale used by the USGS, the decision to put all boundaries downstream of reservoirs may not be favorable to water supply analysis. Even further, the USGS makes no consideration of gage locations, tidal or backwater effects, or Standard Metropolitan Statistical Areas in the designation of cataloging units.[11] Each of the previously mentioned considerations may be important to water supply availability analysis, and therefore, USGS demand cataloging units may limit the validity of the analysis.

2.3 Water Supply in the Base Year and in Future Years

Water supply measurements in a particular geographic area must encompass water available from the various phases of the hydrologic cycle over the long term. From a practical perspective, potential sources include flow in streams, water contained in lakes or artificial impoundments, and groundwater occurring below the ground surface under saturated conditions (ignoring atmospheric water and soil moisture existing under

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[10] Seaber, P.R., F.P. Kapoinos, and G.L. Knapp. "Hydrologic Unit Maps." US Geological Survey Water Supply Paper 2294, 1987, p. 8.
[11] Id.

non-saturated conditions). Available supply must be viewed as a dynamic concept involving continuous flow rather than a set amount in storage or available for capture at a particular time.

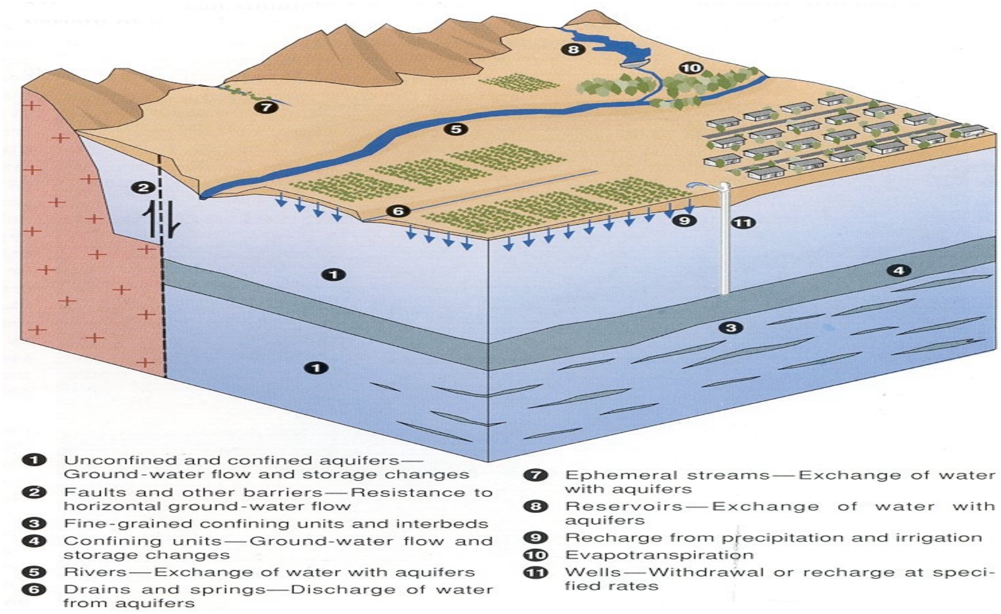

Figure 2.3: Leake's representation of the factors affecting water supply measurement.[12]

One of the basic issues to resolve in measuring water supply is how to account for surface and groundwater interactions. Winter et. al (1998) describe surface water-groundwater interactions as one of "three basic [types]: streams gain water from inflow of groundwater through the stream bed (gaining stream), they lose water to groundwater by outflow through the streambed (losing stream), or they do both, gaining in some reaches and losing in others"[13] (see Figures 2.4 and 2.5). The specific patterns of interaction are generally only important in the local scope of analysis. On a regional scale, the net effect

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[12] Leake, S.A. "Modeling Ground-Water Flow with MODFLOW and Other Programs." USGS Fact Sheet FS-121-97, August 1997, p. 1, figure 1.
[13] Winter, T.C., J.W. Harvey, O.L. Franke and W.A. Alley. "Ground Water and Surface Water, A Single Resource." USGS Circular 1139, 1998, p. 9.

of the surface and ground water interaction tends to be more average over time and space, and the details of the interaction at specific points become less important to the analysis.

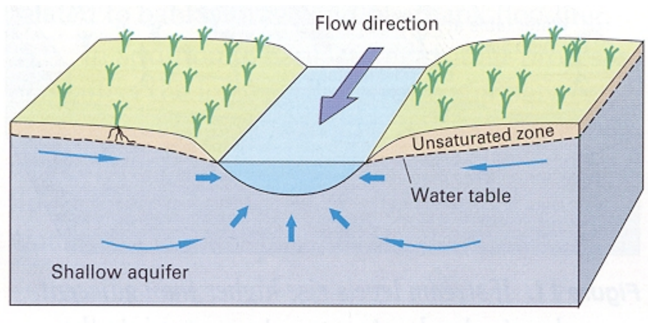

Figure 2.4: Winters et. al's depiction of a stream gaining from groundwater.[14]

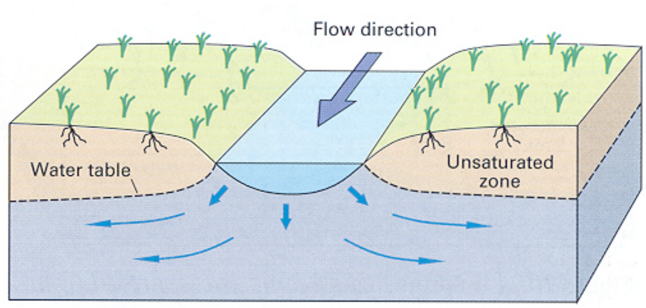

Figure 2.5: Winters et. al's depiction of a stream losing water to groundwater.[15]

Surface water streams are sustained by groundwater discharge during periods of little or no precipitation. Therefore, historical surface water parameters will include the amount of groundwater discharged to the surface water body. Rutledge (1993) quantified the contribution of groundwater discharge to low-flow conditions using USGS streamflow data. The estimation procedure quantified "mean groundwater recharge and discharge" assuming that "all, or nearly all, groundwater [in the basin] discharges to the

[14] Id., p. 9, figure 8A.
[15] Id., p. 9, figure 9A.

stream."[16] Streamflow records then served as a quantification of the entire water flow system within a "basin for which a streamflow-gaging station at the downstream end can be considered the only point of outflow."[17] In other words, surface water and groundwater were combined into a flow system quantified as a single measure - streamflow as measured by stream gages.

The interaction of surface and ground water will be a function of local climatic and physiographic characteristics. Groundwater in a wet climate will usually contribute water to a stream, where as a stream in a drier climate under the same physiographic conditions will usually contribute to the groundwater system.[18] Streams in mountainous terrain are generally sustained by groundwater between storm and snowmelt periods[19] and can groundwater can be generally assumed to discharge to the stream.[20] In riverine environments, commonly classified by wide, gently defined river valleys, the interaction of surface and groundwater often depends on the size of the stream but groundwater can generally be assumed to discharge to the stream.[21] Small streams in the riverine environment will receive discharge from the local groundwater flow system, but the discharge will "usually have limited extent and are highly variable seasonally."[22] Large rivers in a riverine environment will often receive discharge from regional groundwater flow systems.[23] In coastal terrain upward and downward groundwater flow directions can be associated with water table interactions with topographic features on the land

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[16] Rutledge. "Computer Programs for Describing the Recession of Ground-Water Discharge and for Estimating Mean Ground-Water Recharge and Discharge from Streamflow Records." USGS Water Resources Investigations Report 93-4121, 1993, p.1.
[17] Id., p.2.
[18] See note 13, supra, p. 33.
[19] Id., p. 34.
[20] Id., p. 34, Figure 20.
[21] Id., p. 39, Figure 22.
[22] Id., p. 38.

surface; however, "few estimates of the location and magnitude of groundwater discharge to coasts have been made."[24] As a result, surface and ground water interaction in coastal environments is difficult to generalize. Despite the variability of the surface and ground water interaction with physiographic and climatic conditions, the preliminary assessment procedure will assume that groundwater available for supply in the long-term is included in the surface water gage measurement in all physiographic and climatic conditions. The groundwater availability may need to be assessed more specifically if surface water is not sufficient or available to satisfy development especially if the planning area lies within a coastal physiographic environment.

2.3.1 Water Supply in the Base Year

Base year water supply was determined from the average flow conditions measured over the period of record at gaging locations throughout the United States. In the United States, the USGS has developed a gaging network in cooperation with state agencies along many of the streams across the country that reports data over a period of record. The gages record the depth of water in a stream at a specified location that can be converted to a flow rate by means of a rating curve developed at the gage location. The rating curve is developed by breaking the stream width into "about 25 increments with approximately equal discharges."[25] For each portion of the width, the depth and average velocity of the water is measured. The average velocity in shallow streams is assumed to exist at .6 times the depth; the average velocity in deeper waters is approximated as the

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[23] Id.
[24] Id., p. 44.
[25] Wahl, K.L., W.O. Thomas, Jr., R.M. Hirsch. "Stream-Gaging Program of the US Geological Survey." USGS Circular 1123, 1995, "Measuring Discharge."

average of the measurements taking at .8 and .2 times the depth.[26] "The product of the width, depth and velocity of the section is the discharge through that increment of the cross section. The total of the incremental section discharges equals the discharge of the river."[27] Taking measurements under multiple stream stages allows the development of the rating curve at each gaging location. Continuous measurements are used to develop average measurements for each day of the year and reported annually for each gaging location within each state that can be used as estimates of water supply.

Statistical analysis of average daily flow measurements can be used to develop flow parameters that indicate the extent and range of variation from typical conditions. Figure 2.6 illustrates daily flow measurements and flow parameters developed from daily measurements at USGS gaging station 02060500 at Altavista, Virginia on the Roanoke River.

[26] Id.
[27] Id.

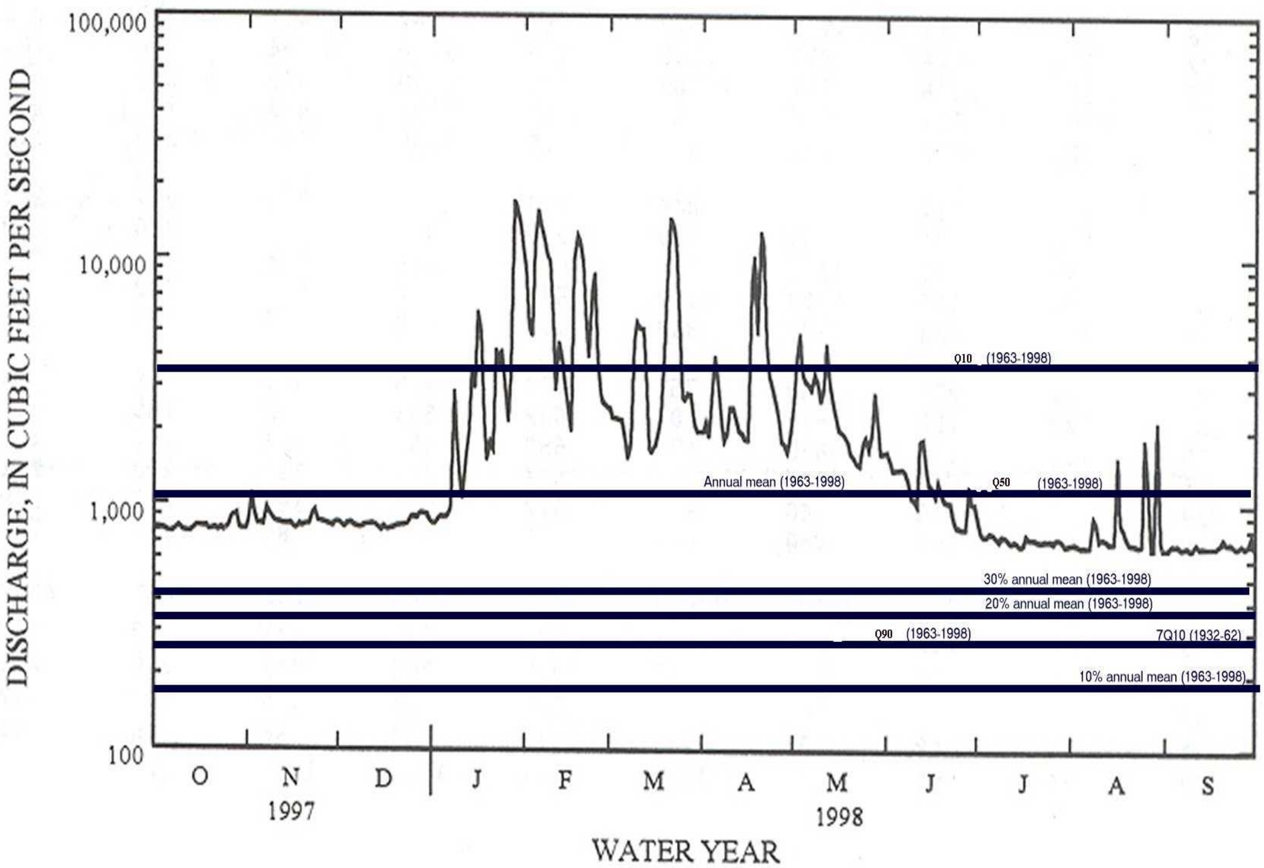

Figure 2.6: Flow parameters and daily average flow measurements from USGS gage 02060500 on the Roanoke River.[28]

The daily average flow data shows daily water availability in water year 1998. The daily data is overlain by statistical expressions of the flow data that have been developed from the entire period of record.

The annual mean flow (Q_{AM}), in theory, is the amount of water that could be expected to be passing the gaged location on the average day in the average year between 1963 and 1998. Other statistically derived expressions of the average daily flow measurements may help to express the variability of flow in the stream. A common flow condition that helps to express flow variability is the exceedance flow, which is commonly represented by Q_n. The subscript n represents the percentage of time that the reported flow is expected to be equaled or exceeded based on the entire period of record of flow measurement at the specified location. Figure 2.6 indicates Q_{90}, Q_{50} and Q_{10} as determined from data measured at a gaging site between 1963 and 1998.

Another statistical parameter often used to describe the variability of low flow conditions in the stream is the lowest average flow expected to occur over a specified number of consecutive days with a specified frequency of occurrence. For example, the $7Q_{10}$ expression represents the lowest 7 consecutive day average flow expected to occur once every ten years (10% annual occurrence). The $7Q_{10}$ parameter is often considered to measure the amount of water instream that will assure waste assimilation and maintain water quality standards. A similar flow expression is the $1Q_{30}$ parameter that represents the lowest 1 day average flow expected to occur once every 30 years (3.3% annual occurrence). The $1Q_{30}$ parameter is the low flow measure that is considered by the Virginia Department of Health to be the safe yield of water supply intakes on Virginia streams.[29] Figure 2.6 shows the $7Q_{10}$ parameter; however, $1Q_{30}$ is less than 100 cfs and is not shown in Figure 2.6 because of the scale used.

Portions of the average annual mean flow can represent instream use and thresholds of the amount of water available for development. As developed by Tennant (1976), sixty percent of the average annual mean indicates the amount of water that should be left instream if optimum fish habitat and a majority of recreation is to be

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[28] White, R.K., D.C. Hayes, M.R. Eckenwiler, and P.E. Herman. "Water Resources Data Virginia Water Year 1998." USGS Water-Data Report VA-98-1, p.385.

[29] Virginia Administrative Code. Section 12VAC5-590-830. Subsection 2-b.

protected.[30] Also from Tennant's empirical study, thirty percent of the average annual mean specifies the protection of instream waters that will provide good fish survival conditions and that will support general recreational use.[31] According to Falkenmark and Lindh (1976), twenty percent of the average annual mean is the maximum portion of streamflow that can be captured before encountering severe water supply development problems.[32] As defined by Tennant, ten percent of the average annual mean designates the short-term fish survival minimum and near inability to sustain recreational activities.[33] With the exception of 60% of the average annual mean flow, the discussed portions of the annual average mean flow are indicated on Figure 2.6.

2.3.1.1 Transferring Streamflow Parameters to Ungaged Sites on Gaged Streams

In order to describe the water availability estimate for a particular planning area, it is often required that the array of streamflow parameters be transferred from a gaged site to another location. A technique developed to estimate flow at an ungaged site on a gaged stream is to transfer the upstream gage measurements to the downstream ungaged site (or vice versa) proportional to the contributing land area at each location. In order to describe low flow conditions throughout Virginia, Hayes (1991) adjusted $7Q_{10}$ and $7Q_2$ low flows at ungaged sites on gaged streams in Virginia by the ratio of drainage areas raised to the power of 1.2. The $7Q_{10}$ and $7Q_2$ estimates at the ungaged sites were calculated according to the following equation:

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[30] Tennant, D.L. "Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources." In *Fisheries*, American Fisheries Society, vol. 1, no. 4, 1976, p. 6-10.
[31] Id.
[32] See note 6, supra, p.18.
[33] See note 30, supra.

$$7QT_j = 7QT_i \times [A_j/A_i]^{1.2}$$

where $7QT_j$ is the low flow at the ungaged site,
$7QT_I$ is the low flow at the gaged site,
A_j is the drainage area of the ungaged site,
and, A_i is the drainage area of the gaged site.

The exponent 1.2 was derived from the evaluation of streamflow records at continuous-record sites. Sites were paired on selected streams and were adjusted if "no major tributaries entered the stream at any point between the selected sites," or if tributaries did enter the stream between the paired sites, the tributary drainage area did not increase the overall drainage area by "more than 25 percent."[34] The paired sites were then analyzed by relating "logarithms of the low flow ratios at the upstream site to the low flow characteristics at the downstream site…to logarithms of the ratios of the drainage area at the upstream site to the drainage area at the downstream site."[35] The results were then plotted using a least-squares regression method, "resulting in a computed value of [the exponent equal to] 1.2."[36]

The VSWCB (1983) adjusted $1Q_{30}$ low flows in Virginia by direct correlation of the low flow value and the drainage area of gaged sites to ungaged sites. Analysis was made in order to estimate the safe yield of instream intakes for water supply according to the following equation:[37]

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[34] Hayes, D.C. "Low-Flow Characteristics of Streams in Virginia." US Geological Survey, Water Supply Paper 2374, 1991, p.10.
[35] Id., p.11.
[36] Id.

$$1Q30_I = 1Q30_G (A_I/A_G)$$

where $1Q30_I$ is the low flow at the intake,
$1Q30_G$ is the low flow at the gage,
A_I is the drainage area at the intake,
and, A_G is the drainage area at the gage.

The gage location was chosen to represent the ungaged location based on the length of the period of record at the gage, "similarities in drainage basin size, topography, geology, and proximity of the gage's watershed to the intake's watershed."[38]

The difference between the two gage transfer methodologies is the exponent on the land area ratio. If both methodologies were applied to transfer gaged sites downstream to an ungaged site, the exponent on the land area ratio in the Hayes methodology would result in a higher transferred flow than the VSCWB methodology. It may be concluded that the VSWCB methodology may result in an underestimate of flow conditions at the downstream, ungaged location in comparison to Hayes' estimates at the same location. However, the application of the VSWCB methodology from a downstream gaged site to an upstream, ungaged site may result in an overestimate of flow conditions at the ungaged location in comparison to Hayes' estimates at the same location.

2.3.1.2 Determining the Limits of Water Use and Development

Although various flow parameters can be used to describe the variability of water in the stream over time, all the water that passes a specific point in a stream cannot be captured, stored and developed for human use. For uses that require a continuous supply,

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[37] Virginia State Water Control Board. "Safe Yield of Municipal Surface Water Supply Systems in Virginia." Virginia State Water Control Board Planning Bulletin No. 335, March 1985, p.viii.

withdrawals from free-flowing streams are limited to those available during drought conditions. The fact that withdrawals may be practically unlimited during high flow conditions has no significance where continuous supply is required unless water is withdrawn from the stream during high flow periods and stored to offset any deficits during low flow periods. Storing and using all of the water passing a gaged point over the period of record is not possible because that would require huge storage facilities and would assume that no water is needed downstream. So, how much of the water instream is actually available for satisfying human demands?

Falkenmark and Lindh (1976) suggest that "water needs"[39] beyond twenty percent of the "total water resources" will "impose a limit on social development."[40] Although they do not specify how they define "water needs," cumulative offstream withdrawal upstream from the point in a basin where the determination is made appears to constitute "water needs" based upon the treatment of the concepts on a continental scale. Falkenmark and Lindh comment further that "favorable" water supply conditions generally exist "as long as water needs are less than 5 percent of total runoff" and "generally still favorable if water demand amounts to between 5 and 10 percent of total runoff."[41] "Water needs" between 5 and 10 percent of total runoff require the development of regional plans for water supply, and the "number of areas destined to encounter temporary difficulties" will increase.[42] Demands between 10 and 20 percent of total runoff "can be said to constitute a problem" requiring "general planning…and heavy

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[38] Id.
[39] See note 6, supra, p. 36.
[40] Id., p. 18.
[41] Id., p. 36.
[42] Id.

investments…for the solution of water supply problems."[43] If "needs" exceed 20 percent of total runoff, "water supply can be described as the absolute limiting factor of economic development."[44]

If Falkenmark and Lindh's analysis is used as an estimate of amount of water available for capture, a reasonable conclusion is that 20% of the total streamflow is the maximum of water that can be developed in each cumulative basin. Nevertheless, capturing and developing 20% of the total streamflow assumes large investments in storage facilities that can collect and accumulate water from high flow periods and distribute them during low flow periods.

2.3.2 Water Supply in Future Years

In 1960, the Select Committee on National Water Resources (SCNWR) developed 1980 and 2000 water balances for the United States, by comparing "the projected required flow in a region…with existing minimum flows" to determine potential supply deficits in the region.[45] The SCNWR used flows equalled or exceeded 50, 70, 80, 90 and 95 percent of the time, together with the long term average, in order to characterize the inherent variability of streamflow and the dependability of various flow levels. The SCNWR considered the flow equalled or exceeded 95 percent of the time as the limiting flow condition and the "longrun average flow" over the period of record as the "theoretical maximum sustained flow."[46]

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[43] Id., p. 37.
[44] Id.
[45] U.S. Congress Select Committee on National Water Resources. "Water Resources Activities in the United States: Water Supply and Demand." Committee Print Number 32, August 1960, p.4.
[46] Id., p.51.

The amount of water available at a particular location depends not only on naturally occurring supplies but also on upstream development conditions. The amount of water consumed by upstream withdrawals will not be available for supply development and should not be included in the supply estimate. A headwater planning area will not have upstream consumption occurring; and, therefore, the full amount of water expected to be instream will be available for use. In the case of a planning area with upstream withdrawals, the impact of upstream consumption on the supply may be accounted for in two ways: (1) by subtracting the total expected upstream consumption from the amount of water expected at the outlet of the planning area or (2) by subtracting the expected increase in consumption expected to occur beyond the base year. By subtracting the total upstream consumption from the current area supply estimate, the effect of long-term consumption on the flow conditions developed from measurements at the gage will be ignored. This approach introduces an error since consumption took place before the last year in the period of record and may be reflected to some extent in the gage data. However, adjusting supply estimates in future years only by the increase in consumption from the base year introduces another type of error. This approach assumes that prior consumption is completely reflected in the gage data and does not account for consumption that has not taken place since the beginning of the period of record. Considering that the removal of the entire upstream consumption from the transferred flow parameter may underestimate the supply and that the removal of the increase in consumption from the base year may overestimate the supply, it seems that underestimating the supply may be the more moderate approach. Therefore, the supply estimate will be adjusted by subtracting the total projected upstream consumption from the transferred flow parameters, and the effect of previous and existing upstream consumption on gage data will be ignored (for a discussion of projecting consumption see *2.4.2.1.2*).

The method for projection of supply availability adopted in this study assumes that each historical flow condition will remain relatively stable in the future despite potential change from multiple causes. Climate changes may occur that could increase or decrease precipitation in the planning area, and thereby, increase or decrease supply availability. In addition to changes in climate, changes in water quality may alter future water supply availability. Contaminated water or river sediments may eliminate once dependable supplies from being able to be treated. The reclamation of contaminated sites may enable once contaminated waters to be treated and added to the available supply.

Upstream changes may also affect the availability of water in the stream. Changes in land use upstream may increase flood peaks and/or decrease groundwater recharge; changes in water use patterns upstream (i.e., reservoir construction or destruction) may limit and/or increase availability downstream. However, the enforcement of legislative controls at the Federal and state level may limit the amount of water that is available for supply development.

2.3.2.1 Potential Impact of Current Legislation on Future Water Supply Availability

Although "public water supply development has been viewed as a function of local government[,]…all levels of government participate in water supply" activities.[47] Generally, federal involvement in water supply constitutes grants and loans to needed water supply developments under specific federal programs.[48,49] State governments participate in water supply developments by providing "direct state funds for the project" or by acting on behalf of the locality at the federal level to increase the likelihood of federal funding.[50] Although states may also assist local water supply developments by providing planning and technical assistance, the "passage of enabling legislation" to provide the necessary authority and funding for local water supply development can be viewed as the main function of state governments in water supply development.[51] However, despite a large role in water supply developments, local governments must abide by Federal and state water development requirements before potential projects can be developed.

Legislative controls that specify the amount of water that must remain instream for environmental protection purposes could affect the amount of water available for offstream use in the future. Currently, instream flow requirements for uses such as aquatic ecosystem protection can be established by federal and/or state legislation that affect specific stream segments. Presently, there is no streamflow condition defined as a generally applicable minimum instream flow at the federal level, and it is unlikely that

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[47] Cox, W.E. and L.A. Shabman. "Institutional Issues Affecting Water Supply Development: Illustrations from Southeastern Virginia." Virginia Water Resources Research Center, Bulletin 138, March 1983, p.10.
[48] Id.
[49] United States Code. Title 42. Section 300j-2 and 300j-3c.
[50] Cox, W.E. and K.S. Patrizi. "Institutional Framework for Rural Water Supply in North Carolina, South Carolina and Virginia." Virginia Water Resources Research Center, Bulletin 142, February 1984, p.111.

one will be designated in the future. However, a few statutes at the federal and state levels could potentially affect the development of future water supply projects on local streams currently considered developable.

2.3.2.1.1 Potential Impact of Federal Legislation on Water Supply in Future Years

The Clean Water Act, the Endangered Species Act, and the Wild and Scenic Rivers Act are three statutes with potential to impose future minimum instream flow requirements at the federal level that could restrict future water supply developments. Section 404 of the Clean Water Act declares that the Secretary of the Army "may issue" permits for potential projects that will discharge "dredged or fill material into the navigable waters" of the United States.[52] In addition to the permit discretion granted to the Army Corps of Engineers, section 404 of the Clean Water Act authorizes the Administrator of the Environmental Protection Agency to deny permits granted by the Corps if it is determined that such an action "will have unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas, wildlife, or recreational areas."[53] Although "fill" can be applied to a variety of construction projects that may disturb water resources, the ability to dam navigable waters is subject to 404 approval because dam material is subject to the "fill material" definition included in the Act. The EPA has been upheld in decisions to veto Corps permit approvals.[54] The veto power of the EPA does not have to consider the need for water supply developments;[55] EPA need

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[51] See note 47, supra.
[52] United States Code. Title 33. Section 1344-a.
[53] United States Code. Title 33. Section 1344-c.
[54] "Almeda Water and Sanitation District vs. Reilly." 930 F. Supp. 486; 1996 U.S. Dist. LEXIS 9446; 43 ERC(BNA) 1471; 26 ELR 21526.
[55] "James City County vs. EPA." 12 F.3d 1330; 1993 U.S. App. LEXIS 34401; 37 ERC (BNA) 2104; 24 ELR 20182.

only consider adverse environmental impacts because of the "language of 404(c) which refers only to environmental factors."[56]

The Endangered Species Act (ESA) states that Congress recognizes that "various species of fish, wildlife, and plants in the United States have been rendered extinct as a consequence of economic growth and development untempered by adequate concern and conservation."[57] The recognized species will be protected under the ESA by "insur[ing] that any action authorized, funded or carried out by [a Federal] agency is not likely to jeopardize the continued existence of endangered species or threatened species."[58] Threats to the existence of endangered or threatened species, as determined by the Secretary of the Interior or the Secretary of Commerce, include threats to the "critical habitat" of the species that is "essential to the conservation of the species and which may require special management consideration or protection"[59] and can include required streamflow conditions for endangered aquatic species. Although "Congress and Federal agencies shall cooperate with State and local agencies to resolve water resource issues in concert with conservation of endangered species,"[60] protection of species under current ESA guidelines could prevent water supply developments in recognized critical habitat areas.

The Wild and Scenic Rivers Act may protect future streams or stream sections, upon recognition of particular scenic values from Congress, from "dams, water conduit, reservoir, powerhouse, transmission lines or other project works…that would have a

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[56] Id.
[57] United States Code. Title 16. Section 1531-a-1.
[58] United States Code. Title 16. Section 1536-2.
[59] United States Code. Title 16. Section 1532-5-A-i
[60] United States Code. Title 16. Section 1531-c-2.

direct and adverse impact on the values for which such river was established."[61] The identified water resource projects are restricted from license by the Federal Energy Regulatory Commission and from assistance "by loan, grant, license or otherwise in the construction" from any agency of the United States along any identified section of a stream.[62] Such restrictions can prohibit developments from being granted necessary Federal permits for construction of new development projects or permit renewals for existing water supply developments.

2.3.2.1.2 Potential Impact of Virginia Legislation on Water Supply in Future Years

In addition to the protection of instream flows by the Federal government, state government may also restrict future water supply availability. Virginia has adopted three programs that could potentially require minimum instream flow restrictions on new supply developments: the Virginia Scenic Rivers program, the Virginia Water Protection Permit and the Virginia Surface Water Management Act. The Virginia Scenic Rivers (VSR) program requires that along "river[s] or section[s] of river[s] that [have] been designated 'scenic river[s]'…by the General Assembly[63]…because of their scenic, recreational and historic attributes and natural beauty"[64] that "no dam or other structure shall be constructed, operated or maintained" without the consent of the General Assembly.[65] Commonwealth agencies also "may review and make recommendations regarding all planning for …the construction of impoundments, diversions, roadways, crossings, channels, locks, canals or other uses" that could potentially "change the

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[61] United States Code. Title 16. Section 1278.
[62] Id.
[63] Virginia Code. Section 10.1-400.
[64] Virginia Code. Section 10.1-401.
[65] Virginia Code. Section 10.1-407.

character of a stream or waterway and destroy its scenic values."[66] Therefore, rivers currently viewed as available for reservoir developments may not be available in the future if that river or river section is added to the 18 scenic stream sections currently recognized by the General Assembly.[67]

The Virginia Water Protection Permit (VWPP) program evaluates whether or not proposed activities requiring Federal permits will satisfy "provisions of the Clean Water Act and the State Water Control Law and will protect instream beneficial uses."[68] The VWPP conditions for point discharge projects, such as dams and effluent discharges, may include, "but are not limited to, the volume of water which may be withdrawn" from the stream in order to satisfy the activity under consideration.[69] The permit may include the designation of waters that will insure the "protection of navigation, maintenance of waste assimilation capacity, the protection of fish and wildlife resources and habitat, recreation, cultural and aesthetic values."[70] However, the permit conditions will be decided with "domestic and other existing beneficial uses…considered the highest priority uses." [71] The VWPP program "constitue[s] the certification required under §401 of the Clean Water Act"[72] that requires that point discharge projects be granted "a certification from the State in which the discharge originates or will originate" prior to Federal permit approval.[73] The certification requirement fulfilled by the VWPP program provides Virginia with the opportunity to veto projects that might be granted a Federal permit but

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[66] Virginia Code. Section 10.1-402.
[67] Virginia Code. Sections 409 - 419.
[68] Virginia Code. Section 62.1-44.15:5-B.
[69] Virginia Code. Section 62.1-44-15:5-C.
[70] Id.
[71] Id.
[72] Virginia Code. Section 62.1-44-15:5-A.
[73] United States Code. Section 1341.

do not protect instream use in Virginia. Under the VWPP, the recognition of the benefits of instream uses may prevent a Virginia river from being developed for water supply if the volume of water withdrawn by a point discharge project is seen as detrimental to instream use.

The Surface Water Management Area Act (SWMAA) is designed to protect surface waters where "the levels or supply of surface water [may] be potentially adverse to public welfare, health and safety."[74] The SWMAA enables the Virginia Department of Environmental (DEQ) to identify "geographically defined surface water management area[s]"[75] where there is "evidence to indicate that:

> 1.A stream has substantial instream values indicated by evidence of fishery, recreational, habitat, cultural or aesthetic properties; and 2. Historical records or current conditions indicate that a low flow condition could occur which would threaten important instream uses; and 3. Current or potential offstream uses contribute to or are likely to exacerbate natural flow conditions to the detriment of instream values."[76]

Once areas are designated, withdrawals within the surface water management area require permits from the SWCB, which are to "include a flow requirement appropriate for the protection of beneficial instream uses."[77] Therefore, water supply developments that currently exist could be restricted by permit limitations in the future if those withdrawals under low flow conditions significantly impair recognized instream values. However, despite studies of low flow conditions at various locations in Virginia, a surface water management area has yet to be designated in the Commonwealth of Virginia.

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[74] Virginia Code. Section 62.1-242.
[75] Id.
[76] Virginia Code. Section 62.1-246.
[77] Virginia Code. Section 62.1-248.

2.4 Water Demand in the Base Year and in Future Years

The third step in the procedure for preliminary assessment of water supply availability is the measurement of offstream and instream water demand. The offstream demand will be based on USGS demand data reported by USGS cataloging unit in 1995; offstream demand will be the sum of the demand from each sector that consumes a portion of the withdrawal. Instream demand will be estimated as the controlling instream demand in the planning area; the instream demand is often estimated by an appropriate flow parameter. Offstream demand will be projected according to population growth; the 1995 total offstream use will be divided by the 1995 population and the resulting per capita estimate will be assumed to remain constant under each projected population condition. The amount of water consumed will be projected assuming the rate of total consumption in the base year will remain constant in the future. The instream demand will also be assumed to remain constant; the controlling instream demand in the base year will be the projected instream demand. Total demand is expressed as the sum of the offstream and instream demand estimates. With offstream and instream demand estimates in the base year and projections of the demands in future years, the total demand can be determined for each year in the analysis.

2.4.1 Water Demand in the Base Year

Water demand estimation is often divided into two main categories: offstream and instream demands. The USGS began collecting offstream water use data in 1950 and reporting the estimates in all fifty states every five years. The USGS collects measured offstream data from local government bodies and estimates portions of the totals to adjust for missing data.[78] Instream demands can be estimated depending upon the instream demand that controls in the specified stream. The separate estimates can then be combined to estimate the total demand.

2.4.1.1 Offstream Water Demand in the Base Year

Offstream water demand refers to waters "being diverted or withdrawn from a surface or ground water source and conveyed to the place of use."[79] Offstream uses are reported by the USGS according to eight categories: public supply, self-supplied domestic, commercial, irrigation, livestock, industrial, mining and thermoelectric withdrawals. All eight categories used in the USGS reporting system include total withdrawals that are expressed as the sum of fresh surface water, fresh groundwater, saline surface water, and saline ground water extracted from the planning area.[80] Within each cataloging unit, the USGS reports annual average daily water withdrawn and consumed in each category of offstream demand.

Although the offstream demand and consumption within each sector is reported by the USGS in the base year, the freshwater total offstream demand and consumption is the focus of the projected demand quantities in the preliminary assessment described in this report. The preliminary assessment defines total offstream demand as the sum of the demand of each sector reported by the USGS that consumes a portion of the withdrawal during use. If the specified geographic area is coincidental to a USGS cataloging unit, annual average daily demand estimates in each category can be reported for the entire

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[78] Solley, W.B., R.B. Pierce and H.A. Perlman. "Estimated Use of Water in the United States in 1995." USGS Circular 1200, 1998, p.2.
[79] Id. p.4.
[80] "U.S. Geological Survey National Water-Use data files - Data Dictionary." U.S. Geological Survey, Feb 23, 1999. http://water.usgs.gov/watuse/spread95/dictionary95.txt

cataloging unit. A summary of average daily demand in the study area provides the information necessary to compare supply and demand measurements and develop the water balance. However, average daily demand estimates do not account for the fluctuations of the demand throughout the days and the months of the year.

Figure 2.7 depicts the fluctuation in domestic demand that occurs in the typical household.

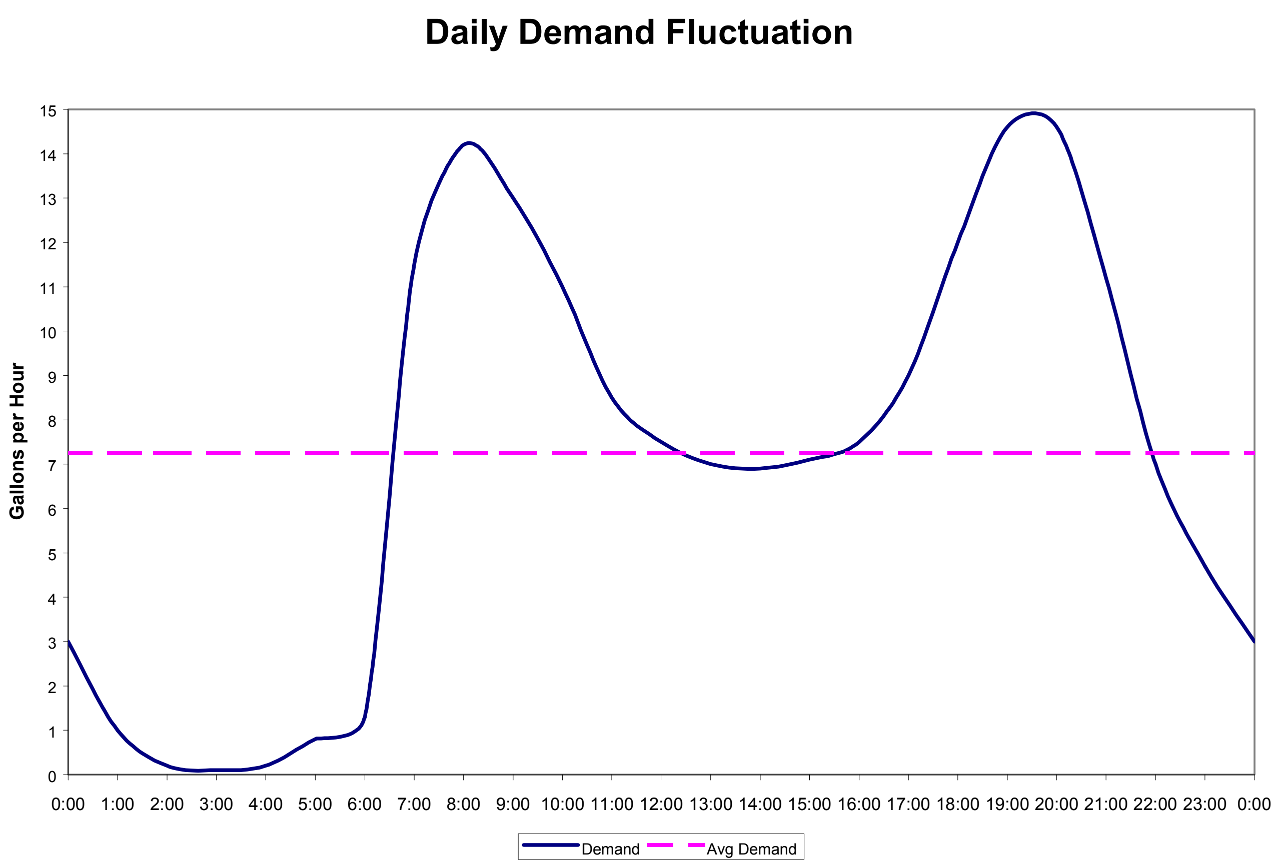

Figure 2.7: The fluctuation of domestic demand as a function of time of day.[81]

The use varies over the time of day as activities within the home change. The peak demand in the home during the evening hours exceeds the daily average by nearly 100

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[81] So, F.S., I. Stollman, F. Beal and D.S. Arnold. "The Practice of Local Government Planning." International City Management Association, 1979. Adopted from Figure 7-2, p.194.

percent. These fluctuations are important at the local level in order to design supply delivery systems that can meet the peak demand value. However, the USGS does not report daily peak demand; therefore, despite the importance of the peak demand, peak demand analysis will not be included in this overview methodology.

The daily demand reported as an average over the year also obscures fluctuations in water use that occur from month to month during the year. Figure 2.8 depicts the typical fluctuations in total public supply demanded by the Roanoke City public water supply system within the Upper Roanoke planning area in 1985:

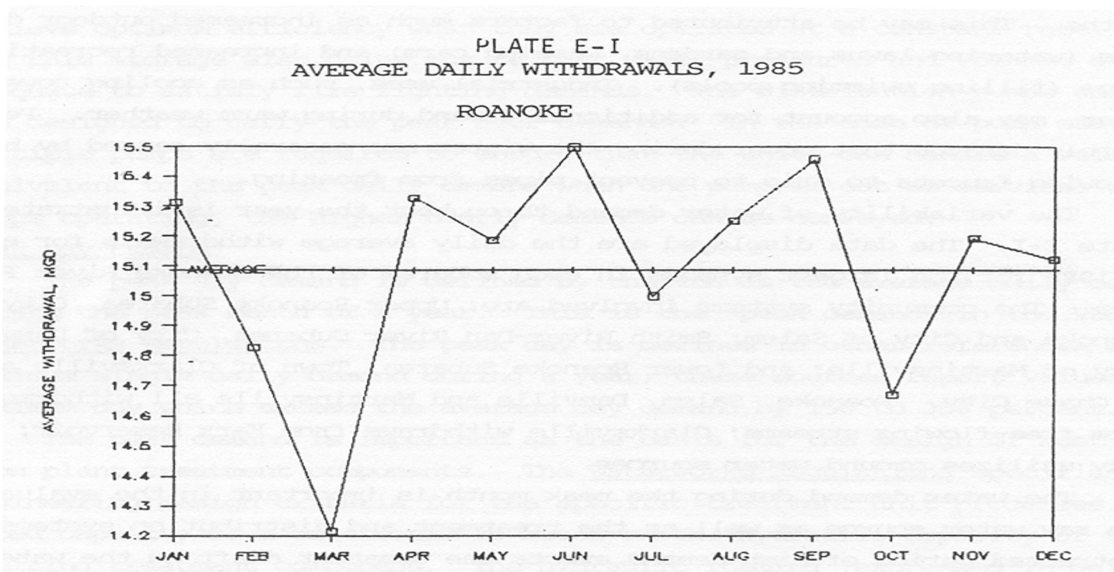

Figure 2.8: The monthly variation of demands in Roanoke, Virginia in 1985.[82]

In Roanoke City, June is the peak demand month and exceeds the daily average demand for 1985 by about 3 percent. Therefore, the critical demand value is 15.5 MGD, rather than the average 15.1 MGD. Again, the USGS does not report monthly average daily demand for each month of the year, but instead annual average daily demand. As a result

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[82] Virginia State Water Control Board. "Roanoke Basin Water Supply Plan." VSWCB Planning Bulletin No. 339, 1988, p. E-4.

of the availability of annual average daily demand data from the USGS for every demand cataloging unit in the United States, the monthly variation in demand will not be included in the preliminary analysis.

2.4.1.2 Instream Water Demand in the Base Year

Instream water demands are "water[s] that [are] used, but not withdrawn, from a ground or surface water source for such purposes as hydroelectric power generation, navigation, water-quality [maintenance], fish propagation, recreation,"[83] and scenic purposes. Instream demands are often difficult to determine because of the nature of the definition of the demand; "demand" traditionally implies a diversion from the stream for a human use. However, to the extent that some instream demands receive legal recognition and protection, they can be viewed as "consumptive" in the sense that they are not available for the satisfaction of offstream demands. However, the "consumptive" nature of the demand will be defined only by the enforcement of protected status under any applicable legislation. Instream demands commonly are estimated as the minimum flow necessary to sustain a particular activity and commonly are represented by known instream flow parameters. The controlling instream demand value will be defined according to the river or river section under investigation or the state in which the investigation is taking place.

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[83] Id., p. viii.

2.4.1.2.1 Hydroelectric Demand

Hydroelectric waters are those "used at power plants where the turbine generators are driven by falling water."[84] Hydroelectric use is the only instream use estimated by the USGS because it is measurable from records at each generating location. Records can be obtained from individual facilities, state permitting agencies, EPA, DOE, the US Army Corps of Engineers (COE), and the Federal Energy Regulatory Commission (FERC).[85] Energy generated per year and at each facility can be estimated using indices of water required to produce each kilowatt hour of electricity.[86] Consumption is generally considered to be zero because of the small percentage of liquid water that is lost to evaporative processes. Power generation at each facility should be available and should be reported as a net amount.

2.4.1.2.2 Navigation Demand

Navigation waters are those used to transport goods and conduct commerce. The protection of navigable waters requires maintenance of stream flows that will sustain boat passage. The quantification of water necessary to sustain navigation depends on the size of the waterway and the vessel intending to pass. Generally, navigational waters will be protected under most other instream demand conditions (please see *2.4.1.2.4* for a discussion of small boat navigation).

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[84] Linsey, K.S. "1995 Water-Use Guidelines: Hydroelectric Water Use." US Geological Survey, May 28, 1996. http://water.usgs.gov/watuse/guidelines/hy.html
[85] Id.
[86] Id.

2.4.1.2.3 Aquatic Wildlife Demand

Aquatic wildlife waters are those necessary to "protect fishes, waterfowl, furbearers, reptiles, amphibians, molluscs, other aquatic invertebrates, and related life forms" from the many uses competing for surface waters.[87] The amount of water that is required to perpetuate fish and other aquatic wildlife will change over the course of the year and from species to species, but a few general procedures have been developed. Tennant (1976) developed the "Montana Method" (now frequently referred to as the "Tennant Method"[88,89]) between 1957 and 1974 at 58 cross-sections in 11 states; the results of the initial study were confirmed in 21 different states as able to be "applied rapidly to many segments of thousands of streams."[90] The Tennant Method recommends 10 percent of average flow as a minimum for "short-term survival [of] most aquatic life forms," 30 percent of average flow to "sustain good survival conditions," and 60 percent of average flow to maintain "excellent to outstanding habitat for most aquatic life forms during their primary periods of growth"[91] (generally the spring months). The wide applicability of the Tennant Method has been criticized as not taking into account differences in stream "size, shape, hydrology, and geography, particularly since it may overestimate flow needs during summer in many streams."[92]

Because of the criticisms associated with empirically derived, blanket methodologies such as the Tennant Method, the computerized instream flow incremental

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[87] See note 30, supra.
[88] Bayha, K. "Instrean Flow Methodologies for Regional and National Assessments." US Fish and Wildlife Servies, Instream Flow Information Paper No. 7, December 1978, p. 6.
[89] Vadas, R.L. and D.L. Weigmann. "The Concept of Instream Flow and Its Relevance to Drought Management in the James River Basin." In *James River Basin Drought Preparedness Study*, US Army Corps of Engineers, July 1994, p.D4.
[90] See note 30, supra, p. 6.
[91] Id.
[92] See note 89, supra, p. D6.

methodology (IFIM) has been developed using the Physical Habitat Simulation System (PHABSIM) model.[93] The IFIM is a "habitat-rating method…[that]…is more directly relevant to aquatic ecosystems and organisms because it (a) has a biotic, as well as a hydraulic component and (b) requires multiple transects to better sample aquatic habitats"[94] (for a detailed discussion of IFIM outputs please see Appendix 4.1). The IFIM approach to quantifying minimum instream flows requires an in-depth collection of data and modeling of representative reaches in the stream under consideration in order to develop an optimum strategy for implementation. "Rule of thumb" applications, such as the Tennant Method, require only knowledge of USGS streamflow data that can be applied quickly to the stream under analysis.

2.4.1.2.4 Recreation Demand

Recreation waters are those that sustain such activities as swimming, fishing, boating, canoeing, kayaking, riverrunning (rafting), sailing, and water-skiing.[95] Instream measurements often focus mainly on fish propagation quantities, but "recreation… requirements, at times, may not be the same as for a fishery."[96] Fishery and recreation demand analysis use the same data and techniques, but the conclusions diverge based on the difference in "the response of the individual fish or recreationist to various physical parameters of stream flow."[97] Tennant (1976) recommends 30 percent of mean annual flow for "general recreation" and 60 percent of average flow for "the majority of

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[93] Zappia, H. and D.C. Hayes. "A Demonstration of the Instream Flow Incremental Methodology, Shenandoah River, Virginia." USGS Water-Resources Investigations Report 98-4157, 1998, p. 1.
[94] See note 89, supra, p. D7.
[95] Rea, P. and R. Warren. "Recreation Management and Water Resources." Publishing Horizons, Inc., 1986, p. 1.
[96] Hyra, R. "Methods for Assessing Instream Flows for Recreation." US Fish and Wildlife, Instream Flow Information Paper No. 6, June 1978, p. 1.
[97] Id.

recreational uses."[98] Hyra (1978) recommends two empirical approaches to the estimation of recreation demand: the single cross-section method (SCSM) and the incremental method (a.k.a. IFIM).[99] Both methods require the collection of physical data in the stream. The SCSM, as the name implies, requires a single cross-section measurement strategically located at the "area [in the stream] displaying the least depth" in order to develop minimum flow characteristics for recreational use.[100] The SCSM results are displayed in Table 2.2 as minimum values:

Table 2.2: Minimum stream depths and widths for various recreation activities.[101]

Activity	Depth (ft)	Width (ft)
Canoeing/kayaking	.5	4
Raft	1.0	6
Tube	1.0	4
Power boat	3.0	6
Sail boat	3.0	25

The IFIM, as in fish propagation studies, requires multiple cross-sections in order to develop optimum rather than minimum conditions for recreation activities. Optimum conditions are determined from graphical outputs that indicate probability-of-use as functions of depth and velocity.[102]

2.4.1.2.5 Scenic Demand

Scenic waters "possess outstandingly remarkable scenic…values."[103] The quantification of the amount of water that must remain instream for scenic purposes is difficult to define, but can be protected to insure the beauty of the landscape. The amount

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[98] See note 30, supra, p.6.
[99] See note 96, supra, p.2.
[100] Id., p.3.
[101] Id., adopted from Table 1, p.3.
[102] Id., p.7.

of water that should remain instream is not usually specifically enumerated, but scenic values are generally assumed to be satisfied if other instream requirements, such as fish propagation or water quality maintenance water, are required (see also *2.3.3.1*).

2.4.1.2.6 Water Quality Maintenance Demand

Water quality maintenance waters are those needed so the natural environment can assimilate waste that is discharged into water bodies. The Clean Water Act states the national policy that water quality protection should "maintain the chemical, physical and biological integrity of the Nation's waters…which provides for the protection and propagation of fish, shellfish and wildlife and provides for the recreation in and on the water."[104] Water quality standards evolved from the Water Quality Act of 1965 that required states to develop stream quality standards on interstate waters, a requirement subsequently extended to all surface waters. In order to meet ambient water quality standards at a particular location, the amount of water instream must be able to assimilate any discharged effluent at the specified location. Therefore, from stream standard requirements, it is possible to define a minimum amount of water in the stream that will ensure the assimilation of effluent discharge conditions in a given stream. The regulations of each state will control the means of enforcing the federally required stream standards; states establish stream standards as long as the Environmental Protection Agency (EPA) approves that the standards can be "expected to contribute to the attainment…of such water quality."[105] The states enforce technology based effluent

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[103] United States Code. Title 16. Section 1271.
[104] United States Code. Title 33. Section 1251.
[105] United States Code. Title 33. Section 1312.

limitations at the point of discharge so that the water quality standards in the stream will be met.

2.4.1.2.7 The Controlling Instream Demand Value

Instream flows are often defined as minimally acceptable flows over definitive periods of time; "unfortunately, [minimum instream flows (MIF) are] not one single, unambiguous number that managers can use for all rivers in every situation."[106] Therefore, the amount of water needed instream during low flow periods will vary according to the instream use being considered; generally, the largest value will be the control. Unlike offstream demands, instream demands are not considered additive; a large value will capture and include equal or lesser needs in most cases. The estimation of all instream demands requires an array of flow information; however, a choice of the controlling instream demand allows quantification of the instream portion of the demand.

Hydroelectric demands are generally of large quantities, depending upon the size of the facility, that pass large amounts of stored water through turbines generators for short periods of time. Because the amount of water passing the turbines is large and over short periods, daily average demands can seem to exceed the average daily flow in the river. For instance, within the Upper Roanoke planning area (Plate XIX) in 1995, three hydroelectric facilities used stored water to pass an average of 2864.2 MGD through the turbines used to generate electricity (see Appendix J). However, two of these facilities, Smith Mountain Lake and Leesville Lake, are operated as a pump storage reservoir, an arrangement that allows water passing through the turbines to be pumped back upstream and passed through the turbines repeatedly. As a result, the hydroelectric demand seems to exceed the average annual mean flow at the outlet of the planning area that was estimated as 1363 MGD. However, the hydroelectric demand reported by the USGS does not reflect the amount of water that is recycled, and it would be an unlikely choice for the controlling instream demand.

Instream quantities required for navigation are another unlikely choice for the controlling instream demand in a preliminary assessment of water supply availability. Generally, navigation waters are difficult to define in terms of the flow of water required for certain vessels to pass. Navigational water requirements are often defined on a case by case basis that defines the properties of the channel, particularly depth and width, rather than properties of the flow required to pass specific ships. Certain major coastal waterways, like the Norfolk Port at the mouth of the James River in Virginia, will be required to maintain a specific depth in order to pass deep-draft ships (Hyra (1978) identified similar depth requirements for recreational ships[107], see Table 1.2). The depth requirement complicates the analysis, and determinations of navigation requirements have generally not been made except for specific waterways and individual navigation facilities.

Scenic instream demands are generally not considered the controlling instream except along designated rivers or river sections that have been individually identified. Because scenic demands cannot be assigned a flow parameter that can be used as an indication of the amount of water that should be left instream over a large regional area, scenic demand is not likely to be used as the controlling instream for a preliminary

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[106] See note 89, supra, p.D2.
[107] See note 96, supra, p. 1.

analysis. Although in some cases aesthetics may be the primary concern, scenic demands may be safeguarded by the protection of other instream demands.

Recreation, fish propagation and water quality maintenance are the three instream demands that are most likely to control the amount of water left instream. Choosing a controlling value requires an understanding of the factors that control water availability on each specific stream. Although rules of thumb, such as Tennant's Montana Method for recreational and fish propagation demands, provide an easily instituted methodology, the general application of empirically derived formulas may not account for specific needs at a specific site. Generally it is difficult to choose a value that will provide instream demand protection without a specific analysis of the main waterway in the study area. However, in order to streamline the water supply availability assessment, a controlling instream flow can be chosen to represent all instream uses based on the recommendations of applicable legislation in the planning area or the state.

In Virginia, law does not currently prescribe general instream flow requirements for all waters. However, the $7Q_{10}$ flow parameter is identified by the Department of Environmental Quality (DEQ) as the low flow for the calculation of waste load allocations and total maximum daily load. The Virginia Administrative Code defines assimilative capacity of a stream segment as the "maximum amount of waste that can be discharged…under specified conditions…without violating the minimum stream quality standards."[108] The DEQ regulation determines stream standards using Virginia State Water Control Board (VSWCB) modeling procedures that use the $7Q_{10}$ flow condition as

[108] Virginia Administrative Code. Section 9VAC25-440-150.

an "initial flow" for the calculation of stream wasteload allocations.[109] Flow equivalent to the $7Q_{10}$ is the only instream demand parameter identified by the DEQ as significant to water quality, but a mechanism to require maintenance of such flow does not exist except in locations where special regulatory provisions are in effect (see *2.3.2.1*).

2.4.2 Water Demand in Future Years

Demand projections can be prepared for each sector of offstream use over the planning period and for any recognized instream use. Each category of the offstream demand will be projected according to the growth expected to occur within that category in the specified planning area. Despite sector-specific growth indicators, the growth within each category of the demand may be influenced by the expected population in the planning area. Therefore, population may be a primary indicator for the expected growth in all offstream demand sectors in a planning area. Recognized instream demands may be projected assuming that they will be constant to conditions in the base year but subject to changes in legislative requirements that protect instream uses (see *2.3.2.1*).

2.4.2.1 Offstream Demand in Future Years

The USGS develops unit-value indices of use for offstream water demands. The index of use for each category of demand is developed by dividing the total estimated water demand by the total number of units produced within each demand sector. If it is assumed that the amount of water required to produce each unit remains constant, water-use projection requires only that future units of production be estimated. This approach, however, will not produce accurate estimates of water use if the amount of water used in

[109] Id.

a producing a given unit changes. Even if this approach is adopted, difficulty arises in determining the number of units that will be serviced or produced in the future. It is important to understand that "Since the demand for water is a function of [the amount of product], production, and the technical relationship between a unit of product and the required water input, accuracy of the final figure cannot be divorced from the accuracy of the underlying demographic and production estimates."[110]

Projections of use within the commercial demand sector can serve as an example of the difficulty that arises in attempting to quantify the number of units expected in the future. The USGS recommends that commercial water demands be estimated in terms of an index value such as water used per employee per day for each type of commercial facility. Use of this index requires projection of how many employees are expected in each type of facility in the planning area. In order to predict the number of employees, it becomes necessary to predict the number of each type of commercial facility expected to be in operation during the study period. The number of consumer oriented businesses such as hotels, restaurants, retail stores, and office buildings will be a function of the local economy and the transient and local populations. In order to project the number of each type of commercial facility expected in the area in the future, a detailed analysis of the growth potential for the area must be undertaken in response to the development plans of the local or regional government planning body. However, it is often difficult to determine whether economic or population factors drives the growth potential within the commercial sector of the demand.

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[110] Id.

In spite of the difficulty associated with identifying a single factor that will determine the water use within each sector of the demand, it may be necessary to estimate total demand as a function of a single variable in order to make demand projection manageable at a regional scale. In 1960 the SCNWR made the assumption "that all studies for the committee would be prepared [assuming] that there would be no wars or severe economic depressions, and that our economy would continue to grow roughly at the same rate as it has in the past."[111] Gross national product (GNP) and the Federal Reserve Board index of industrial production (FRBIPP) were recognized as indicators of economic growth in the projection period.[112] Although these measures of economic activity may have indicated future water demand associated with commercial, industrial, mining and manufacturing activities within a region, the SCNWR recognized that "Demand for water is a function of direct consumer demand and demand for products that require water."[113] Therefore, by eliminating significant economic changes and relating water demand to the number of consumers, the SCNWR projected water demand as a function of projected population. [114]

2.4.2.1.1 Population as an Indicator of Offstream Demand in Future Years

> "The way in which the future demand for water was estimated depended upon its use. Except for navigation and hydroelectric power, however, all projections were ultimately related to changes in national or regional population."[115]

Population can be a general indicator of total offstream water withdrawal requirements in the future. Although economic conditions play a significant role in water

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[111] U.S. Congress Select Committee on National Water Resources. "Water Resources Activities in the United States: Population Projections and Economic Assumptions." Committee Print Number 5, March 1960, p.1.
[112] See note 45, supra, p.3.
[113] Id., p. 2.
[114] Id., p.16.

demand projection, the local economy is significantly stimulated by the population, and, therefore, population can be seen as the first cause of an increasing need for water. Although population is generally recognized only as a direct indicator of the amount of water needed for domestic purposes, if economic conditions are assumed to continue to grow consistent to historical trends, population can be used as the determinant of future total offstream demand.

Along with the reporting of demand estimates within each cataloging unit, the USGS reports an estimate of the planning area population in each year that the demand is evaluated so that per capita indices can be determined. The planning area population can be projected from USCB state population projections using the Ratio method. Irwin and the Census Bureau (1977) identify the Ratio method for projecting the population "as [using] shares or ratios of a larger, or 'parent' population for which a projection already exists"[116] to estimate projections in the smaller area. The Ratio method identifies the historical trend of the ratio of the smaller population to the larger population and projects the population into the future based on the assumption that the ratio determined from the historical data will remain constant.[117] The procedure for the preliminary assessment of water supply availability uses the Ratio method to determine the ratio of the population in the planning area in the base year to the total state population in the base year and multiplying that ratio by the available USCB projections.

Assuming per capita use and the distribution of the state population within the planning area will remain constant in the future (see *2.3*), the total daily offstream need

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[115] Id., p. 16.
[116] Irwin, John. "Guide for Local Population Projections." US Department of Commerce, Bureau of the Census, Technical Paper 39, 1977, p. 14.

for water can be calculated as a product of the number of persons expected to inhabit the study area and the expected per capita use. However, this approach is limited by assuming that total offstream demand, including industrial withdrawals, is a function solely of population and that per capita use will be stable.

The USGS has indicated that total per capita use has declined since 1980 as indicated in Figure 2.9.

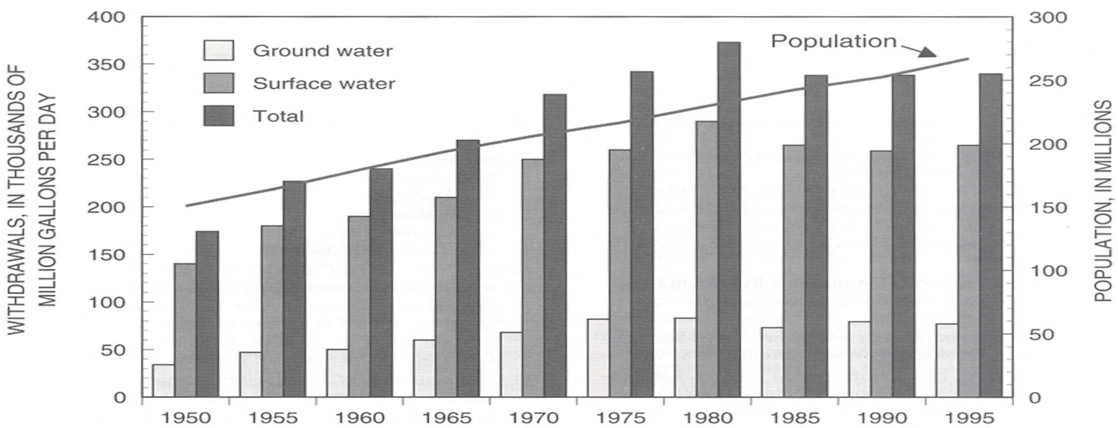

Figure 2.9: Trends in water use through 1995.[118]

Figure 2.9 shows that despite a steady increase in population, total water withdrawals in the United States have remained relatively stable since 1985 at approximately 325,000 MGD. If per capita use continues to decrease and the projection assumes total per capita use will remain constant, the resulting projection may be an overestimate of expected demand.

[117] Id.
[118] See note 78, supra, p. 65.

2.4.2.1.2 Consumption in Future Years

With projections of offstream demand from population, consumption projections can be made based on the consumption rate in the base year. Because projections of the offstream demand include only those sectors that consume a portion of the water withdrawn, the consumption can be projected as a function of the projected offstream demand. The USGS reports the amount of water consumed in each sector of the demand. Although consumption may vary per sector, the total amount of consumption in the planning area is the focus of the preliminary assessment, and like the total demand, consumption will be projected as a total rather than for individual categories. The consumption rate in the base year can be calculated by dividing the total reported consumption by the total offstream demand, which will result in the consumption rate in the base year. The base year consumption rate is assumed to remain constant, like the total per capita demand, and multiplied by the total offstream demand projection to indicate the amount of water consumed. The assumption that consumption rates will remain constant may not be the case in the future; as water use becomes more efficient and recycling rates increase, consumption rates as a portion of withdrawals may increase. However, because the intention of the analysis is to indicate an overview of water supply availability, the consumption rate will be assumed to remain constant.

2.4.2.2 Instream Demand in Future Years

Instream uses are difficult to anticipate under future conditions because of the need to quantify non-withdrawal demands on a case-by-case basis. As has been mentioned, the largest of the instream demands on each river can be assumed the controlling value, because if it is satisfied, each of the lesser demands will be fulfilled.

Just as the flow conditions chosen to represent water supply will be assumed to remain constant (see *2.3.3*), an instream demand equivalent to one of the low flow parameters is assumed to remain constant, subject to potential impacts that future legislation may have on future instream demand requirements (see *2.3.3.1*).

2.4.2.3 Total Demand in Future Years

Total projected offstream and instream demand estimates can be combined to indicate the total demand that will be needed in the study area. The future total water demand can then be compared to future estimates of water supply availability in order to indicate future water supply availability if the controlling instream demand is not considered available for use.

2.5 Preliminary Assessment of Water Supply Availability

> "The BRN [balance of water resources and needs] is compiled by comparing the existing water resources (input side) with the water demands (output side), so that the measures necessary for satisfying [or reducing] the demands can be evaluated…The long-term BRN (balance of water resources and needs) is in general established for a period beyond the implementation of the development plan, i.e. for a period beyond 15 years. Its purpose is to check whether the water management concepts are valid for the long term. Its accuracy is open to doubt, but it may be influential in shaping the national economy."[119]

The procedure for preliminary assessment culminates in a determination of water supply availability within the planning area at a given time. Assuming all the preceding estimates and projections have been determined for a common planning area (i.e., a USGS demand cataloging unit), the estimation of water supply availability should be relatively simple to obtain. The base year water supply availability conditions can be described by subtracting the total daily offstream demand from the supply estimates within the planning area. Similarly, water supply availability in the future years can be projected by subtracting projected demand from projected supplies. The resulting surplus or deficit of supply indicates the potential for or need for water resource development at the specified time in the planning area.

Water supply availability can also be described including an instream demand as part of the total daily demand. Depending upon the quantity that may represent the instream demand in the state or region under investigation, the total daily demand can be estimated as the total daily offstream demand and the instream demand quantity. A particular point of interest is that if the instream water demand is represented by a low flow parameter, the preliminary assessment will always indicate a deficit under the total demand condition when the instream flow condition occurs. However, the preliminary assessment does not include local storage facilities that currently exist to reduce the effect of naturally occurring low flow conditions.

2.5.1 Limitations of the Preliminary Assessment of Water Supply Availability

Because the procedure for preliminary assessment contains simplifying assumptions and is developed over the long term, the conclusions should be viewed as approximations of water supply availability in the designated planning area as a whole. The procedure is intended to give an overview of the potential for water supply problems in the given regional area without providing detail about water supply storage, treatment or distribution at the individual city, town or county municipal scale. Actual local

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[119] United Nations. "Manual for the Compilation of Balances of Water Resources and Needs." United Nations Publication ECE/WATER/5, 1974, p. 44- 45.

conditions may be substantially better or worse than indicated by the generalized regional approach.

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3. Illustration of the Procedure for Preliminary Assessment of Water Supply Availability: the Upper Roanoke Planning Area of Virginia

3.1 The Upper Roanoke Planning Area

Chapter 3 uses the Upper Roanoke planning area in Virginia to illustrate in detail the application of the overview assessment methodology outlined in Chapter 2. The Upper Roanoke planning area is coincidental with USGS cataloging unit 03010101 and is between 60 and 70 miles from its upstream to downstream boundaries.

Figure 3.1: USGS cataloging unit 03010101 represents the Upper Roanoke planning area.

Within the planning area are portions of the Cities of Bedford, Roanoke and Salem and portions of Bedford, Botetourt, Campbell, Floyd, Franklin, Henry, Pittsylvania and Roanoke Counties as shown in Table 3.1.

Table 3.1: The portions of municipal jurisdictions in the Upper Roanoke planning area.

Jurisdiction	Acres	Sq. miles
Bedford City	4,327.9	6.76
Roanoke City	27,141.9	42.41
Salem City	9,201.5	14.38
Bedford County	423,894.2	662.33
Botetourt County	44,018.3	68.78
Campbell County	79,648.2	124.45
Floyd County	19,129.2	29.89
Franklin County	386,867.9	604.48
Henry County	7,549.4	11.80
Montgomery County	121,146.7	189.29
Pittsylvania County	134,458.1	210.09
Roanoke County	144,280.7	225.44
TOTAL	**1,401,664.0**	**2,190.10**

Included in the Upper Roanoke planning area are the Roanoke River mainstream and minor tributaries that are represented by Virginia hydrologic units L01 through L29 as listed in Table 3.2 and pictured in Figure 3.1.

Table 3.2: The Virginia hydrologic units included in the Upper Roanoke planning area.

L01	88,608	South Fork Roanoke River--Bottom Creek--Elliott Creek	138.45	6.32%
L02	74,077	North Fork Roanoke River--Bradshaw Creek	115.74	5.28%
L03	40,545	Upper Roanoke River	63.35	2.89%
L04	53,302	Roanoke River--Mason Creek	83.28	3.80%
L05	71,628	Tinker Creek--Carvin Creek--Glade Creek	111.92	5.11%
L06	37,546	Back Creek	58.67	2.68%
L07	94,855	Roanoke River--Smith Mountain Lake--Beaverdam Creek	148.21	6.76%
L08	75,652	Upper Blackwater River	118.21	5.39%
L09	29,184	Maggodee Creek	45.60	2.08%
L10	45,837	Lower Blackwater River--Smith Mountain Lake	71.62	3.27%
L11	27,352	Gills Creek	42.74	1.95%
L12	12,096	Lower Smith Mountain Lake	18.90	0.86%
L13	41,783	Leesville Lake--Old Womans Creek	65.29	2.98%
L14	69,593	Upper Pigg River	108.74	4.96%
L15	39,222	Big Chestnutt Creek--Little Chestnutt Creek	61.28	2.80%
L16	23,277	Middle Pigg River	36.37	1.66%
L17	66,059	Snow Creek--Turkeycock Creek	103.22	4.71%
L18	52,840	Lower Pigg River	82.56	3.77%
L19	45,989	Roanoke River--Sycamore Creek	71.86	3.28%
L20	38,992	Upper Goose Creek	60.93	2.78%
L21	62,799	Middle Goose Creek--Bore Auger Creek--Wolf Creek	98.12	4.48%
L22	63,017	Lower Goose Creek	98.46	4.49%
L23	34,766	Upper Big Otter River	54.32	2.48%
L24	32,427	North Otter Creek	50.67	2.31%
L25	42,829	Big Otter River--Elk Creek	66.92	3.05%
L26	44,269	Little Otter River--Machine Creek	69.17	3.16%
L27	44,636	Big Otter River--Buffalo Creek	69.74	3.18%
L28	27,661	Lower Big Otter River	43.22	1.97%
L29	21,594	Flat Creek	33.74	1.54%
TOTAL	1,402,434		2191.30	100.00%

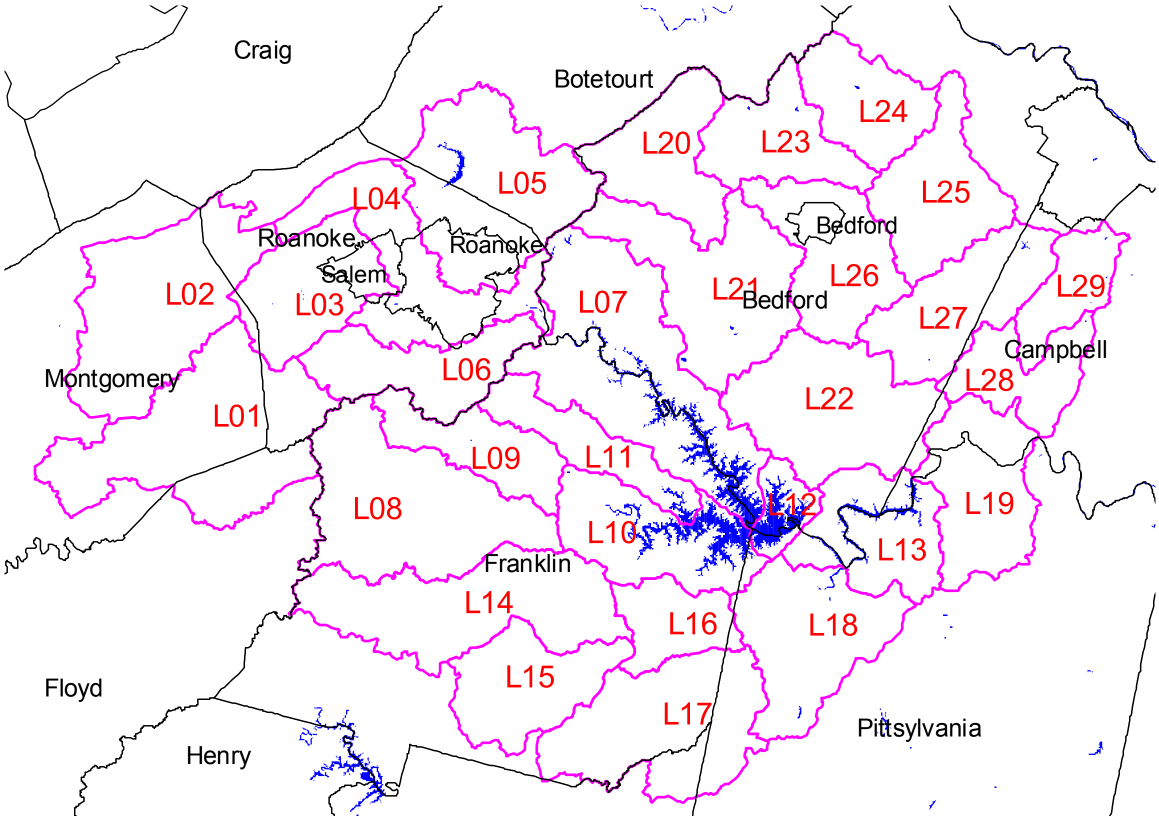

Figure 3.2: The hydrologic units that are included in the Upper Roanoke planning area.

The planning area includes water stored for hydroelectric purposes in Smith Mountain Lake and Leesville Lake that have been in operation since 1962. The downstream point of the planning area is at the confluence of the Roanoke and Big Otters Rivers at the outlets of hydrologic units L19 and L28. USGS gage 02060500 on the Roanoke River is located about 5 miles upstream from the downstream point of the planning area.

3.2 Water Supply Estimates and Projections in the Upper Roanoke Planning Area

In Chapter 2, surface water gages were assumed to include available groundwater as groundwater discharge to the stream over the long term. USGS gage 02060500 on the Roanoke River at Altavista, Virginia was chosen as the gage that will represent the supply in the Upper Roanoke planning area because it was the most downstream gage and has record flow information since water year 1932. Supply estimates and projections will be made from the gage data.

3.3.1 Water Supply in the Upper Roanoke Planning Area in 1998

With continuous flow measurements at USGS gage 02060500 on the Roanoke River, the supply estimate for the base year can be estimated. The gage has recorded flow information continuously since 1932. The base year for the Upper Roanoke planning area analysis for the supply estimates was chosen to be 1998, because 1998 was the most current year of USGS stream gage data at the beginning of this analysis. In 1998, the flow parameters in Table 3.3 were developed from continuous measurements from 1789 square miles of drainage and were available at the gage.

Table 3.3: Flow estimates at USGS gage 02060500 on the Roanoke River.

Flow Parameter	Gage (cfs)	Gage (MGD)
Q_{AM} (1963-1998)	1723	1113.5
Q_{AM} (1932-1962)	1940	1253.8
$7Q_2$ (1932-1962)	492	318.0
$7Q_{10}$ (1932-1962)	266	171.9
$1Q_{30}$ (1930-1977)	49	31.7
Q_{95} (1932-1962)	440	284.4
Q_{90} (1963-1998)	267	172.6
Q_{90} (1932-1962)	542	350.3
Q_{50} (1963-1998)	1030	665.7
Q_{50} (1932-1962)	1310	846.6
MBF_{est} (1932-1962)	1267	818.8
Q_{10} (1932-1962)	3590	2320.1
Q_{10} (1963-1998)	3440	2223.2

The flow parameters have been split into two periods to account for the regulation of streamflow introduced by putting the reservoirs online in 1963. The average annual mean flow and the flows equalled or exceeded 90, 50, and 10 percent of the time (Q_{90}, Q_{50}, and Q_{10}, respectively) came from records through 1998 that show the average annual mean under regulated and non-regulated conditions before and after 1963.[120] The lowest consecutive seven day average flow expected to occur once every two years ($7Q_2$), the lowest consecutive seven day average flow expected to occur once every ten years ($7Q_{10}$), the flow equalled or exceeded 95 percent of the time (Q_{95}), and the estimate of mean baseflow (MBF_{est}) were determined from unregulated streamflow conditions.[121] The mean baseflow estimate was made by Nelms, et. al (1997) at select USGS stream gages in the Valley and Ridge, Blue Ridge, and Piedmont physiographic provinces of Virginia in order to "indicate the long-term average contribution of groundwater to streams."[122] The lowest average one day flow expected to occur once every thirty years was determined by the Virginia State Water Control Board from records between 1932 and 1977, which does not account for the change in streamflow conditions because of upstream regulation.[123]

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[120] See note 28, supra, p. 385.
[121] Nelms, D.L., G.E. Harlow, Jr. and D.C. Hayes. "Base-flow Characteristics of Streams in the Valley and Ridge, the Blue Ridge and the Piedmont Physiographic Provinces of Virginia." US Geological Survey Water Supply Paper 2457, 1997, App. 1
[122] Id., p.8.
[123] Virginia State Water Control Board. "Hydrologic Analysis of Virginia Streams, volume II: South Atlantic Slope Basin." VSWCB Basic Data Bulletin 57, November 1982, p. xx.

3.3.1.1 Supply Estimates at the Outlet of the Upper Roanoke Planning Area in 1998

Because the gage captures 1789 square miles of the 2190 square mile planning area, the flow parameters at gage 02060500 at Altavista, Virginia on the Roanoke River need to be transferred downstream to the confluence of the Roanoke and Big Otter Rivers. Table 3.3 indicated all the flow parameters that have been determined at the gage location as of 1998. In order to equalize the supply and demand areas, it is necessary to express the flow conditions at the downstream outlet of the demand cataloging unit five miles downstream from the gage location. Between the gaging point in Altavista and the outlet of the cataloging unit near Hodges, Virginia, the Big Otter River contributes flow to the Roanoke River from hydrologic units L23-L29. By transferring the gage data downstream, the drainage from the Little and Big Otter Rivers is included as ungaged area and increases the total drainage area by 400.9 square miles (22.4% of the initial drainage). Table 3.4 displays selected flow parameters if adjusted according to VSWCB transfer methodology (*see 2.3.2.1*) is applied to gage 02060500.

Table 3.4: Flow values at USGS gage 02060500 transferred to the outlet of the planning area.

Flow Parameter	Gage (cfs)	Gage (cfs/mi^2)	Adjusted (cfs)	Adjusted (MGD)
Q_{AM}	1723	0.9631	2109.1	1363
60% Q_{AM}	1034	0.5780	1265.7	818
30% Q_{AM}	517	0.2890	632.9	409
20% Q_{AM}	345	0.1928	422.3	273
10% Q_{AM}	172	0.0961	210.5	136
5% Q_{AM}	86	0.0481	105.3	68
$7Q_{10}$	266	0.1487	325.6	210
$1Q_{30}$	49	0.0274	60.0	38
Q_{90}	267	0.1492	326.8	211
Q_{50}	1030	0.5757	1260.8	814
Q_{10}	3440	1.9229	4210.9	2724

The adjusted values included in Table 3.4 are those parameters that are most often associated with water supply discussions (see *2.3.2*). Average annual mean flow is included because it represents the average flow over each year in the period of record in the Upper Roanoke planning area. Five, ten, and twenty percent of the average annual mean flow have been included in order to express the feasibility of capture thresholds at the outlet of the planning area (see *2.3.2.2*). Ten, thirty and sixty percent of annual flow have been included to indicate recreation and fish propagation conditions within the planning area (see *2.3.2.1* and *2.4.2.2.3*). The $7Q_{10}$ parameter has been included because it is used as the low flow condition for calculating total maximum daily loads in Virginia and the Upper Roanoke planning area (see *2.3.2.1* and *2.4.2.2.7*). The $1Q_{30}$ parameter has been included because it is used to represent the safe yield of instream supply systems in Virginia and the Upper Roanoke planning area (see *2.3.2.1*).

As was discussed previously (see *2.3*), the stream gage measurements in the Upper Roanoke planning area are assumed to include the long-term groundwater discharge to the stream. However, a portion of the 1995 demand was satisfied by direct groundwater withdrawals that may not be included in the supply estimates from Roanoke River gage data. In 1995, 12.52 MGD was supplied from direct groundwater withdrawals, representing about 22% of the total supply utilized in 1995. Although the supply estimate assumes long-term groundwater availability is included in the gage measurements, the amount of groundwater used as a supply source in 1995 may be an important factor in a more detail intensive study of the planning area.

3.3.2 Water Supply in the Upper Roanoke Planning Area in the Future

Projections of supply in the Upper Roanoke planning area can be made from the supply estimates made in the base year, 1998 in this case. Keeping in mind the impact of potential legislative change at the Federal and/or state levels (see *2.3.3.1*), the supply projections can be made for each specified year of the planning period assuming that the estimated flow parameters will remain constant to the estimates indicated in Table 3.4. Although planning areas located downstream from other planning areas may have to have supply projections adjusted for projected consumption (see *2.3.3.2*), the Upper Roanoke planning area is a headwater planning area and does not need to have supply projections adjusted for projected consumption.

3.3 Water Demand Estimates and Projections in the Upper Roanoke Planning Area

Demand in the Upper Roanoke planning area was estimated and projected as the total offstream demand (i.e., those offstream demands that consumed a portion of the withdrawal) and as the instream demand. The two can be combined to indicate the total estimated and projected demand amounts. The base year of the Upper Roanoke planning area assessment was chosen to be 1998 (as discussed in *3.3.1*), and, as a result, the 1995 USGS offstream data had to be used as to estimate the 1998 base year condition.

3.3.1 Water Demand in the Upper Roanoke Planning Area in 1998

3.3.1.1 Offstream Demand in the Upper Roanoke Planning Area in 1998

The total freshwater offstream demand of 57.54 MGD within the Upper Roanoke planning area in 1995 was distributed as shown in Table 3.5 (all values in MGD).

Table 3.5: Demand in the Upper Roanoke planning area in 1995.[124]

UPPER ROANOKE

1995 Population	345,840
TOTAL FRESH OFFSTREAM USAGE (MGD)	57.54
Per Capita Withdrawal (gpcd)	166.38
Total consumptive uses (MGD)	57.10
Per capita consumptive uses (gpcd)	165.11
Withdrawal plus hydroelectric (gpcd)	2,921.30
Per capita plus hydroelectric (gpcd)	8,446.97

FRESH WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	5.66	5.66	n/a
PS Domestic	n/a	n/a	21.62	n/a
Total Domestic	**n/a**	**n/a**	**27.28**	**2.73**
SS Commercial	2.32	4.25	6.57	n/a
PS Commercial	n/a	n/a	6.06	n/a
Total Commercial	**n/a**	**n/a**	**12.63**	**1.52**
SS Industrial	5.18	0.16	5.34	n/a
PS Industrial	n/a	n/a	4.16	n/a
Total Industrial	**n/a**	**n/a**	**9.5**	**1.14**
SS Thermoelectric	0.44	0	0.44	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0.44**	**0**
Mining	**0.01**	**0.01**	**0.02**	**0**
Livestock	3.96	2.33	6.29	6.29
Animal Specialties	0.01	0.01	0.02	0.02
Total Livestock	**3.97**	**2.34**	**6.31**	**6.31**
Irrigation	**1.25**	**0.11**	**1.36**	**0.9**
FRESH TOTAL	**n/a**	**n/a**	**57.54**	**12.6**

SALINE WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	2864.2	0	2864.2	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-0.11	n/a
WW Returns (MGD)	n/a	n/a	36.85	n/a
Reservoir Evap (AC-FT/yr)	44570	n/a	44570	44570

[124] "Downloading 1995 water-use data." US Geological Survey, February 19, 1999. http://water.usgs.gov/watuse/spread95.html. "Virginia."

Table 3.5 indicates that in 1995 a total of 57.54 MGD was withdrawn for offstream use. Of the 57.54 MGD withdrawn, .44 MGD was used for thermoelectric uses in a nonconsumptive capacity. Therefore, the total offstream use, indicated in column 2 and row 4 at the top of the table, was 57.10 MGD. When the total offstream demand of 57.10 MGD was divided by the 1995 USGS population estimate within the Upper Roanoke planning area, the per capita use was 165.11 gallons per capita per day (gpcd). This per capita estimate includes 9.5 MGD, or 16% of the total offstream demand, that was used for industrial applications. The amount of water consumed of the 57.10 MGD offstream withdrawal was 12.6 MGD, or 22% of the offstream withdrawal. In 1995, 36.85 MGD of water (nearly 65% of the offstream withdrawal) was returned to the Upper Roanoke planning area via wastewater treatment plants. Table 3.5 contains demand information per sector about the Upper Roanoke planning area, but only the total offstream demand will be considered in the preliminary analysis. However, the detailed per sector information maybe useful for a more in-depth demand analysis at the municipal or individual water supply system scale.

The total 1995 offstream demand per capita expression was used to estimate the total offstream demand in the Upper Roanoke planning area in 1998. With an estimate of per capita use in 1995 and the assumption that per capita use in 1998 was equal to per capita use in 1995, the demand in the base year was estimated as a function of the 1998 population. But before developing the 1998 offstream demand estimate, it was necessary to estimate the 1998 population in the Upper Roanoke planning area.

3.3.1.1.1 Population in the Upper Roanoke Planning Area in 1998

The population for the planning area in 1998 was estimated from municipal population densities developed from USCB 1998 county and city population estimates and municipal land area contributing to cataloging unit 03010101in 1998. The 1998 USCB population estimates for the municipalities[125] were divided by the total land area in order to develop population densities as shown in Table 3.6.

Table 3.6: 1998 population densities by municipality in the Upper Roanoke planning area.

	1998 population	Area(mi.^{2})	pop.dens./m
Bedford City	6,317	6.76	934.12
Bedford County	55,872	769.31	72.63
Botecourt County	28,561	545.54	52.35
Campbell County	50,335	505.95	99.49
Floyd County	13,091	381.27	34.34
Franklin County	44,358	711.23	62.37
Henry County	55,627	383.71	144.97
Montgomery County	75,878	388.45	195.34
Pittsylvania County	57,384	977.70	58.69
Roanoke City	93,749	42.41	2,210.57
Roanoke County	80,839	251.53	321.39
Salem City	24,679	14.38	1,716.61

The 1998 population densities were then multiplied by the land area of each municipality contained in the planning area as shown in Table 3.7.

[125] U.S. Census Bureau. "County Population Estimates for July 1, 1999 and Population Change: July 1, 1998 to July 1, 1999." March 9, 2000.

Table 3.7: 1998 population estimates for the Upper Roanoke planning area.

Jurisdiction	Sq. miles	pop./mi2	pop(f(mi2))
Bedford City	6.76	934.12	6,317
Bedford County	662.33	72.63	48,103
Botetourt County	68.78	52.35	3,601
Campbell County	124.45	99.49	12,381
Floyd County	29.89	34.34	1,026
Franklin County	604.48	62.37	37,700
Henry County	11.80	144.97	1,710
Montgomery County	189.29	195.34	36,976
Pittsylvania County	210.09	58.69	12,331
Roanoke City	42.41	2210.57	93,749
Roanoke County	225.44	321.39	72,454
Salem City	14.38	1716.61	24,680
TOTAL	**2,190.10**	160.28	**351,028**

With the 1998 Upper Roanoke planning area population estimate, the 1998 offstream demand estimate was developed as a function of the population.

3.3.1.1.2 Offstream Demand as a Function of Population in 1998

The total offstream demand in 1998 was estimated as a function of the 1998 population. The total 1998 population estimate of 351,028 people was approximated as 351,000 people and multiplied by the 1995 gpcd index of 165.11 gpcd to indicate a total offstream demand of 57.95 MGD in 1998. The amount of water consumed in 1998 was estimated as 22% of the total offstream demand, as in 1995, equivalent to 12.75 MGD.

3.3.1.2 The Controlling Instream Demands in the Upper Roanoke Planning Area in 1998

Specific sites within the Upper Roanoke planning area are limited by instream requirements. For instance, the US Army Corps of Engineers (COE) requires that flows downstream of the Roanoke County Spring Hollow water supply reservoir at USGS gage 02054530 at Glenvar meet requirements specified in the COE issued Army Permit 84-0404-06. Items 13, 14 and 15 of the permit require that flows in the Roanoke River as measured at the Glenvar USGS gage be required to be 40 percent of mean annual flow (MAF) or the natural flow in April and May, 30 percent MAF or natural flow from June to March under normal water supply conditions, and 20 percent MAF or natural flow from June to March under emergency water supply conditions. Emergency water supply conditions are in effect if Spring Hollow has less than 100 days of water supply remaining, at which time the flowby requirements are relaxed.

A flow equivalent to the $7Q_{10}$ supply estimate in Table 3.4, 210 MGD, was designated as the controlling instream demand in 1998 in the Upper Roanoke planning area. Although the protection of fish propagation and recreational waters (quantified by empirical methods such as those determined by Tennant - see *2.4.2.2.3*) is a concern in the Upper Roanoke planning area and Virginia, there is not means of enforcing the maintenance of minimum instream flows. Despite language in the Constitution of the Commonwealth that suggests "the use of and enjoyment for recreation of adequate public …waters,"[126] protection of recreation and fish habitat instream demands is not mandated by law. The $7Q_{10}$ is recognized as the basis for TMDL calculations, but $7Q_{10}$ conditions cannot be ensured to be in the stream under all flow conditions and may not fully protect aquatic habitat or sustain recreational use. However, because TMDL calculations are based on $7Q_{10}$ as the minimum flow that will ensure stream quality standards, it seems the most likely controlling instream demand value in 1998.

3.3.1.3 Total Demand in the Roanoke Planning Area in 1998

The total demand in the Upper Roanoke planning area can be expressed as the sum of the offstream demand estimate in 1998 and the controlling instream demand. Table 3.8 indicates the total demand as the sum of the 1998 offstream and instream demands.

Table 3.8: Total demand in the Upper Roanoke planning area in 1998.

Offstream Demand	57.95 MGD
Instream Demand	210 MGD
Total Demand	267.95 MGD

3.3.2 Demand in the Upper Roanoke Planning Area in Future Years

3.3.2.1 Offstream Demand in the Upper Roanoke Planning Area in Future Years

In the Upper Roanoke planning area in 1995, cataloging unit 03010101 withdrew 57.10 MGD of offstream demand and had 345,840 people inside its boundaries, a per capita use of was 166 gpcd. The expected offstream demand was projected based on the planning area population projections through 2025 that were developed from U.S. Census Bureau population projections. Therefore, in order to project the offstream demand, it was necessary to project the planning area population.

3.3.2.1.1 Population Projections for the Upper Roanoke Planning Area

Population in the Upper Roanoke planning area was projected using the Ratio method of population projection.[127] The 1998 population ratio of .0515 was developed by dividing the 1998 population estimate for the planning area, 351,028 people, by the 1998 population estimate for the Commonwealth, 6,819,937 people.[128] The 1998 population ratio was assumed to remain constant for each future year of the projection period and multiplied by the USCB population projections for Virginia[129] as shown in Table 3.9.

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[126] Virginia Constitution. Article XI. Section 1.
[127] See note 116, supra.
[128] See note 125, supra.

Table 3.9: Projected population in the Upper Roanoke planning area using the Ratio Method.

YEAR	VA population	Upper Roanoke population
2000	6,997,000	360,141
2005	7,324,000	376,972
2015	7,921,000	407,701
2025	8,466,000	435,752

3.3.2.1.2 Offstream Demand as a Function of Future Population

With population projections for the Upper Roanoke planning area, offstream demand can be projected based on the per capita usage in 1998. The per capita usage in the Upper Roanoke planning area in 1998 was 165.11 gpcd, the per capita total offstream demand from the 1995 USGS demand data, and is assumed constant in the demand projection in Table 3.10. The offstream demand was projected by multiplying the 1995 per capita demand by the approximate population projections. Consumption was projected assuming the 22% consumption rate from the 1995 data will remain constant.

Table 3.10: Projected offstream demand and consumption in the Upper Roanoke planning area.

YEAR	Population	Offstream Demand	Consumption
2000	360,100	59.46 MGD	13.12 MGD
2005	377,000	62.25 MGD	13.74 MGD
2015	407,700	67.32 MGD	14.86 MGD
2025	435,800	71.95 MGD	15.88 MGD

3.3.2.2 Instream Demand in the Upper Roanoke Planning Area in the Future

A flow equivalent to $7Q_{10}$ was chosen as the controlling instream demand in Virginia because of its use in State Water Control Board modeling procedures to determine daily stream wasteload allocations. Because the $7Q_{10}$ flow estimate is derived

[129] U.S. Census Bureau. "State Population Projections." April 22, 1999. http://www.census.gov/population/projections/state/stpjpop.txt

from data measured at the Altavista gage from 1932-1962 under unregulated flow conditions, the instream demand will be assumed to remain constant at 210 MGD.

3.3.2.3 Total Demand in the Upper Roanoke Planning Area in the Future

The total projected demand in the Upper Roanoke planning area can be expressed as the sum of the offstream and instream demand projections. Table 3.11 indicates the total projected demand for 2000, 2005, 2015, and 2025.

Table 3.11: Projected total demand in the Upper Roanoke planning area.

YEAR	2000	2005	2015	2025
Instream Demand	210 MGD	210 MGD	210 MGD	210 MGD
Offstream Demand	59.5 MGD	62.3 MGD	67.3 MGD	72.0 MGD
Total Demand	**269.5 MGD**	**272.3 MGD**	**277.3 MGD**	**282.0 MGD**

3.4 Water Supply Availability

With estimates and projections of supply and demand, the water balance can be used to indicate water supply availability in the Upper Roanoke planning area. Water supply availability in the base year and in the future can be assessed by comparing supply conditions in the specified year to offstream demand and total demand to indicate the impact of instream demand protection. In order to demonstrate the effects of changes in the Upper Roanoke planning area population on water supply availability, the deficit or surplus of water supply can also be expressed per capita.

3.4.1 Water Supply Availability in 1998 in the Upper Roanoke Planning Area

Table 3.12 describes the relationship of current offstream demand, 57.97 MGD, to water supply estimates on the Roanoke River at the downstream outlet of the Upper Roanoke planning area in 1998. The offstream demand has been compared to the supply estimates in Table 3.4.

Table 3.12: Offstream demand water supply availability in the Upper Roanoke planning area in 1998.

Flow Parameter	Supply (MGD)	1998 Off. Demand (MGD)	Deficit/surplus (MGD)	Deficit/surplus (gpcd)
Q_{AM}	1363	58	+1305	+3718
20% Q_{AM}	273	58	+215	+612
10% Q_{AM}	136	58	+78	+222
5% Q_{AM}	68	58	+10	+28
$7Q_{10}$	210	58	+152	+433
$1Q_{30}$	38	58	-20	-57
Q_{90}	211	58	+153	+436
Q_{50}	814	58	+756	+2154
Q_{10}	2724	58	+2666	+7595

When compared to the average annual mean, the withdrawal of 59.75 MGD will allow about 96% percent of the annual mean, more than 1300 MGD, to pass the downstream point. Water supply availability surpluses can also be expected to exist under the $7Q_{10}$, Q_{90} and Q_{50} conditions. However, under $1Q_{30}$ flow conditions, the 1998 offstream demand exceeds the streamflow supply estimate by 20 MGD. The estimated deficit under $1Q_{30}$ conditions suggests the reason for the existence of local storage facilities in the Upper Roanoke planning area that have not been included in this preliminary assessment.

If the 1998 total demand, 268 MGD, equivalent is compared to each streamflow estimate, the water supply availability in the Upper Roanoke planning area changes considerably.

Table 3.13: Total demand water supply availability in the Upper Roanoke planning area in 1998.

Flow Parameter	Supply (MGD)	1998 Total Demand (MGD)	Deficit/surplus (MGD)
Q_{AM}	1363	268	+1095
$7Q_{10}$	210	268	-58
$1Q_{30}$	38	268	-230
Q_{90}	211	268	-57
Q_{50}	814	268	+546
Q_{10}	2724	268	+2456

The water balance indicates that water supply availability under the total demand condition may be deficient under $7Q_{10}$, $1Q_{30}$, and Q_{90} flow conditions. The water supply availability is not assessed for the 5, 10, and 20 percent of the average annual mean flow in Table 3.3 because these expressions of maximum streamflow capture apply only to the offstream demand condition. The deficits in Table 3.13 indicate the need for the artificial storage that has been developed in the Upper Roanoke planning area and has not been included in the supply estimate. Also not included in the supply estimates is the amount of water that can be withdrawn from groundwater under short-term emergency conditions without affecting the long-term contribution of groundwater to the surface system.

3.4.2 Water Supply Availability in Future Years in the Upper Roanoke Planning Area

Table 3.14 displays the water supply availability by comparing projected water supply and projected offstream demand in the Upper Roanoke planning area in 2000, 2005, 2015, and 2025.

Table 3.14: Offstream demand deficits and surpluses in the Upper Roanoke planning area.

YEAR	2000	2005	2015	2025
Offstream Demand	**59.5 MGD**	**62.3 MGD**	**67.3 MGD**	**72.0 MGD**
$1Q_{30}$ supply estimate	39 MGD	39 MGD	39 MGD	39 MGD
DEFICIT	**- 20.5 MGD** **- 57 gpcd**	**- 23.3 MGD** **- 62 gpcd**	**- 28.3 MGD** **- 69 gpcd**	**- 33.0 MGD** **- 76 gpcd**
$7Q_{10}$ supply estimate	210 MGD	210 MGD	210 MGD	210 MGD
SURPLUS	**+150.5 MGD** **+418 gpcd**	**+147.7 MGD** **+392 gpcd**	**+142.7 MGD** **+350 gpcd**	**+138.0 MGD** **+317 gpcd**
Q_{90} supply estimate	211 MGD	211 MGD	211 MGD	211 MGD
SURPLUS	**+151.5 MGD** **+421 gpcd**	**+148.7 MGD** **+394 gpcd**	**+143.7 MGD** **+352 gpcd**	**+139.0 MGD** **+319 gpcd**
Q_{50} supply estimate	814 MGD	814 MGD	814 MGD	814 MGD
SURPLUS	**+754.5 MGD** **+2095 gpcd**	**+751.7 MGD** **+1994 gpcd**	**+746.7 MGD** **+1831 gpcd**	**+742.0 MGD** **+1703 gpcd**
5%Q_{AM} supply estimate	68 MGD	68 MGD	68 MGD	68 MGD
Surplus/Deficit	**+8.5 MGD** **+24 gpcd**	**+5.7 MGD** **+15 gpcd**	**+0.7 MGD** **+2 gpcd**	**- 4.0 MGD** **- 9 gpcd**
10%Q_{AM} supply estimate	136 MGD	136 MGD	136 MGD	136 MGD
SURPLUS	**+76.5 MGD** **+212 gpcd**	**+73.7 MGD** **+195 gpcd**	**+68.7 MGD** **+169 gpcd**	**+72.0 MGD** **+165 gpcd**
20%Q_{AM} supply estimate	273 MGD	273 MGD	273 MGD	273 MGD
SURPLUS	**+213.5 MGD** **+593 gpcd**	**+210.7 MGD** **+559 gpcd**	**+205.7 MGD** **+505 gpcd**	**+201.0 MGD** **+461 gpcd**
Q_{AM} supply estimate	1363 MGD	1363 MGD	1363 MGD	1363 MGD
SURPLUS	**+1303.5 MGD** **+3620 gpcd**	**+1300.7 MGD** **+3450 gpcd**	**+1295.7 MGD** **+3178 gpcd**	**+1292.0 MGD** **+2965 gpcd**

With the exception of the occurrence of the $1Q_{30}$ flow condition, the projected total daily offstream demands of the Upper Roanoke planning area do not exceed projected water supply. Table 3.14 does not include water supplies available from local storage facilities already existing in the planning area in order to overcome the 1998 deficit under $1Q_{30}$.

The expression of water supply availability per capita indicates that as the population and demand increase, the amount of water available per person decreases.

If the total demand in each future year is compared to each streamflow estimate, the future water supply availability in the Upper Roanoke planning area changes considerably.

Table 3.15: Total demand deficits and surpluses in the Upper Roanoke planning area.

YEAR	2000	2005	2015	2025
Instream Demand Offstream Demand	210 MGD 59.5 MGD	210 MGD 62.3 MGD	210 MGD 67.3 MGD	210 MGD 72.0 MGD
TOTAL Demand	**269.5 MGD**	**272.3 MGD**	**277.3 MGD**	**282.0 MGD**

$1Q_{30}$	39 MGD	39 MGD	39 MGD	39 MGD
DEFICIT	**- 230.5 MGD**	**- 233.3 MGD**	**- 238.3 MGD**	**- 243.0 MGD**
$7Q_{10}$	210 MGD	210 MGD	210 MGD	210 MGD
DEFICIT	**- 59.5 MGD**	**- 62.3 MGD**	**- 67.3 MGD**	**- 72.0 MGD**
Q_{90}	211 MGD	211 MGD	211 MGD	211 MGD
DEFICIT	**- 58.5 MGD**	**- 61.3 MGD**	**- 66.3 MGD**	**- 71.0 MGD**
Q_{50}	814 MGD	814 MGD	814 MGD	814 MGD
SURPLUS	**+544.5 MGD**	**+541.7 MGD**	**+563.7 MGD**	**+532.0 MGD**
Q_{AM}	1363 MGD	1363 MGD	1363 MGD	1363 MGD
SURPLUS	**+1093.5 MGD**	**+1090.7 MGD**	**+1085.7 MGD**	**+1081.0 MGD**

Table 3.15 indicates that the projected total demand will create water availability deficits under $1Q_{30}$, $7Q_{10}$ and Q_{90} flow conditions in the Upper Roanoke planning area. Although the supply projection do not include existing local storage facilities, the deficits represent the theoretical amount of storage that must exist in the Upper Roanoke planning area in order to satisfy total projected daily demand under each projected supply condition.

3.5 Conclusion

Through the application of the procedure for preliminary assessment of water supply availability to the Upper Roanoke planning area in Virginia, the methodologies included in the procedure have been discussed in detail. The procedure indicates that within the Upper Roanoke planning area, the overview of water supply availability indicates that total daily offstream may exceed the $1Q_{30}$ flow conditions throughout the planning period. The overview analysis also indicates that total daily demand may exceed $1Q_{30}$, $7Q_{10}$, and Q_{90} flow conditions throughout the planning period. However, existing storage facilities have not been accounted for in the procedure for preliminary assessment. Chapter 4 illustrates the application of the procedure to the entire Commonwealth of Virginia and specifies additional difficulties that may be encountered by applying the procedure to 27 planning areas, one of which is the Upper Roanoke.

3.5 REFERENCES: Chapter 3

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4. Preliminary Assessment of Water Supply Availability in the Commonwealth of Virginia

4.1 Water's Role in the History of Virginia

From the first English and Spanish settlers in the 1550's and 1560's[130] to the establishment of the first successful English colony in 1607[131] and the present day, water has been an important part of the development of the Commonwealth of Virginia. The Chesapeake Bay and the tidal and navigable portions of the York and James Rivers provided the first European settlers with places "where ships of great burden [could] harbour in safety."[132] The tributaries to each of these great rivers provided a "great plenty of fish of all kinds"[133] to feed the original settlers and sustain the growing population in Jamestown. The waterscape also provided landmarks to establish political boundaries in an unsettled frontier. Maryland and Virginia were divided in 1534 by the Potomac River and Currituck Sound distinguished the claims of Virginia from those of the Carolinas in 1665.[134] The waters of Virginia have played an important part in the successful colonization of Virginia, and they continue to sustain the economic development of Virginia today.

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130 "The Hornbook of Virginia History." Ed. E.J. Salmon and E.D.C. Campbell, Jr. Library of Virginia, 1994, p.7.
131 Id., p. 10.
132 Ashe, D.J. "Four Hundred Years of Virginia, 1584-1984: An Anthology." University Press of America, 1985, p. 10. An excerpt from George Percy's "Purchas His Pilgrims", 1625.
133 Id.
134 See note 130, supra, p. 3.

4.2 An Overview of the Geography, Geology, Climate, and Hydrology of Virginia

4.2.1 Virginia Geography

Geographically, Virginia is bounded to the east by the Atlantic Ocean, to the west by West Virginia and Kentucky, to the south by Tennessee and North Carolina and to the north by Maryland. The Commonwealth is divided into 95 counties (see plate 46) and 40 independent cities (see plate 47) that cover over 40,000 square miles of the Middle Eastern portion of the United States. Population densities vary from about 7714 persons per square mile in the City of Alexandria to 6 persons per square mile in Highland County.

4.2.2 Virginia Geology

Virginia is commonly divided into five geological or physiographic provinces: the Coastal Plain, the Piedmont, the Valley and Ridge, the Blue Ridge and the Appalachian Plateau.

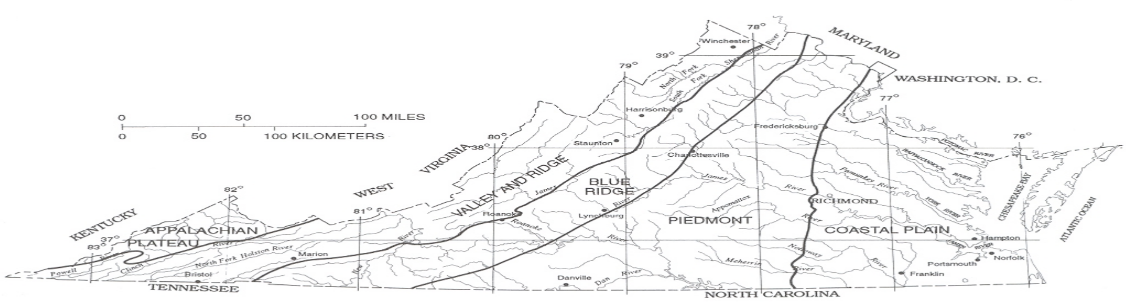

Figure 4.1: The Physiographic Provinces of Virginia (not to scale).[135]

The Coastal Plain is divided from the Piedmont by the imaginary "fall line" that runs from the western boundary of the District of Columbia in the north, just east of the city of

Richmond in Central Virginia and just to the west of the City of Emporia in the south. The fall line indicates the "the point where [the rivers of eastern Virginia] cease to be navigable" and are generally no longer under tidal influence.[136] The Coastal Plain province is generally "flat and featureless" along the seaboard, but "has a rolling topography along its western margin, where it blends with the Piedmont." [137] Unconsolidated Late Mesozoic and Cenozoic formations characterize the deposits of the Coastal Plain, generally younger and having "suffered few disturbances" when compared to the geology of the other provinces.[138]

The Piedmont extends westward from the fall line in the east to the foothills of the Blue Ridge Mountains in the west with elevations ranging from 200 feet to 1000 feet above sea level, respectively.[139] The "gently rolling plain" of the Piedmont is generally underlain by "metamorphosed sediments of Pre-Cambrian and early Paleozoic age"[140] that overlay "fractured crystalline bedrock."[141]

Moving west, the Blue Ridge province is a "narrow northeast-trending belt between the Valley and Ridge and the Piedmont…consist[ing] of a chain of mountains and highlands underlain by metamorphosed Proterozoic and Paleozoic rocks."[142] Elevations range from about 220 feet above sea level along the Potomac River on the

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[135] See note 121, supra, p. 6.
[136] See note 130, supra, p. 3.
[137] Clark, W.B. and E.W. Berry. "Physiography and Geology of the Coastal Plain Province of Virginia." Virginia Geological Survey, 1912, p.13.
[138] See note 121, supra.
[139] Id.
[140] Id.
[141] Id.
[142] Id., p. 5.

northern border to about 5700 feet above sea level at Mount Rogers on the southern border.[143]

Further west, the Valley and Ridge province "consists of a belt of northeast/southwest-trending ridges and valleys formed by the differential erosion of a thick sequence of folded and faulted Paleozoic sedimentary rocks."[144] Elevations range from about 380 feet above sea level at the outlet of the Shenandoah River into Maryland in the north to about 4600 feet above sea level along the southwestern border of Virginia and Kentucky in the south.[145]

In the southwestern portion of Virginia is the Appalachian Plateau province characterized by "generally… rugged terrain"[146] over laying "coal bearing Mississippian and Pennsylvania strata."[147] Elevations range from about 2000 feet above sea level on the Buchanan County/West Virginia line in the north to around 3000 feet above sea level along the Virginia/Kentucky border in the southwest.

4.2.3 Virginia Climate

Climate in Virginia can generally be described as moderate with temperatures ranging from well below freezing in the winter to above 100 degrees Fahrenheit in the summer; annual mean temperatures range from 46 to 58 degrees Fahrenheit (see figure 4.2). Precipitation, on average, is plentiful across the Commonwealth with an annual

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[143] Id.
[144] Id., p. 5.
[145] Id.
[146] Virginia State Water Control Board. "Virginia's Water Supply: Statewide Summary and Technical Data." VSWCB Planning Bulletin 347, March 1988, p. 5.
[147] LaCaze, Jr., J.A. "Structural Analysis of the Petersburg Lineament in the Eastern Appalachian Plateau Province, Tucker County, West Virginia." West Virginia University, 1978, p. 4.

mean of 42 inches; annual precipitation can range from 33 to 49 inches depending upon location (see figure 4.3).

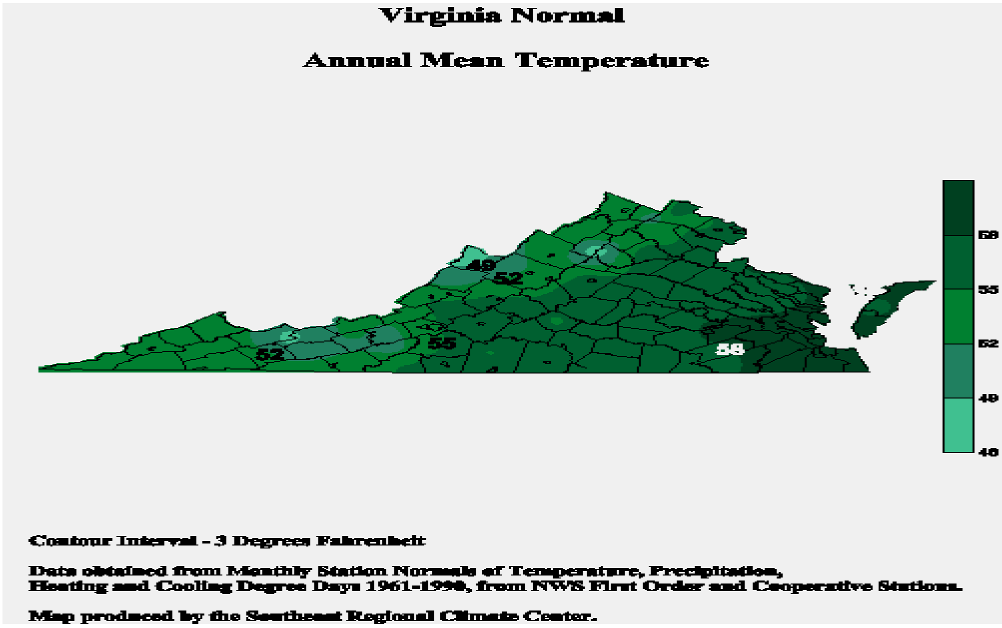

Figure 4.2: Annual mean temperatures.[148]

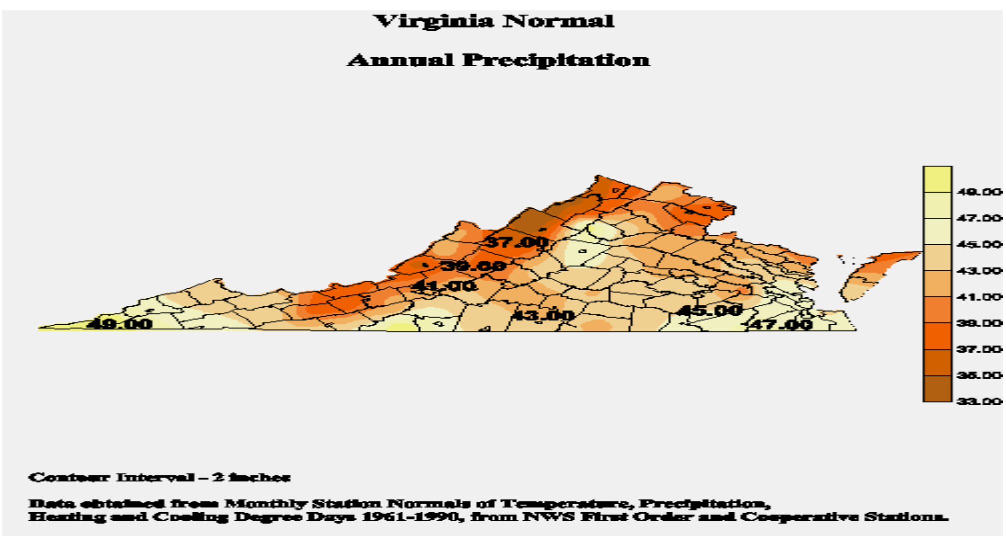

Figure 4.3: Annual precipitation.[149]

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[148] "Climate Atlas: Maps of 1961-1990 Normals for the Southeast US." Southeast Regional Climate Center, 8/3/2000. http//water.dnr.state.sc.us/climate/sercc/products/maps/climate_atlas/vaatlas_ann_mean.gif.

4.2.4 Virginia Hydrology

Virginia's hydrology is defined by the nine major river basins and several hundred hydrologic units (see plate 48) that are partially and wholly contained within the Commonwealth's political boundaries. The Potomac, Roanoke, Chowan, New, Tennessee and Big Sandy River Basins share drainage areas with neighboring states. The Rappahannock and York River basins and over 99% of the James River basin are captured in the jurisdictional boundaries of Virginia.

Six of Virginia's nine major rivers are interstate waters. Virginia's portion of the Potomac River Basin (see plate 1) drains 5701.79 square miles of Virginia land area and includes the Shenandoah River Basin (see plate 4) that stretches from just northeast of the Rockbridge/Augusta County border to the Frederick and Clarke County borders with West Virginia. The Roanoke River Basin (see plate 32) includes the drainage areas of the Dan River (see plates 35 and 36), the Banister River (see plate 36), the Smith River (see plate 35) and the Mayo River (see plate 35). The Roanoke River Basin drains 6391.91 square miles of Virginia land area and stretches from its headwaters in Montgomery and Roanoke Counties to the southeast at Lake Gaston on the North Carolina border. The Chowan River Basin (see plate 27) is comprised of the drainage areas of the Meherrin (see plate 28), Nottoway (see plate 29) and the Blackwater River Basins (see plate 30) and also includes coastal drainage in Southeastern Virginia in the cities of Chesapeake and Virginia Beach (see plate 31). Virginia's contribution to the Chowan River system is drained from 4251.33 square miles with headwaters in Lunenburg, Nottoway and Dinwiddie Counties before crossing the North Carolina border. The New River Basin

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[149] "Climate Atlas: Maps of 1961-1990 Normals for the Southeast US." Southeast Regional Climate Center, 8/3/2000.

(see plate 38) has its headwaters in North Carolina before entering Virginia. Virginia drainage area is 3065.34 square miles before entering West Virginia at Glen Lyn in Giles County. The headwaters of the Tennessee River Basin (see plate 41) are drained from the Holston (see plate 42), the Clinch (see plate 43) and the Powell (see plate 44) Rivers. These three rivers drain 3132.85 square miles of Virginia land area. The Big Sandy River Basin (see plate 45) has headwaters in Wise, Dickenson and Buchanan Counties in southwestern Virginia capturing drainage from the Pound River and the Russell, Levisa and Tug Forks. This relatively small area drains 998.81 square miles of Virginia land area before entering Kentucky.

The Rappahannock River Basin (see plate 9) stretches from its headwaters in Madison and Rappahannock Counties to its mouth in the Chesapeake Bay downstream in Middlesex, Lancaster and Northumberland Counties. It drains 2714.03 square miles of Virginia. The York River Basin (see plate 12) includes the drainage of the Mattaponi (see plate 13) and Pamunkey (see plate 14) Rivers and drains 2669.24 square miles of Virginia. The York's headwaters are in Louisa, Orange and Spotsylvania Counties before emptying into the Chesapeake Bay in Gloucester and York Counties and the city of Poquoson. The James River Basin (see plate 16) drains 10,236.23 square miles of Virginia and is the largest major river basin in the Commonwealth. Headwaters in Highland, Bath, Alleghany and Craig Counties and a small portion of Monroe County, West Virginia eventually discharge into the Chesapeake Bay in Hampton and Norfolk. The James River Basin includes drainage collected from the Jackson (see plate 17), the Maury (see plate 18), the Rivanna (see plate 20) and the Appomattox (see plate 22)

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http//water.dnr.state.sc.us/climate/sercc/products/maps/climate_atlas/vaatlas_ann_precip.gif.

Rivers. Although the lack of significant surface waters prevents it from being classified as a river basin, the Eastern Shore of Virginia (see plate XV) drains 1105.30 square miles of Virginia directly into the Chesapeake Bay (see plate 25) and the Atlantic Ocean (see plate 26).

4.3 The Scope and Purpose of the Virginia Case Study

The following assessment of water supply availability in Virginia will evaluate the amount of water that is potentially available for development across the state on a partial river basin scale. An evaluation on such a large scale requires a certain set of assumptions that exclude details of water use and availability on a smaller scale; hence, the overview approach to the assessment. Potential conflicts between specific users within each planning area will not be evaluated[150] with the exception of the two local case studies included in the appendices. Supply and demand will be evaluated under known conditions and will be projected into the future based on general assumptions that are specifically applied to each planning area. A unique feature of the assessment is that it will present an analysis of water supply conditions with and without instream flowby requirements. The Commonwealth has not yet determined a specific minimum instream flow requirement policy, and as a result, the minimum instream demand scenarios presented are speculative and do not indicate any decisions that have been or will be made about legislated instream flow requirements in Virginia. A weakness of the preliminary nature of the case study is that it will not include an analysis of short term groundwater availability across the state as a whole. Long term groundwater availability will be assumed included in the historical streamflow parameters as discharge to the natural flow of surface water streams. The result is a conservative estimate of the available resource within each planning area where groundwater is an actively used resource, particularly east of the fall line (i.e., in the Coastal Plain).

The purpose of the case study is to identify potential water supply deficient areas in Virginia within natural drainage basins through 2025. Each planning area will be designated based upon the natural boundaries of the hydrologic units that drain into each of the nine major river basins rather than the traditional municipal and political jurisdictions. Within each planning area, supply availability will be quantified in terms of the average flow conditions expected to occur in the average year (see Appendix D). Where applicable, supply availability will be quantified in terms of the projected supply adjusted for the effects of the projected rate of increasing upstream consumption (see Appendix E). Demand will be projected according to the anticipated growth of the population within each planning area assuming that per capita use in the 1995 base year will remain steady (see Appendix K). Consumption will be projected assuming the percentage of consumption in the 1995 base year will remain steady (see Appendix K). The result will be a comparison of projected available supply and anticipated demand in 1998, 2000, 2005, 2015 and 2025 indicating potential surpluses and deficits in million gallons per day (MGD) and in gallons per capita per day (gpcd).

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[150] For a detailed analysis of the withdrawal and distribution systems within each planning area, see the March 1988 "Water Supply Plan" Series, Virginia State Water Control Board Planning Bulletins Nos. 336-347.

4.4 The Preliminary Assessment of Water Supply Availability in Virginia

In each of the twenty-seven planning areas, a general format was used to identify the planning area, to project population, to quantify water supply available from the surface water yield of the local flow system, to project water demands, and to quantify the anticipated condition of the water balance over the planning period. Although the specific assumptions made within each planning area were variable, the general approach was not altered, and the procedure is outlined in the following five subsections.

4.4.1 Planning Area Boundary Designation in Virginia

With USGS cataloging units and natural drainage basins as a primary consideration in the designation of planning area boundaries (see Plates 1-45), the Commonwealth was segregated into twenty-seven planning areas (see Plates I-XXVII). In some cases, specifically the Upper Shenandoah/Laurel, the Lower Shenandoah/Opequon, the Upper New, the Lower New, the Martinsville, and the Danville planning areas, the USGS demand area boundaries were truncated and planning area boundaries were re-drawn along the borders of the smaller hydrologic units. The designation of each of these planning areas along boundaries different from the USGS cataloging units enabled each planning area to be no more than about 75 miles from the most upstream to the most downstream point. The seventy-five mile limitation from upstream to downstream was imposed in order to limit the planning areas to distances that could conceivably have water transmitted from the downstream supply point to upstream distribution centers.[151] Gage locations along the mainstream also played a role in the designation of planning area boundaries and enabled the quantification of supply available at the downstream point of each river section.

4.4.2 Supply Estimation and Projection in Virginia

Streamflow records were assumed to include long-term groundwater discharge to the stream. Records from gaging stations maintained by the USGS and the VSWCB at selected sites within Virginia were selected at the most downstream point available within the each designated planning area (see Appendix D). A wide array of flow conditions was chosen to represent water in the stream under varying circumstances within the local hydrology. Annual mean flow and the flow equalled or exceeded ninety, fifty, and ten percent of the time were derived from USGS data available beginning in the first year of measurement through 1998[152] or most recently available data. Other parameters include the lowest consecutive seven-day average expected to occur every ten years ($7Q_{10}$), the flow equalled or exceeded ninety-five percent of the time (Q_{95}), and the mean baseflow estimate (MBF_{est}). These characteristics, developed from records through 1984, were taken from Nelms, et. al's (1997) analysis of streams in the Valley and Ridge, Blue Ridge and Piedmont Physiographic Provinces of Virginia.[153] The lowest one-day flow expected to occur every thirty years ($1Q_{30}$) at each gaging site was taken from VSWCB estimates made for records through 1977 for the North Atlantic Slope Basin,[154]

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[151] The Lake Gaston pipeline from Pea Hill Creek in Mecklenburg County successfully transfers water over a 76-mile distance to Norfolk's water system and represents the upper end of transferability, hence the seventy-five mile restriction.
[152] See note 28, supra.
[153] See note 121, supra, Appendix 1.
[154] Virginia State Water Control Board. "Hydrologic Analysis of Virginia Streams, volume I: North Atlantic Slope Basin." VSWCB Basic Data Bulletin 56, November 1982, p. xi-xvi.

the South Atlantic Slope Basin[155] and the Ohio River Basin[156] of Virginia. The VWSCB (1982) and Nelms, et al. (1997) records were used to provide any flow statistics where current USGS gage records were unavailable (see Appendix C).

The flow conditions were then used to develop estimates of the flow available at the downstream point in each planning area by developing an average yield in cubic feet per second per square mile (cfs/mi^2) at the gage site and applying it to the total land area at the selected downstream point (see Appendix D) according to the VSWCB transfer methodology (see *2.4.2.1.2*). Hayes (1991) recommends that ungaged areas added to gaged areas only if no tributaries enter the ungaged section of the stream that would increase the total land area by "more than twenty-five percent."[157] In some cases, the land area added to the gage(s) in each planning area did exceed twenty-five percent. Ungaged land area additions exceeded the twenty-five percent mark because gages further downstream were unavailable and a measure of supply from surface water records was needed for the analysis (see Appendix D). In addition to the supply estimates from streamflow, all twenty-seven planning areas include information about groundwater withdrawals made from the planning area, as data was available, to indicate groundwater that maybe available in the short-term in the planning area.

The supply was projected by assuming that current transferred streamflow estimates would be constant in the future. The flow under each specified condition was assumed to be the amount of water that would be replenished to the stream each "average" year and that each future year would be an average year. Planning areas that

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[155] See note 123, supra, p. xii-xxii.
[156] Virginia State Water Control Board. "Hydrologic Analysis of Virginia Streams, volume III: Ohio River Basin." VSWCB Basic Data Bulletin 58, November 1982, p. x-xiv.

are headwater drainage areas (i.e. that do not have planning areas upstream) were assumed to have the average flow in the stream at the downstream point for each year of the planning period. In the planning areas that are not headwaters (i.e. that have a planning area upstream), the supply projection at the downstream point was adjusted by subtracting the total amount of water consumed in upstream planning areas (see Appendix E) from the transferred flow estimates.

4.4.3 Demand Estimation and Projection in Virginia

Total demand estimates and projections were made for each planning area from instream and offstream demand estimates and projections. Instream demand was estimated to be a flow equivalent to the $7Q_{10}$ estimate for the planning area. The instream demand was projected as a flow equivalent to the instream demand estimate in the base year. Offstream demand estimate and projected from USGS demand data available for each USGS cataloging unit in 1995 in Virginia.

The total offstream demand was estimated as the sum of the withdrawal in each category reported by the USGS that consumed a portion of the withdrawal during use. With the exception of the six planning areas that were drawn on boundaries other than the USGS units, 1995 demand in each planning area was developed as an additive function of any and all portion of USGS demand cataloging units contained therein. In the six planning areas that contained partial USGS demand cataloging units, the reported values were distributed evenly over the land area that contributed to each planning area. For example, in the Upper Shenandoah/Laurel planning area, the USGS cataloging unit 02070005 covered 1672.11 mi^2 of the South Fork of the Shenandoah; planning area 3

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[157] See note 34, supra, p. 10.

covers only 1125.20 mi^2 of the South Fork of the Shenandoah. The resulting ratio is .67292236, and it was multiplied by the reported values and added to the 1995 estimates for USGS cataloging unit 02070001 that includes other Potomac River tributaries (the "Laurel" drainage area) to develop total estimates in planning area 3 in 1995. Similar procedures were developed for the five other partial USGS demand cataloging unit planning areas (see *4.5* for detail in each planning area).

The total offstream demand was projected using population as an indicator of future total offstream demand. The 1995 total offstream demand estimate was then divided by the 1995 USGS population estimate in order to develop a per capita total daily offstream demand. The total offstream demand for each planning area was then projected by multiplying the 1995 total per capita offstream demand by the projected population over the planning period (see Appendix K).

4.4.3.1 Population Estimation and Projection in Virginia

In order to develop population estimates for the planning areas, it was first necessary to estimate the population in the base year - 1998 in this case. Because population estimates and projections are not often made for hydrologic boundaries, county and city populations served as the starting place for the planning area population estimates. Populations for each county and city in Virginia were taken from 1998 Census Bureau estimates.[158] The 1998 population estimate was then divided by the total land area of each municipality in order to develop a population density estimate in 1998 (see Appendix F). The population density was then multiplied by the amount of land of each contributing municipality based on Virginia hydrologic unit information (see Appendix

G.3). The result was the population contributed to the planning area by each municipality partially or wholly contained therein (see Appendix G.2). The Virginia State Water Control Board (VSWCB) applied a similar technique in developing populations within hydrologic units in 1980, but the "areal prorating" was used only as a staring point; these were used as "initial allocations [that] were then adjusted taking into consideration population density inhomogeneities due to suburban areas, topographic features and small communities, using informed judgement."[159] The methodology applied in this case study assumes that population densities are evenly applied across all counties and cities within Virginia. The result of the dismissal of density inhomogeneities was an overestimate of 1998 population that exceeded the Census Bureau 1998 estimate by 28,772 people (0.4% of the Bureau's 1998 estimate of 6,791,165 people).

US Census Bureau projections of total population within Virginia served as the initial starting place of population projections for each increment in the planning period. The Census Bureau estimated that Virginia's population would grow to 6,997,000 in 2000, 7,324,000 in 2005, 7,921,000 in 2015 and 8,466,000 in 2025.[160] Utilizing a Ratio method[161] technique, the ratio of planning area population to the state population in 1998 was then multiplied by the total projected population of the Commonwealth in each year of the planning period. USGS demand data from 1995 included estimates of the population in each USGS cataloging unit, and with the exception of the six aforementioned planning areas that had boundaries that were not based on USGS units, the contribution to 1995 population was relatively consistent (see Appendix H).

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[158] See note 125, supra.
[159] Virginia State Water Control Board. "Hydrologic Unit Populations for Virginia, 1980 with projections for 1990, 2000, 2010, 2020 and 2030." VSWCB Basic Data Bulletin 63, July 1984, p. 28.

Population estimates for three North Carolina hydrologic units also had to be developed. Because the consumptive portion of the demand had to be accounted for in order to estimate and project available supply, populations in the Upper Dan, Lower Dan, and Lower New drainage areas of North Carolina had to be estimated and projected. Estimates for 1995 population were taken from the 1995 USGS demand report for North Carolina,[162] and projections for total North Carolina population were taken from US Census Bureau projections.[163] Growth between the 1995 estimate and the 2000 projection was assumed linear in order to develop population projections for 1998.

4.4.3.2 Consumption Estimation and Projection in Virginia

The amount of water consumed within each planning area was reported in 1995 and divided by the total offstream demand estimate in 1995 to develop a percentage of the demand that was consumed (see Appendix J). The resulting percentage of the total was assumed to remain constant in each planning area in each future year of the planning period. The projected total daily offstream withdrawal in each year of the planning period was multiplied by the 1995 percentage of consumption in order to estimate the amount of water consumed within each planning area (see Appendix K).

4.4.4 Preliminary Assessment of Water Supply Availability in Virginia

With projections of water supply and demand available within each planning area, a comparison of water supply and demand by planning area was developed in order to quantify the anticipated status of water supply availability under each future condition.

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[160] See note 129, supra.
[161] See note 116, supra, p. 14.
[162] See note 124, supra.
[163] See note 129, supra, North Carolina.

The total daily consumptive offstream demand and the total demand (as a sum of the total daily consumptive demand and instream demand) were subtracted from each anticipated adjusted natural flow supply condition in order to identify potential areas of water supply deficiencies and surpluses under each streamflow condition. The resulting quantity, in MGD, can be used as a preliminary indication for decisions to increase water supply storage, to encourage development within the area or to protect instream flows within each planning area.

The water balance was also described as a function of population by dividing the million gallon per day result by the projected population. The result was an identical series of deficits and surpluses, but the advantage is the description of the deficit or surplus in terms of how much water per person needs to be or can be developed under future natural flow and projected demand scenarios.

4.5 An Analysis of Water Supply Availability in Virginia by Planning Area

Each of the twenty-seven planning areas was analyzed according to the general procedure outlined in section 2.5 and specific to Virginia as outlined in section 3.2. The result was twenty-seven individual analyses that account for the water supply availability potential across the entire Commonwealth through 2025. Each planning area has a unique set of boundaries based on the hydrologic unit designations of individual watersheds in Virginia.[164] The population was estimated in 1998, 2000, 2005, 2015 and 2025 and used to project the availability of the Commonwealth's surface waters in each year of the projection. Supply estimates include groundwater only in terms of the baseflow discharge to the stream in times of low flow and does not account for groundwater that can potentially be mined in the short term. The results of the comparison of supply and demand projections (the water balances) are expressed for each planning area under two conditions: (1) no instream flowby requirement, and (2) an instream requirement equivalent to the estimated $7Q_{10}$ flow in the planning area. Conclusions for the water balance conditions in each planning area are intended only to highlight those areas across Virginia that could potentially face water supply deficiencies in the future. They are not intended as actual development requirements or development potentials.

4.5.1 The Upper Potomac Planning Area

4.5.1.1 The Upper Potomac Planning Area and Its Population

The Upper Potomac planning area covers Virginia hydrologic units A01-A25 (see Plate I and Plate 2) and USGS cataloging units 02070008 and 02070010. It drains 1625.60 square miles of Virginia's Potomac tributaries, including Accotink Creek, Goose Creek and the Occoquan River as major tributaries and numerous other minor tributaries (see Appendix A). Residents from Arlington, Fairfax, Fauquier, Loudoun, Prince William and Stafford Counties and the cities of Fairfax, Alexandria, Manassas and Manassas Park (Appendix G.2) make up the total population of the planning area. The planning area has a total estimated 1998 population of 1,676,803 people based on 1998 US Census Bureau estimates (see Appendix F), making it the most populated planning area with a total density of about 1031 people per square mile. Based on US Census

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[164]Virginia Department of Conservation and Recreation. "Virginia Hydrologic Unit Atlas." Virginia Department of

Bureau projections for Virginia, that population is expected to grow according to Table 4.1.

Table 4.1: Upper Potomac planning area projected population (see Appendix H).

YEAR	Projected Population
2000	1,720,300
2005	1,800,700
2015	1,947,500
2025	2,081,500

4.5.1.2 The Supply Condition

Supply availability in the Upper Potomac planning area was developed as a function of gage data at locations on smaller Potomac River tributaries. There is no single gage in the drainage basin that effectively captures the total planning area; as a result, an extraordinary amount of ungaged land area was added to the original land area. Although the Potomac River does supply the Fairfax County Water Authority with 33 MGD,[165] it was not considered in the supply estimate because it is not solely available to water users in the Virginia portion of the Upper Potomac planning area. The water supply availability was calculated as a sum of the gage data measured at USGS gages 01655000, 01644000 and 01657500 on Accotink Creek, Goose Creek and the Occoquan River, respectively. The total gaged area was 939 square miles, and when applied to the entire planning area, 686.6 square miles (73.12 % of the original gaged area) were added to the gaged area. In combination, the flows generated within the total land area in the average year are shown in Table 4.2 (for the development of the total flow estimates see Appendix D.1; for the periods of record for each flow statistics see Appendix C).

Conservation and Recreation, November, 1995.

Table 4.2: Supply estimates in the Upper Potomac planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**922.5**	100.00%
$7Q_{10}$	**12.8**	1.39%
$1Q_{30}$	**3.2**	0.35%
Q_{95}	**45.3**	4.91%
Q_{50}	**406.7**	44.09%
MBF_{est}	**440.7**	47.77%

Because the Upper Potomac is a headwater planning area (i.e. no planning areas directly upstream), the supply estimates do not have to be adjusted for upstream consumption. Although Table 4.2 indicates the flows in the Upper Potomac basin under specified conditions, it does not indicate the amount of water that is actually available for supply purposes because the partial river basin scale eliminates the assessment of "mineable" groundwater and artificial surface storage water supply systems.

The Fairfax County Water Authority operates two sources of supply that are not accounted for in an analysis of streamflow conditions in the Upper Potomac planning area. The first is a stream intake on the Potomac River capable of withdrawing and treating up to 50 MGD.[166] The second system is the Occoquan Reservoir system that can treat up to 112 MGD and would yield 67.5 MGD under the 1930-1931 drought of record.[167] Also not included in the natural flow availability analysis are over 60 wells, 7 springs and 13 minor surface water sources that provided about 29.44 MGD to the Upper Potomac planning area in 1985.[168] The partial river basin scale, therefore, eliminates about 130 MGD of viable supply from the water supply quantification by looking only at the surface water discharge in streams under natural conditions. In 1995 the USGS

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[165] "Potomac Water Supply Plan." Virginia State Water Control Board, Planning Bulletin No. 336, March 1988, p. II-17, II-107.
[166] See note 37, supra, p. 87.

reported that 15.08 MGD of groundwater was utilized in the Upper Potomac planning area.

4.5.1.3 The Demand Condition

In 1995 in USGS demand cataloging units 02070008 and 02070010, the Upper Potomac planning area withdrew 183.42 MGD of water that was partially consumed (i.e. total daily offstream demand) (see Appendix J). With an estimated population of 1,585,940 people in 1995, the total daily per capita offstream use in 1995 was 115.65 gpcd. The total offstream per capita freshwater estimate includes 3.89 MGD of industrial withdrawals (2.12% of the total offstream demand). The per capita estimate of 115.65 gpcd does not include the 282.11 MGD withdrawn for thermoelectric purposes because there is no portion of the thermoelectric withdrawal consumed. Of the 183.42 MGD withdrawn in the Upper Potomac in 1995, 19.28 MGD (10.51% of the total daily consumptive withdrawal) was estimated to have been consumed.

Assuming the 1995 total daily per capita offstream demand and the 1995 percentage of the total daily offstream withdrawal consumed will be the same in each future year of the planning period, the demand was projected through 2025. The result of the demand projection can be seen in Table 4.3 (see Appendix K).

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[167] Id.
[168] See note 165, supra.

Table 4.3: Total daily offstream demand for the Upper Potomac planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	193.92	20.38
2000	198.95	20.91
2005	208.25	21.89
2015	225.23	23.67
2025	240.73	25.30

If the $7Q_{10}$ is included as part of the demand, the resulting total daily demand will be as seen in Table 4.4 (see Appendix K).

Table 4.4: Total demand in the Upper Potomac planning area.

YEAR	Total Demand (MGD)
1998	206.72
2000	211.75
2005	221.05
2015	238.03
2025	253.53

4.5.1.4 Water Supply Availability in the Upper Potomac Planning Area

Upon comparing the natural supply availability (Table 4.2) to the total daily offstream demand (Table 4.3), the following surpluses and deficits in natural supply availability can be anticipated to exist in the future under each flow condition:

Table 4.5: Offstream demand water supply availability in the Upper Potomac planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	729	724	714	697	682
$7Q_{10}$	-181	-186	-195	-212	-227
$1Q_{30}$	-191	-196	-205	-222	-238
Q_{95}	-149	-154	-163	-180	-195
$10\%Q_{AM}$	-102	-107	-116	-133	-148
$20\%Q_{AM}$	-9	-14	-24	-41	-56

The deficits indicated in Table 4.5 are indicative of the amount of water in excess of the streamflows that may be needed in the Upper Potomac planning area to satisfy projected demands. With the exception of the annual mean as measured over the period record (Q_{AM}), all projected natural supply conditions ($7Q_{10}$, $1Q_{30}$ and Q_{95}) will not satisfy the projected total daily offstream consumptive demand. Table 3.5 expresses the surpluses and deficits of Table 4.5 as a function of the projected population in the specified year.

Table 4.6: Offstream demand water supply availability in the Upper Potomac planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	435	421	397	358	328
$7Q_{10}$	-108	-108	-109	-109	-110
$1Q_{30}$	-114	-114	-114	-114	-114
Q_{95}	-89	-89	-90	-92	-94
$10\%Q_{AM}$	-61	-62	-64	-68	-71
$20\%Q_{AM}$	-6	-8	-13	-21	-27

The deficits indicate that artificial surface water storage or groundwater may need to be developed in order to satisfy future anticipated demands. When compared to total daily offstream demand, the natural available supply falls nearly 300 MGD short of the needed demand under the extreme $1Q_{30}$ low flow condition. In order to meet the projected demand with water available from the natural flow condition 114 gpcd of artificial storage would have to be developed.

However, if twenty percent of the historical annual mean represents the maximum development potential of the river basin, as suggested by Falkenmark and Lindh (1976), the municipalities within the planning area must look to water resources outside the river basin to satisfy growing demands under low flow conditions. Current offstream development requires about 21% of the annual mean flow. Additional sources could include increased withdrawal permits from the State of Maryland or purchases from surrounding suppliers that may have excess water to sell. Theoretically, water may also be available to transfer from the surrounding river basins and watersheds; but, traditionally, transfers are difficult to attain because the common law principles of Eastern water rights does not permit out of basin transfers.

The deficits in Tables 4.5 and 4.6 do not account for artificial storage, Potomac River withdrawals and groundwater accessibility currently utilized by individual water systems in the Upper Potomac. If these resources, about 130 MGD, are included as an amount guaranteed above the naturally available streamflow, the following surpluses and deficits result:

Table 4.7: Offstream demand water supply availability in the Upper Potomac planning area incorporating groundwater withdrawals, Potomac River water usage and artificial surface water storage into supply projections (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	859	854	844	827	812
$7Q_{10}$	-51	-56	-65	-82	-97
$1Q_{30}$	-61	-66	-75	-92	-108
Q_{95}	-19	-24	-33	-50	-65

Table 4.8: Offstream demand water supply availability in the Upper Potomac planning area incorporating groundwater withdrawals, Potomac River water usage and artificial surface water storage into supply projections (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	512	496	469	425	390
$7Q_{10}$	-30	-33	-36	-42	-50
$1Q_{30}$	-37	-38	-42	-47	-55
Q_{95}	-11	-14	-18	-26	-33

Even including the amount of groundwater, Potomac River water and artificial surface water storage available in the Upper Potomac in 1985, water supply availability seems potentially jeopardized because supply is less than the water demanded by the current estimated and future projected populations under low flow conditions.

Another factor that has not been included in the analysis is that a regional water supply system is in place in the Washington, D.C. Metropolitan Area in the Upper

Potomac planning area. Water supply in and around the Metropolitan Area is managed and distributed by three major suppliers that average 468 MGD delivery.[169] The Fairfax County Water Authority (FCWA) distributes water to Alexandria, Dale City, Loudoun County, Prince William County and the majority of Fairfax County in Virginia with water withdrawn from the from Potomac River and the Occoquan Reservoir.[170] The Washington Aqueduct serves the District of Columbia, Arlington County, and the City of Falls Church;[171] and, the Washington Suburban Sanitary Commission serves most of Montgomery and Prince George's Counties.[172] Because the water supply is regionalized and coordinated amongst many different jurisdictions, it is difficult to accurately assess water supply availability on a broad overview scale.

Regional supplies aside, the preliminary assessment indicates that about 108 MGD (55 gpcd) may need to be made available for use within the planning area under $1Q_{30}$ conditions to satisfy demands through 2025 including the water developments within the planning area through 1985. The preceding analysis projects demand as a function of a growing population; however, population in the planning area may reach a saturation point in the future that may inhibit the growth rate. Therefore, it is important to keep in mind that these projections are intended as an overview of water supply availability. Although information for developments between 1985 and 1998 are not included in the analysis, the Upper Potomac planning area indicates one area of the

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[169] League of Women Voters of the National Capital Area. "Drinking Water Supply in the Washington, D.C. Metropolitan Area: Prospects and Options for the 21st Century." Executive Summary, February, 1999.
[170] Washington Council of Governments. "Overview of Water Supply System in the Washington Region." October 5, 1999, Washington, D.C.
[171] See note 169, supra.
[172] See note 170, supra.

Commonwealth that may require further study in order to eliminate potential water supply conflicts.

Neither the deficits in Table 4.5 nor the deficits in Table 4.7 require any water to be left instream for wastewater assimilation, aquatic ecosystem protection or recreational use. If the total demand, the sum of total daily consumptive offstream demand and the instream demand, is compared with the natural surface water flow availability, the surpluses and deficits shown in Table 4.9 may result.

Table 4.9: Total demand water supply availability in the Upper Potomac planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	716	711	701	684	669
$7Q_{10}$	-194	-199	-208	-225	-241
$1Q_{30}$	-204	-209	-218	-235	-250
Q_{95}	-161	-166	-176	-193	-208

4.5.2 The Lower Potomac Planning Area

4.5.2.1 The Lower Potomac Planning Area and Its Population

The Lower Potomac planning area (see Plate II) includes hydrologic units A26-A34 of the Virginia portion of tributaries to the Lower Potomac River (see Plate 3). The Lower Potomac planning area covers a total of 691.08 square miles and coincides with the boundaries of USGS cataloging unit 02070011. Small surface streams in the planning area flow directly to the Potomac River and include the Yeomico and Wicomico Rivers and Quantico, Chopawamsic, Aquia, Beaverdam, Potomac, Machodoc, Popes and Nominin Creeks (see Appendix A). Population in the Lower Potomac planning area consists of residents from portions of Fauquier, King George, Northumberland, Prince William, Richmond, Stafford and Westmoreland Counties (see Appendix G.2). The 1998

Census Bureau population density estimates for each contributing municipality (see Appendix F) indicated a planning area population of 147,033 people, an average population density of about 213 people per square mile. If the population within the planning area grows proportional to the Census Bureau projections for the Commonwealth, the projected population through 2025 is shown in Table 4.10.

Table 4.10: Lower Potomac planning area population projections (see Appendix H).

YEAR	Projected Population
2000	150,851
2005	157,900
2015	170,771
2025	182,521

4.5.2.2 The Supply Condition

Streamflow availability in the Lower Potomac planning area was developed from flow records kept at USGS stations 01655000, 01644000 and 01657500 on Accotink Creek, Goose Creek and the Occoquan River, respectively, in the Upper Potomac planning area. The streamflow availability estimates were not adjusted for upstream consumption because the Lower Potomac planning area was not affected by withdrawals in the Upper Potomac planning area. Despite the presence of several gages in the area, only one gage captures a drainage area greater than 13 square miles. Because of the insufficient gaging information within the Lower Potomac planning area, the gage data gathered from the Upper Potomac planning area was applied to the Lower Potomac planning area.

The average cfs/mi^2 yield for the combined gaged statistics at each Upper Potomac gage was applied to the 691.08 square mile land area of the Lower Potomac planning area (see Appendix D.2). Table 4.11 indicates the yield per square mile for total flow conditions developed in the Upper Potomac planning area.

Table 4.11: Flow per square mile indices used to estimate flow in the Lower Potomac planning area.

Flow	Gaged flow (cfs)	Yield (cfs/ mi^2)
Q_{AM}	**824.5**	.878062
$7Q_{10}$	**11.46**	.012204
$1Q_{30}$	**2.86**	.003046
Q_{95}	**40.5**	.043131
Q_{50}	**363.5**	.387114
MBF_{est}	**393.9**	.419489

The addition of 691.08 square miles of ungaged land area to the 939 gaged miles in the Upper Potomac planning area increased the gaged area by nearly 74 percent.

Table 4.12: Supply estimates in the Lower Potomac planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**392.2**	100.00%
$7Q_{10}$	**5.5**	1.39%
$1Q_{30}$	**1.4**	0.35%
Q_{95}	**19.3**	4.91%
Q_{50}	**172.9**	44.09%
MBF_{est}	**187.4**	47.77%

Besides increasing gaged land area by 25 percent, another weakness in the analysis of the Lower Potomac streamflow availability is that the Upper Potomac planning area is located almost entirely in the Piedmont and the Lower Potomac land area is located almost entirely in the Coastal Plain (see Figure 4.1). The application of surface water yields in the Piedmont to the streams in the Coastal Plain may introduce significant error into the analysis. However, streams in both physiographic provinces are small tributaries to the Potomac that could potentially provide freshwater for consumptive uses under impoundment and reservoir development schemes. The water supply estimates do not include 2.9 MGD of water developed from 8 groundwater well systems and 2 reservoir systems in 1982 and 1983.[173] In 1995 the USGS reported that 7.9 MGD of groundwater was utilized in the Lower Potomac planning area.

4.5.2.3 The Demand Condition

In 1995 in USGS demand cataloging unit 02070011, an estimated 18.88 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Lower Potomac planning area (see Appendix J). Based on the 1995 population estimate of 136,000 people, the total per capita daily offstream demand was 138.82 gpcd (18.88 MGD/136,000 people). The total offstream per capita freshwater estimate includes .18 MGD of industrial withdrawals (0.95% of the total offstream demand). Of the 18.88 MGD total daily offstream demand, 2.94 MGD (15.57% of the partially consumed offstream withdrawal) was estimate to have been consumed. Assuming that the total per capita daily offstream demand and the percentage of that demand consumed remains constant in each year of the planning period, the projected demand is shown in Table 4.13 (see Appendix K).

Table 4.13: Projected total daily offstream demand for the Lower Potomac planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	20.41	3.18
2000	20.95	3.26
2005	21.92	3.41
2015	23.71	3.69
2025	25.33	3.94

Table 4.14 shows the total daily demand if an instream equivalent to the $7Q_{10}$ is required to flow into the Potomac from the total land area (see Appendix K).

[173] Virginia State Water Control Board. "Rappahannock Water Supply Plan." Virginia State Water Control Board,

Table 4.14: Projected total daily demand in the Lower Potomac planning area.

YEAR	Total Demand (MGD)
1998	25.91
2000	26.45
2005	27.42
2015	29.21
2025	30.83

4.5.2.4 Water Supply Availability in the Lower Potomac Planning Area

Upon comparison of the projected total streamflow availability (Table 4.12) and the projected total daily offstream demand (Table 4.13), the following water balance conditions result:

Table 4.15: Offstream demand water supply availability in the Lower Potomac planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	372	371	370	368	367
$7Q_{10}$	-15	-16	-16	-18	-20
$1Q_{30}$	-19	-20	-21	-22	-24
Q_{95}	-1	-2	-3	-4	-6
$10\%Q_{AM}$	19	18	17	16	14
$20\%Q_{AM}$	58	57	57	55	53

Offstream development in the Lower Potomac planning area is not expected to exceed 7% of the annual mean flow estimate for the planning area through 2025. The preceding deficits and surpluses can also be expressed in terms of the projected population in order to identify the amount of water that can or needs to be developed per capita.

March 1988, p. II-15 - II-17 and II-103 - II-105.

Table 4.16: Offstream demand water supply availability in the Lower Potomac planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	2529	2460	2345	2157	2010
$7Q_{10}$	-102	-103	-104	-107	-109
$1Q_{30}$	-130	-130	-130	-131	-131
Q_{95}	-8	-11	-17	-26	-33
$10\%Q_{AM}$	128	121	110	91	76
$20\%Q_{AM}$	395	381	358	320	291

Water supply conditions could be significantly affected if a flow equivalent to the total estimated $7Q_{10}$ was required as an instream demand.

Table 4.17: Total demand water supply availability in the Lower Potomac planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	366	366	365	363	361
$7Q_{10}$	-20	-21	-22	-24	-25
$1Q_{30}$	-25	-25	-26	-28	-29
Q_{95}	-7	-7	-8	-10	-12

The deficits and surpluses included in Tables 4.15, 4.16 and 4.17 do not include the 254.3 MGD demanded in 1995 for nonconsumptive thermoelectric purposes from surface water sources (see Appendix J). The thermoelectric demand is assumed to be from the Maryland owned Potomac River waters because multiple surface water developments would have to exist in order to satisfy such a large demand. The large scope of the partial-river basin scale eliminates the analysis of potential conflict between individual users during period of localized low flow or the condition of individual system treatment, storage or distribution facilities.

4.5.3 The Upper Shenandoah/Laurel Planning Area

4.5.3.1 The Upper Shenandoah/Laurel Planning Area and Its Population

The Upper Shenandoah/Laurel planning area covers Virginia hydrologic units B01-B03 and B10-B34 (see Plate III, Plate 5 and Plate 8) and USGS cataloging unit 02070001 and part of USGS cataloging unit 02070005. USGS cataloging unit 02070005 was truncated at the northeastern edge of hydrologic unit B34 in order to keep the upstream to downstream distance around 75 miles. The resulting planning area drains 1125.29 square miles of the headwaters of the South Fork of the Shenandoah River and 107.94 square miles of the headwaters of the South Branch of the Potomac River for a total drainage area of 1233.23 square miles. Minor tributaries include the Middle River, the North River, the Dry River and Christians Creek (see Appendix A). Portions of Augusta, Rockingham and Highland Counties as well as of the cities of Staunton, Waynesboro and Harrisonburg are included in the planning area (see Appendix G.2). Based on population densities developed from 1998 US Census Bureau estimates (see Appendix F), the Upper Shenandoah/Laurel 1998 population consists of roughly 146,166 people, an overall population density of about 119 people per square mile. Assuming that the planning area population grows at the same rate as the Commonwealth, the projected population of the planning area can be expected to be as shown in Table 4.18.

Table 4.18: Upper Shenandoah/Laurel planning area projected population (see Appendix H).

YEAR	Projected Population
2000	149,960
2005	156,970
2015	169,760
2025	181,440

4.5.3.2 The Supply Condition

Supply availability was developed in the Upper Shenandoah/Laurel planning area as a function of USGS gage 01628500 on the South Fork of the Shenandoah River. The gage data was moved to the downstream point of B33 where Cub Run empties into the South Fork of the Shenandoah, adding 41.29 square miles of South Fork drainage to the gage. An additional 107.94 square miles was also added to the gage to account for the potential yield of the Potomac headwaters in hydrologic units B01, B02 and B03. The addition of this land area to the South Fork gage was necessary because of the lack of gages in the Laurel drainage basin and may be considered acceptable because both drainage areas are headwaters of the Potomac River system. Thus, a total of 149.23 square miles (13.77% of the gaged land area) was added to the gage. Based on the cfs/mi^2 yield developed at the gage, the adjusted flows are shown in Table 4.19 (for the development of the flow estimates see Appendix D.3; for the period of record for each flow see Appendix C).

Table 4.19: Supply estimates in the Upper Shenandoah/Laurel planning area.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**770.5**	100%
$7Q_{10}$	**108.1**	14.03%
$1Q_{30}$	**89.0**	11.55%
Q_{95}	**138.2**	17.94%
Q_{90}	**176.5**	22.90%
Q_{50}	**447.0**	58.02%
MBF_{est}	**522.0**	67.75%
Q_{10}	**1573.4**	204.20%

The South Fork of the Shenandoah and the Laurel portion of the Potomac are both headwater planning areas, and as a result, the supply estimates did not have to be adjusted for upstream consumption. The supply estimates in Table 4.19 indicate the supply available from natural flow conditions in the stream; however, they do not account for the water available from groundwater wells or artificial storage developments in the Upper Shenandoah/Laurel planning area. In 1995 the USGS reported that 15.61 MGD of groundwater was utilized in the Upper Shenandoah/Laurel planning area.

4.5.3.3 The Demand Condition

In 1995, the Upper Shenandoah/Laurel planning area withdrew a total of 37.22 MGD that was partially consumed (i.e. total daily offstream demand) (see Appendix J). Total daily offstream demand for cataloging unit 02070005 was distributed between the Upper Shenandoah/Laurel and the Lower Shenandoah/Opequon planning areas on the basis of the amount of land area within each portion of the planning areas. Thus, the reported total daily offstream demand values for the Upper Shenandoah/Laurel portion of cataloging unit 02070005 was the ratio of the South Fork land area in the planning area (1125.5 mi^2) to the total cataloging unit area (1672.11 mi^2), a value of .6729. The 1995 population of 120,770 people was developed according to the land area distribution method as well; the resulting 1995 total daily per capita offstream demand was 308.19 gpcd. The total offstream per capita freshwater estimate includes 16.38 MGD of industrial withdrawals (44.01% of the total offstream demand). The total hydroelectric instream demand reported for cataloging unit 02070005 was 796.4 MGD; and, in combination with the SWCB 1988 report for the Shenandoah, all hydroelectric power generation was assumed to be produced in the lower portion of cataloging unit

02070005.[174] Of the 37.22 MGD withdrawn, 5.13 MGD was consumed, 13.78% of the total daily offstream consumptive demand.

Assuming that the 1995 total daily per capita offstream demand and percentage consumed will remain the same in each successive year, the demand was projected as a function of population through 2025 and is shown in Table 4.20 (see Appendix K).

Table 4.20: Total daily offstream demand for the Upper Shenandoah/Laurel planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	45.06	6.21
2000	46.23	6.37
2005	48.39	6.67
2015	52.33	7.21
2025	55.91	7.70

The total daily demand in Table 4.21 represents the demand if the an instream demand equivalent to $7Q_{10}$ is required to pass the downstream outlet of the planning area (see Appendix K).

Table 4.21: Total demand in the Upper Shenandoah/Opequon planning area.

YEAR	Total Demand (MGD)
1998	153.16
2000	154.33
2005	156.49
2015	160.43
2025	164.01

4.5.3.4 Water Supply Availability in the Upper Shenandoah/Opequon Planning Area

Upon comparing the natural supply availability (Table 4.19) to the total daily offstream demand (Table 4.20), the following surpluses result under each flow condition:

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[174] Virginia State Water Control Board. "Shenandoah Water Supply Plan." Virginia State Water Control Board Planning Bulletin No. 345, March 1988, p. I-17.

Table 4.22: Offstream demand water supply availability in the Upper Shenandoah/Laurel planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	725	724	722	718	715
$7Q_{10}$	63	62	60	56	52
$1Q_{30}$	44	43	41	37	33
Q_{95}	93	92	90	86	82
Q_{90}	131	130	128	124	121
$10\%Q_{AM}$	32	31	29	25	21
$20\%Q_{AM}$	109	108	106	102	98

Table 4.22 indicates that a water supply shortage is not anticipated under any of the natural flow conditions in the planning period, and projected offstream developments are not expected to exceed 8% of the annual mean flow. The surpluses within the planning area can also be expressed as function of projected population in order to identify the amount if water that can be potentially developed per capita per day.

Table 4.23: Offstream demand water supply availability in the Upper Shenandoah/Laurel planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4962	4829	4600	4230	3940
$7Q_{10}$	431	412	380	328	288
$1Q_{30}$	300	285	258	216	182
Q_{95}	637	613	572	506	454
Q_{90}	899	868	816	731	665
$10\%Q_{AM}$	219	206	183	146	117
$20\%Q_{AM}$	746	719	673	599	541

However, because the analysis is at the large regional scale, local shortages may occur due to difficulties associated with infrastructure development. It is also important to note that the surpluses do not indicate the groundwater wells that have been developed and are currently in use in the planning area.

Table 4.24 represents the water balance conditions if a flow equivalent to the $7Q_{10}$ were designated as a flowby requirement within the Upper Shenandoah/Laurel planning area.

Table 4.24: Total demand water supply availability in the Upper Shenandoah/Laurel planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	617	616	614	610	607
$7Q_{10}$	-45	-46	-48	-52	-56
$1Q_{30}$	-64	-65	-68	-71	-75
Q_{95}	-15	-16	-18	-22	-26
Q_{90}	23	22	20	16	12

4.5.4 The Lower Shenandoah/Opequon Planning Area

4.5.4.1 The Lower Shenandoah/Opequon Planning Area and Its Population

The Lower Shenandoah/Opequon planning area includes Virginia hydrologic units B04-B09 and B35-B58 (see Plate IV, Plate 6 and Plate 7) and USGS cataloging units 02070006, 02070007 and 02070004 and part of cataloging unit 02070005. Hydrologic units B35-B41 include 546.68 square miles of the South Fork of the Shenandoah River and all minor tributaries including Naked Creek, Cub Run and Mill Creek (see Appendix A). The North Fork of the Shenandoah is broken into hydrologic units B42-B54 and B56, covering 1064.48 square miles, that includes smaller tributaries such as the German River, Little Dry River, Shoemaker River, Linville Creek, Smith Creek, Stony Creek, Cedar Creek, Passage Creek and Crooked Run (see Appendix A). The North and South Fork of the Shenandoah converge as the Shenandoah River near Front Royal, Virginia that receive additional drainage from 201.31 square miles of surrounding land area (B55, B57 and B58). Hydrologic units B04-B09 include 339.41 square miles of Potomac River headwater streams Sleepy Creek, Back Creek, Isaacs Creek, Hogue Creek, Brush Creek and Opequon Creek (see Appendix A).

The total planning area includes 2151.88 square miles of the lower portion of the Shenandoah River basin. Shenandoah, Page, Rockingham, Warren, Frederick and Clarke

Counties and the cities of Harrisonburg and Winchester are included in the planning area (see Appendix G.2). In 1998, the planning area population was estimated to be 217,656 people based on US Census Bureau population density estimates (see Appendix F), an overall population density of about 101 people per square mile. If the planning area population grows proportional to the Census Bureau projections for Virginia, the population of the planning area can be projected as shown in Table 4.25.

Table 4.25: Lower Shenandoah/Opequon planning area projected population (see Appendix H).

YEAR	Projected Population
2000	223,310
2005	233,740
2015	252,800
2025	270,190

4.5.4.2 The Supply Condition

Supply availability for the Lower Shenandoah/Opequon planning area was developed as a function of the Shenandoah drainage area and the Potomac drainage area and combined for a single streamflow supply estimate. The streamflow supply estimate was developed from gage 01615000 on Opequon Creek and gage 01636500 on the Shenandoah River. The average cfs/mi^2 yield under each flow condition was developed and applied to the entire portion of each drainage area in order to developed an adjusted flow estimate.

Opequon Creek was used as an index of the type of yield that might be expected from Potomac headwater tributaries in the 339.41 square mile portion of the Lower Shenandoah/Opequon planning area. Although only 57.4 square miles were gaged and an additional 282.01 ungaged square miles (491.31% of the original land area) were added to the gage, the natural flow estimates based on the gage yield can be expected to be similar to the values shown in Table 4.26 (for the period of record used in the development of each flow statistic see Appendix C).

Table 4.26: Flow estimates in the Opequon portion of the Lower Shenandoah/Laurel planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**163.9**	100%
$7Q_{10}$	**5.4**	3.26%
$1Q_{30}$	**1.8**	1.10%
Q_{90}	**18.0**	10.96%
Q_{50}	**61.1**	37.30%
Q_{10}	**309.5**	188.81%

Gage 01636500 on the Shenandoah River is located near Millville, West Virginia and drains 3022 square miles of the upstream land area. The total land area drained by the Shenandoah River system (hydrologic units B10-B58) is 2937.76 square miles before crossing the Virginia-West Virginia boundary. Therefore, the gage data on the Shenandoah was divided by the total land area drained by the gage to develop a cfs/mi^2 yield for each of the conditions measured, moved upstream to the state border, and multiplied by the contributing Virginia land area to develop the flow conditions indicated in Table 4.27 (for the development of the flow estimates see Appendix D.4; for the period of record of each flow estimate see Appendix C).

Table 4.27: Flow estimates in the Shenandoah portion of the Lower Shenandoah/Opequon planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1750.3**	100%
$7Q_{10}$	**230.6**	13.17%
$1Q_{30}$	**152.0**	8.69%
Q_{90}	**385.1**	22.00%
Q_{50}	**1017.8**	58.15%
Q_{10}	**3537.1**	202.08%

The natural flow availability estimates for each of the drainage basins within the planning area were then combined to estimate the total supply for the planning area (see Appendix D.4).

Table 4.28: Supply estimates in the Lower Shenandoah/Opequon planning area.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**1914.3**	100%
$7Q_{10}$	**235.9**	12.32%
$1Q_{30}$	**153.8**	8.04%
Q_{90}	**403.1**	21.06%
Q_{50}	**1078.9**	56.36%
Q_{10}	**3846.6**	200.95%

Because the Lower Shenandoah/Opequon planning area is downstream from the users in the Upper Shenandoah/Laurel planning area, the total natural flow availability supply estimate must be adjusted to reflect the amount of water consumed upstream. Table 4.29 depicts each flow condition that might be expected to occur in the average year less the average projected annual consumption in the Upper Shenandoah/Laurel planning area in each specific year (see Appendix E).

Table 4.29: Supply projections for the Lower Shenandoah/Opequon planning area (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1908.1	1907.9	1907.6	1907.1	1906.6
$7Q_{10}$	229.7	229.5	229.3	228.7	228.2
$1Q_{30}$	147.6	147.5	147.2	146.6	146.1
Q_{90}	396.9	396.7	396.4	395.9	395.4
Q_{50}	1072.7	1072.5	1072.3	1071.7	1071.2
Q_{10}	3840.4	3840.3	3840.0	3839.4	3838.9

Because of the large scale of the planning area, the analysis of individual water supply systems is not included in the preceding supply estimates. The water supply estimates do not account for 16.5 MGD available from over 40 groundwater wells, 6 springs, and 2 reservoirs systems within the planning area.[175] In 1995 the USGS reported that 18.2 MGD of groundwater was utilized in the Lower Shenandoah/Opequon planning area.

4.5.4.3 The Demand Condition

In 1995, 45.36 MGD of partially consumed water (i.e. total daily offstream demand) was withdrawn from the Lower Shenandoah/Opequon planning area (see Appendix J). The 1995 estimate was developed as a total of the demand values reported by the USGS for cataloging units 02070006, 02070004, 02070007 and 32.70% of the totals reported for unit 02070005. The multiplier of .3270 of the total demand of unit 02070005 is the result of the ratio of the land area contributing to the Lower Shenandoah/Opequon planning area (546.68 mi^2) and the total cataloging unit area (1672.11 mi^2) (see *4.3.3*). Dividing the 45.36 MGD withdrawal by the 1995 reported population estimate of 235,980 people indicates a total per capita daily offstream consumptive use of 192.26 gpcd. The total offstream per capita freshwater estimate includes 11.21 MGD of industrial withdrawals (24.71% of the total offstream demand). Of the 45.36 MGD total daily offstream withdrawal in the planning area, 10.17 MGD or 22.42% of the withdrawal was consumed. As mentioned in *4.3.3.3*, all hydroelectric instream demands for cataloging unit 02070005 took place inside the boundaries of the lower portion of 02070005 and totaled 1003.8 MGD.

Assuming that the total daily per capita offstream withdrawal and the percentage of consumption remain steady in each future year, the demand projected as a function of the anticipated population through 2025 is displayed in Table 4.30 (see Appendix K).

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[175] Estimates of developed supply collected from personal correspondence with the Towns of Stanley, Broadway and Shenandoah, the City of Winchester and Frederick County and from VSWCB Planning Bulletin No. 345, pages II-126,

Table 4.30: Total daily offstream demand for the Lower Shenandoah/Opequon planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	41.86	9.39
2000	42.94	9.63
2005	44.94	10.08
2015	48.61	10.90
2025	51.96	11.65

If an instream demand equivalent to $7Q_{10}$ is included in the total daily demand estimate, the total daily demand could be as displayed in Table 4.31 (see Appendix K).

Table 4.31: Total demand in the Lower Shenandoah/Opequon planning area.

YEAR	Total Demand (MGD)
1998	277.76
2000	278.84
2005	280.84
2015	284.51
2025	287.86

4.5.4.4 Water Supply Availability in the Lower Shenandoah/Opequon Planning Area

Upon comparing the projected total natural supply availability adjusted for upstream consumption (Table 4.29) to the projected total daily offstream demand (Table 4.30), the following surpluses under each flow condition result:

Table 4.32: Offstream demand water supply availability in the Lower Shenandoah/Opequon planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1866	1865	1863	1858	1855
$7Q_{10}$	188	187	184	180	176
$1Q_{30}$	106	105	102	98	94
Q_{90}	355	354	351	347	343

II-144, II-158, II-180 and II-264.

Based on the surpluses listed in the preceding table, it can be concluded that no shortages are projected to occur across the planning area in the planning period. The surpluses can be expressed in terms of the projected population in order to indicate the amount of water available for development on a per capita per day basis in each year of the analysis.

Table 4.33: Offstream demand water supply availability in the Lower Shenandoah/Opequon planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	8572	8352	7970	7351	6864
$7Q_{10}$	863	836	789	712	652
$1Q_{30}$	486	468	437	388	349
Q_{90}	1631	1584	1504	1374	1271

Projected developments in the Shenandoah River basin (which includes the demands in the Upper Shenandoah/Laurel planning area) are not expected to exceed 6% of annual mean flow in the planning period (see Appendix L).

The partial river basin scale eliminates the potential local shortages that may result during times of localized low flow and specific conflict between individual users. It is also important to note that the instream hydroelectric uses are not included in the demand values for which the surpluses have been developed. Despite hydroelectric demands being non-consumptive, potential conflict may arise under low flow conditions unless flowby conditions are specified by permit at each facility.

Although the Lower Shenandoah/Opequon planning area does not appear to face any potential supply and offstream demand conflict at the regional scale, instream demand requirements may change the nature of supply availability locally and regionally (see *A-4.1*). If the a flow equivalent to the total $7Q_{10}$ was designated as a flowby requirement over the total planning area, the following set of conditions might be expected to occur based upon the total daily demand expression:

Table 4.34: Total demand water supply availability in the Lower Shenandoah/Opequon planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1630	1629	1627	1623	1619
$7Q_{10}$	-48	-49	-52	-56	-60
$1Q_{30}$	-130	-131	-134	-138	-142
Q_{90}	119	118	116	111	108

4.5.5 The Upper Rappahannock Planning Area

4.5.5.1 The Upper Rappahannock Planning Area and Its Population

The Upper Rappahannock planning area (see Plate V) includes hydrologic units E01-E18 of the headwaters of the Rappahannock River Basin (see Plate 10) which drains 1556.90 square miles of Virginia. It is coincidental with USGS cataloging unit 02080103 and includes the drainage areas of the Rapidan, Jordan, Hughes, Hazel, Thornton, Conway and South Rivers and Thumb, Carter, Muddy, Indian, Marsh, Mountain, Deep, Rock, Blue, Beautiful, White Oak, Crooked, Cedar, Mine and Mountain Runs (see Appendix A). The planning area includes portions of Albemarle, Culpeper, Fauquier, Greene, Madison, Orange, Rappahannock, Spotsylvania and Stafford Counties (see Appendix G.2). Based on 1998 Census Bureau population estimates for Virginia cities and counties (see Appendix F), the 1998 population of the planning area was approximated as 107,547 people, an average population density of about 69 people per square mile. Assuming Virginia population growth and planning area population growth will be proportional, population estimates were developed for the planning area as a function of Census Bureau projections for the Commonwealth through 2025.

Table 4.35: Upper Rappahannock planning area population projections (see Appendix H).

YEAR	Projected Population
2000	110,340
2005	115,496
2015	124,911
2025	133,505

4.5.5.2 The Supply Condition

Natural flow availability in the Upper Rappahannock planning area was developed as a function of flow data measurements at USGS gage 01664000 on the Rappahannock River at Remington, Virginia and USGS gage 01667500 on the Rapidan River near Culpeper, Virginia. The average cfs/mi^2 yield for each flow condition was developed for each contributing basin and applied to the entire upstream land area in order to estimate the amount of water yielded at the downstream point. At the confluence, the downstream point of hydrologic unit E18, the flow estimates were added together to estimate the total flow yielded by the planning area (see Appendix D.5).

Gage 01664000 at Remington, Virginia on the Rappahannock River measures and records flow from 620 square miles of the 861.71 Upper Rappahannock drainage area. If the 241.71 square miles of ungaged area (an addition of 38.99% of the gaged land area) is included in the total flow estimate, the translated flow conditions in Table 4.36 can be expected (for the period of records for each flow estimate see Appendix C).

Table 4.36: Flow estimates at the downstream point of the Upper Rappahannock River.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**627.0**	100%
$7Q_{10}$	**9.9**	1.58%
$1Q_{30}$	**3.5**	0.56%
Q_{95}	**42.9**	6.85%
Q_{90}	**69.2**	11.03%
Q_{50}	**380.8**	60.74%
MBF_{est}	**388.0**	61.89%
Q_{10}	**1275.5**	203.44%

Gage 01667500 near Culpeper, Virginia on the Rapidan River measures and records flow conditions from 472 square miles of the 695.19 square mile Rapidan River basin. If the 223.19 square miles of ungaged area (an addition of 47.29% of the gaged land area) is included in the total flow estimate, the translated flow conditions in Table 4.37 result (for the period of record used for each flow estimate see Appendix C).

Table 4.37: Flow estimates at the downstream point of the Rapidan River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**516.9**	100%
$7Q_{10}$	**18.5**	3.58%
$1Q_{30}$	**4.1**	0.79%
Q_{90}	**81.9**	15.84%
Q_{50}	**328.4**	63.54%
Q_{10}	**1028**	198.90%

At the confluence of the two drainage areas, the flow conditions can be estimated for the entire 1556.90 square mile upstream drainage area. Upstream consumption does not have to be accounted for because the Upper Rappahannock planning area is a headwater planning area. Nearly 465 square miles of ungaged land area is added to the total gaged area of 1092 square miles (42.57% of the gaged area). However, the lack of downstream gages and the similarity in geology and hydrology enabled the assumption that the estimates are a relatively accurate representation of the overall upstream concentrated water yield.

Table 4.38: Supply estimates for the Upper Rappahannock planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1144.0**	100%
$7Q_{10}$	**28.4**	2.48%
$1Q_{30}$	**7.6**	0.66%
Q_{90}	**151.0**	13.20%
Q_{50}	**709.0**	61.98%
Q_{10}	**2303.0**	201.31%

The water supply estimates in Table 4.38 do not include 1.561 MGD developed from 5 springs, 26 wells, and artificial storage sites in 1983.[176] In 1995 the USGS reported that 6.03 MGD of groundwater was utilized in the Upper Rappahannock planning area.

4.5.5.3 The Demand Condition

In 1995 in USGS demand cataloging unit 02080103, an estimated 13.58 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Upper Rappahannock planning area (see Appendix J). Based on the 1995 population estimate of 102,250 people, the 1995 total daily per capita offstream demand was 132.81 gpcd (13.58 MGD/102,250 people). The total offstream per capita freshwater estimate includes .49 MGD of industrial withdrawals (3.61% of the total offstream demand). Of the total daily offstream withdrawal, 2.29 MGD was consumed (16.86% of the withdrawal). Assuming that the total daily per capita offstream demand and the percentage of that demand consumed will remain constant in each year of the planning period, projected demands through 2025 are shown in Table 4.39 (see Appendix K).

Table 4.39: Total daily offstream demand for the Upper Rappahannock planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	14.28	2.41
2000	14.65	2.47
2005	15.34	2.59
2015	16.59	2.80
2025	17.73	2.99

Table 4.40 indicates the total daily demand if an instream demand equivalent to $7Q_{10}$ is required to pass the outlet point of the planning area (see Appendix K).

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[176] See note 173, supra, p. II-15 - II-17.

Table 4.40: Total daily demand in the Upper Rappahannock planning area.

YEAR	Total Demand (MGD)
1998	42.68
2000	43.05
2005	43.74
2015	44.99
2025	46.13

4.5.5.4 Water Supply Availability in the Upper Rappahannock Planning Area

Upon comparing the projected total natural flow availability (Table 4.38) to the projected total daily offstream demand (Table 4.39), the following water balance conditions result:

Table 4.41: Offstream demand water supply availability in the Upper Rappahannock planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1130	1129	1129	1127	1126
$7Q_{10}$	14	14	13	12	11
$1Q_{30}$	-7	-7	-8	-9	-10
Q_{90}	137	136	136	134	133
$10\%Q_{AM}$	100	100	99	98	97
$20\%Q_{AM}$	215	214	213	212	211

Although natural supply availability in the Upper Rappahannock planning area is generally in surplus, Table 4.41 indicates that natural water supply availability may not satisfy demands under $1Q_{30}$ flow conditions throughout the planning period. The natural supply availability can also be expressed as a function of projected population in order to identify the amount of water that can be or needs to be developed under each flow condition in each year of the analysis.

Table 4.42: Offstream demand water supply availability in the Upper Rappahannock planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	10,509	10,239	9772	9027	8436
$7Q_{10}$	131	125	113	95	80
$1Q_{30}$	-62	-64	-67	-72	-76
Q_{90}	1272	1236	1175	1076	998
$10\%Q_{AM}$	931	904	858	783	724
$20\%Q_{AM}$	1996	1942	1848	1699	1581

As is indicated in Tables 4.41 and 4.42, offstream demand is not expected to exceed the 10% or 20% of annual mean capture threshold. The projected offstream demand indicates that offstream demands are not expected to exceed 2% of the annual mean flow. Water supply conditions may be significantly affected if a flow equivalent to the total natural $7Q_{10}$ estimate was required to pass the downstream point of the upper portion of the Rappahannock River basin.

Table 4.43: Total demand water supply availability in the Upper Rappahannock planning (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1101	1101	110	1099	1098
$7Q_{10}$	-14	-15	-15	-17	-18
$1Q_{30}$	-35	-35	-36	-37	-39
Q_{90}	108	108	107	106	105

The preceding analysis indicates the amount of water that must be developed beyond the average streamflow quantities when compared to the total daily offstream and total daily demands. It does not account for the water that may be available from developments at small sites locally, nor does it attempt to describe potential conflicts between individual users or the condition of treatment, storage and distribution facilities.

4.5.6 The Lower Rappahannock Planning Area

4.5.6.1 The Lower Rappahannock Planning Area and Its Population

The Lower Rappahannock planning area (see Plate VI) includes hydrologic units E19-E26 of the Lower Rappahannock River Basin (see Plate 11). The Lower Rappahannock planning area covers a total of 1157.13 square miles and shares a boundary with USGS cataloging unit 02080104. Tributaries to the Rappahannock River include Corrotman River, Motts Run and Massaponnax, Mill, Goldenvale, Occupacia, Peedee, Catpoint, Piscataway, Totuskey, Lagrange and Lancaster Creeks (see Appendix A). The planning area includes portions of the City of Fredericksburg and Caroline, Essex, King George, Lancaster, Middlesex, Northumberland, Richmond, Spotsylvania, Stafford and Westmoreland Counties (see Appendix G.2). Based on 1998 Census Bureau estimated population densities for each municipality in Virginia, the 1998 estimated population for the planning area was 104,560 people, an average population density of about 91 people per square mile. If the population with the planning area grows proportional to the Census Bureau projections for Virginia, the projected population through 2025 is shown in Table 4.44.

Table 4.44: Lower Rappahannock planning area population projections (see Appendix H).

YEAR	Projected Population
2000	107,275
2005	112,288
2015	121,441
2025	129,797

4.5.6.2 The Supply Condition

Streamflow availability in the Lower Rappahannock planning area was developed from flow records kept at USGS gage 01668000 on the Rappahannock River near Fredericksburg, Virginia. The average cfs/mi^2 yield for each flow condition was applied to the total drainage area of the Rappahannock River to the downstream outlet into the Chesapeake Bay. Although the lower portion of the Rappahannock south of Fredericksburg lies completely in the Coastal Plain and is generally considered under the influence of tidal fluctuation, the tributaries to the stream are freshwater streams that could be developed under reservoir and impoundment development schemes. The lack of sufficient stream gages in the Coastal Plain province required the streamflow estimates to be developed from upstream gage data.

Gage 01668000 on the Rappahannock River near Fredericksburg, Virginia records streamflow data from 1596 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept between 1907 and 1998.[177] Flow conditions for $7Q_{10}$, Q_{95} and the MBF_{est} were developed by Nelms, et al. from records kept between 1911 and 1984.[178] The $1Q_{30}$ estimate was developed by the VSWCB from records kept between 1907 and 1977.[179] By translating the gage data to the mouth of the Rappahannock at the Chesapeake Bay (the downstream point of hydrologic unit E26), the adjusted flow estimates include 1118.03 square miles of ungaged land area (70.05% of the gaged area).

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[177] See note 28, supra, p. 197.
[178] See note 121, supra, Appendix 1.
[179] See note 154, supra, p. xv.

Table 4.45: Flow estimates for the Lower Rappahannock planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1865.0**	100%
$7Q_{10}$	**52.8**	2.83%
$1Q_{30}$	**16.2**	0.87%
Q_{95}	**164.8**	8.84%
Q_{90}	**260.5**	13.97%
Q_{50}	**1099.0**	58.93%
MBF_{est}	**1024.3**	54.92%
Q_{10}	**3670.7**	196.82%

Because of the consumption of water withdrawn by upstream water users in the Upper Rappahannock planning area, the streamflow availability estimates had to be adjusted to account for projected consumption in each year of the planning period. The projected consumption for the Upper Rappahannock planning area was subtracted from the streamflow availability estimates in Table 4.45.

Table 4.46: Supply projections for the Lower Rappahannock planning area.

Flow	1998	2000	2005	2015	2025
Q_{AM}	1862.6	1862.5	1862.4	1862.2	1862.0
$7Q_{10}$	50.3	50.3	50.2	50.0	49.8
$1Q_{30}$	13.7	13.7	13.6	13.4	13.2
Q_{95}	162.4	162.4	162.3	162.1	161.9
Q_{90}	258.1	258.0	257.9	257.7	257.5
Q_{50}	1096.6	1096.5	1096.4	1096.2	1096.0
MBF_{est}	1021.9	1021.8	1021.7	1021.5	1021.3
Q_{10}	3668.2	3668.2	3668.1	3667.9	3667.7

The water supply estimates do not include 2.4 MGD of water developed from 23 wells and 2 stored water facilities in 1983.[180,181] In 1995 the USGS reported that 5.08 MGD of groundwater was utilized in the Lower Rappahannock planning area.

[180] Virginia State Water Control Board. "York Water Supply Plan." Virginia State Water Control Board Planning Bulletin No. 343, March 1988, p. II-73 - II-75.
[181] See note 173, supra, p. II-15 - II-17 and p. II-103 - II-105.

4.5.6.3 The Demand Condition

In 1995 in USGS demand cataloging unit 02080104, an estimated 17.72 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Lower Rappahannock planning area (see Appendix J). Based on the 1995 population estimate of 100,610 people, the total per capita daily offstream demand was 176.13 gpcd (17.72 MGD/100,610 people). The total offstream per capita freshwater estimate includes .39 MGD of industrial withdrawals (2.20% of the total offstream demand). Of the 17.72 MGD total daily offstream demand, 4.25 MGD (23.98% of the partially consumed withdrawal) was estimated to have been consumed. Assuming that the total per capita daily offstream demand and the percentage of that demand consumed remains constant in each year of the planning period, the demand through 2025 is shown in Table 4.47 (see Appendix K).

Table 4.47: Projected total daily offstream demand for the Lower Rappahannock planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	18.42	4.42
2000	18.90	4.53
2005	19.78	4.74
2015	21.38	5.13
2025	22.86	5.48

Table 4.48 shows the total daily demand if an instream demand equivalent to the $7Q_{10}$ estimate is required to pass the mouth of the Rappahannock River (see Appendix K).

Table 4.48: Projected total daily in the Lower Rappahannock planning area.

YEAR	Total Demand (MGD)
1998	71.22
2000	71.70
2005	72.58
2015	74.18
2025	75.66

4.5.6.4 Water Supply Availability in the Lower Rappahannock Planning Area

Upon the comparison of the projected total streamflow availability (Table 4.46) to the projected total daily offstream demand (Table 4.47), the following water balance conditions result:

Table 4.49: Offstream demand water supply availability in the Lower Rappahannock planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1844	1844	1843	1841	1839
$7Q_{10}$	32	31	30	29	27
$1Q_{30}$	-5	-5	-6	-8	-10
Q_{95}	144	144	143	141	139
Q_{90}	240	239	238	236	235

The preceding conditions can also be expressed in terms of the projected population in order to identify the amount of estimated streamflow that can be or needs to be developed in the future on a per capita basis.

Table 4.50: Offstream demand water supply availability in the Lower Rappahannock planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	17631	17182	16408	15163	14169
$7Q_{10}$	305	292	271	235	207
$1Q_{30}$	-45	-49	-55	-66	-75
Q_{95}	1377	1337	1269	1159	1071
Q_{90}	2291	2228	2120	1946	1807

The cumulative withdrawals in the Rappahannock River basin (including the Upper Rappahannock planning area) have not been projected to exceed 3% percent of the annual mean flow (see Appendix L).

Water supply conditions could be significantly altered if a flow equivalent to the estimated $7Q_{10}$ was required to pass the mouth of the Rappahannock River.

Table 4.51: Total demand water supply availability in the Lower Rappahannock planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1791	1791	1790	1788	1786
$7Q_{10}$	-21	-21	-22	-24	-26
$1Q_{30}$	-57	-58	-59	-61	-63
Q_{95}	91	91	90	88	86
Q_{90}	187	186	185	183	182

The large scope of the partial-river basin scale does not permit the analysis of potential conflict between individual users during localized periods of low flow or of individual system treatment, storage or distribution facility conditions.

4.5.7 The Pamunkey Planning Area

4.5.7.1 The Pamunkey Planning Area and Its Population

The Pamunkey planning area (see Plate VII) consists of hydrologic units F01-F14 of the headwaters of the York River Basin (see Plate 13) and drains 1472.76 square miles of the Commonwealth. It coincides with USGS cataloging unit 020801016 and includes drainage from the Anna, Newfound and Little Rivers and Roundabout, Taylors, Contrary, Northeast, Mechumps, Black and Totopotomoy Creeks (see Appendix A). The planning area stretches from its headwaters in Orange and Louisa Counties in the Piedmont to its mouth at the York River in New Kent and King William Counties in the Coastal Plain. The planning area includes portions of Albemarle, Caroline, Fluvanna, Goochland, Hanover, King William, Louisa, New Kent, Orange and Spotsylvania Counties (see Appendix G.2). Developed as a function of the Census Bureau estimates of population density within counties and cities of the Commonwealth in 1998 (see Appendix F), the planning area population in 1998 was estimated to be 141,927 people, an average population density of about 94 people per square mile. Population projections were developed for the planning area as a function of Census Bureau projections for Virginia through 2025.

Table 4.52: Pamunkey planning area population projections (see Appendix H).

YEAR	Projected Population
2000	145,612
2005	152,417
2015	164,841
2025	176,183

4.5.7.2 The Supply Condition

Natural flow availability in the Pamunkey planning area was developed as a function of flow data measurements at USGS gage 01673000 on the Pamunkey River near Hanover, Virginia that captures 1081 square miles of the upstream watershed. The average cfs/mi^2 yield for each flow condition was developed for the gaged land area and applied to the ungaged land area at the downstream point of hydrologic unit F14 before the confluence of the Pamunkey and Mattaponi Rivers to form the tidal York River waterway. Flow conditions in the stream did not have to be adjusted to account for consumption because the Pamunkey planning area is a headwater planning area. Records at the gaging site have been kept since 1942 by the USGS, but in 1972, the Lake Anna project was put online and altered the nature of the streamflow patterns. The Lake Anna reservoir stores a total of 99.43 billion gallons for cooling Virginia Power's nuclear power generation plant; stored waters can also be allocated for water supply, flood control and recreation purposes.[182] Consequently, records of streamflow conditions need to account for the changes induced by Lake Anna's artificial storage capacity. Flow

[182] See note 180, supra, p. II-16.

records derived from USGS publications in Virginia include the annual mean (Q_{AM}) and the ninety (Q_{90}), fifty (Q_{50}) and ten (Q_{10}) percent exceedance flows; each of these flow values was developed from daily records measured from 1972-1998.[183] However, $7Q_{10}$ and $1Q_{30}$ flows at the site were developed by the State Water Control Board in 1983 and were based on records from 1942-1977 that do not account for Lake Anna's affect on the streamflow.[184] Upon comparing the 1942-1971 statistics with the 1972-1998 statistics, Lake Anna has increased the mean flow available annually (Q_{AM}) downstream at the gaging site annually by about 250 cfs, decreased the Q_{90} flow by 6 cfs, increased the Q_{50} flow by 119 cfs and increased the Q_{10} flow by 770 cfs.[185] When gaged flow conditions are applied to the entire watershed, Table 4.53 represents estimates of available flows (see Appendix D.7).

Table 4.53: Supply estimates for the Pamunkey planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1028.4**	100%
$7Q_{10}$	**33.0**	3.21%
$1Q_{30}$	**14.7**	1.43%
Q_{90}	**109.2**	10.62%
Q_{50}	**554.7**	53.94%
Q_{10}	**2403.7**	233.73%

Table 4.53 includes 391.76 square miles of ungaged area added to the 1081 square miles of gaged area, an addition of 36.24% of the original gaged land area. The gage represents waters generated mainly in the Piedmont portion of the basin; the ungaged land area lies mostly in the Coastal Plain portion of the basin. However, the unavailability of any downstream gages on the main stream requires that the gage data be

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[183] See note 28, supra, p. 213.
[184] See note 154, supra, p.xvi.
[185] See note 28, supra, p. 213.

applied throughout the basin area in order to estimate total flow available in the stream. The supply estimates of the total 1472.76 square mile drainage area do not include 4.711 MGD developed from 85 wells, 3 springs, and surface water withdrawals from artificial storage sites in 1984.[186] In 1995 the USGS reported that 6.66 MGD of groundwater was utilized in the Pamunkey planning area.

4.5.7.3 The Demand Condition

In 1995 in USGS cataloging unit 02080106, an estimated 33.45 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Pamunkey planning area (see Appendix J). Based on the 1995 population estimate of 126,690 people, the 1995 total daily per capita offstream demand was 264.03 gpcd (33.45 MGD/126,690 people). The total offstream per capita freshwater estimate includes 3.5 MGD of industrial withdrawals (10.46% of the total offstream demand). Of the 33.43 total daily offstream withdrawal, 5.96 MGD was consumed (17.82% of the partially consumed withdrawal). If the total per capita daily offstream demand and the percentage of that demand consumed remain constant in each year of the planning period, then projected demands through 2025 may be as shown in Table 4.54 (see Appendix K).

Table 4.54: Total daily offstream demand for the Pamunkey planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	37.47	6.68
2000	38.44	6.85
2005	40.24	7.17
2015	43.51	7.75
2025	46.52	8.29

[186] See note 180, supra, p. II-11 - II-13.

Table 4.55 indicates the total daily demand if an instream demand equivalent to the 33.0 MGD total $7Q_{10}$ streamflow estimate is required to pass the mouth of the Pamunkey River (see Appendix K).

Table 4.55: Total daily demand in the Pamunkey planing area.

YEAR	Total Demand (MGD)
1998	70.47
2000	71.44
2005	73.24
2015	76.51
2025	79.52

4.5.7.4 Water Supply Availability in the Pamunkey Planning Area

Upon comparing the projected total stream flow availability (Table 4.53) to the projected total daily offstream demand (Table 4.54), the following water balance conditions result:

Table 4.0.56: Offstream demand water supply availability in the Pamunkey planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	991	990	988	985	982
$7Q_{10}$	-4	-5	-7	-11	-14
$1Q_{30}$	-23	-24	-26	-29	-32
Q_{90}	72	71	69	66	63
$10\%Q_{AM}$	65	64	63	59	56
$20\%Q_{AM}$	168	167	165	162	159

Table 3.56 indicates that water supply shortages may occur in the Pamunkey planning area under $7Q_{10}$ and $1Q_{30}$ flow conditions throughout the planning period. The stream flow availability less anticipated demands can also be expressed as a function of projected population in order to identify the amount of water that can be or needs to be developed in each year of the analysis:

Table 4.57: Offstream demand water supply availability in the Pamunkey planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	6983	6799	6484	5976	5572
$7Q_{10}$	-32	-38	-47	-64	-77
$1Q_{30}$	-161	-163	-168	-175	-181
Q_{90}	505	486	452	399	356
$10\%Q_{AM}$	461	442	411	360	320
$20\%Q_{AM}$	1185	1149	1086	984	903

As indicated in Tables 4.56 and 4.57, projected offstream demands should not exceed the 10 or 20 percent of annual mean flow capture threshold; they are not expected to exceed 5% of annual mean flow.

Water availability conditions may be significantly altered if a flow equivalent to the total $7Q_{10}$ estimate was required to pass the mouth of the Pamunkey River:

Table 4.58: Total demand water supply availability in the Pamunkey planning area (all flows expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	958	957	955	952	949
$7Q_{10}$	-37	-38	-40	-44	-47
$1Q_{30}$	-56	-57	-59	-62	-65
Q_{90}	39	38	36	33	30

The preceding analysis indicates the amount of water that must developed beyond the available streamflow quantities in order to meet projected demand conditions in the Pamunkey planning area through 2025. It does not include the storage potentially available from Lake Anna or the cooling water demands of the nuclear-electric facility located at the reservoir. The analysis is preliminary and does not attempt to describe the water available from developments at small sites locally or the potential water conflicts between individual users.

4.5.8 The Mattaponi Planning Area

4.5.8.1 The Mattaponi Planning Area and Its Population

The Mattaponi planning area (see Plate VIII) is broken into smaller drainage areas represented by hydrologic units F15-F25 collectively covering 911.40 square miles of the Mattaponi River Basin (see Plate 14). It coincides with USGS cataloging unit 02080105 and includes Mattaponi tributaries the Matta, Po, Ni, Poni and South Rivers and Polecat, Herring, Chapel, Maracossic, Garnetts and Courthouse Creeks (see Appendix A). The Mattaponi River system stretches from headwaters in Culpeper and Spotsylvania Counties in the Piedmont to its mouth in King William and King and Queen Counties in the Coastal Plain. The planning area includes portions of Caroline, Essex, King and Queen, King William, Orange and Spotsylvania Counties (see Appendix G.2). Using population densities from Census Bureau population estimates in 1998 (see Appendix F), the planning area population was estimated in 1998 to be 67,292 people, an average population density of about 74 people per square mile. Population projections for the planning are were developed using Census Bureau projections for Virginia through 2025.

Table 4.59: Mattaponi planning area population projections (see Appendix H).

YEAR	Projected Population
2000	69,039
2005	72,266
2015	78,157
2025	83,534

4.5.8.2 The Supply Condition

Streamflow availability on the Mattaponi River was developed as a function of flow data measurements at USGS gage 01674500 on the Mattaponi River near Beulahville, Virginia that captures two-thirds of the entire basin (601 of 911.4 mi^2). The average cfs/mi^2 yield at the gaging station was developed for each flow condition and applied to the entire river basin area in order to estimate the flow conditions at the downstream point of hydrologic unit F25 before joining the Pamunkey River to form the York River. Records at the gaging station have been kept continuously since 1942 with exception of water year 1988 when no records were available. Flows for Q_{AM}, Q_{90}, Q_{50} and Q_{10} have been developed for the full record period through water year 1998;[187] the $7Q_{10}$ and $1Q_{30}$ flow conditions were developed by the State Water Control Board for years 1941-1977.[188] The addition of 310.4 square miles of ungaged land area to 601 square miles of gaged area increases the gaged area by 51.65% (see Appendix D.7).

Table 4.60: Supply estimates for the Mattaponi planning area.

Flow	**Adjusted flow (MGD)**	**%Q_{AM}**
Q_{AM}	**576.3**	100%
$7Q_{10}$	**17.1**	2.96%
$1Q_{30}$	**8.0**	1.39%
Q_{90}	**63.7**	11.05%
Q_{50}	**370.5**	64.29%
Q_{10}	**1313.3**	227.89%

Table 4.60 represents the flow conditions that might be expected to exist at the downstream point of the Mattaponi River. The majority of the gaged land area resides in the Piedmont physiographic province of Virginia, while the ungaged land area lies in the Coastal Plain physiographic province. The hydrology in each of these two portions of the planning area may be considerably variable; however, gage 01674500 is the furthest downstream in the planning area. Therefore, the natural supply availability will be assumed to be reasonably estimated by those values in Table 4.60. The supply estimates

[187] See note 28, supra, p. 225.
[188] See note 154, supra, p. xvi.

do not include 18.23 MGD developed from 57 wells and 2 surface water withdrawals from artificial storage sites in 1984.[189] In 1995 the USGS reported that 4.21 MGD of groundwater was utilized in the Mattaponi planning area.

4.5.8.3 The Demand Condition

In 1995 in USGS demand cataloging unit 02080105, an estimated 30.82 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Mattaponi planning area (see Appendix J). Based on the estimated 1995 population of 61,010 people, the 1995 total daily per capita offstream demand was 505.16 gpcd (30.82 MGD/61,010 people). The total offstream per capita freshwater estimate includes 20.86 MGD of industrial withdrawals (67.68% of the total offstream demand). Of the 30.82 MGD partially consumed withdrawal, 4.52 MGD was consumed (14.67% of the total daily offstream demand). Assuming the total daily per capita offstream demand and the percentage of that demand consumed will remain constant through 2025, the projected demands are seen in Table 4.61 (see Appendix K).

Table 4.61: Total daily offstream demand for the Mattaponi planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	34.00	4.99
2000	34.86	5.11
2005	36.52	5.36
2015	39.50	5.80
2025	42.18	6.19

Table 4.62 indicates the total daily demand if an instream demand equivalent to $7Q_{10}$ is required to pass the mouth of the Mattaponi River.

[189] See note 180, supra, p. II-52 - II-54 and p. II-72 - II-73.

Table 4.62: Total daily demand in the Mattaponi planning area.

YEAR	Total Demand (MGD)
1998	51.10
2000	51.96
2005	53.62
2015	56.60
2025	59.28

It is important to note that nearly 70% of the withdrawals within the planning area are for industrial applications. The projected demands assume that all uses will increase with population.

4.5.8.4 Water Supply Availability in the Mattaponi Planning Area

Upon comparing the projected total natural flow availability (Table 4.60) to the projected total daily offstream demand (Table 4.61), the following water balance conditions result:

Table 4.63: Offstream demand water supply availability in the Mattaponi planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	542	541	540	537	534
$7Q_{10}$	-17	-18	-19	-22	-25
$1Q_{30}$	-26	-27	-29	-32	-34
Q_{90}	30	29	27	24	22
$10\%Q_{AM}$	24	23	21	18	15
$20\%Q_{AM}$	81	80	79	76	73

Table 4.63 indicates that water supply deficits may occur in the Mattaponi planning area under $7Q_{10}$ and $1Q_{30}$ flow conditions throughout the planning period. The projected natural flow availability less anticipated demands can also be expressed on a projected per capita basis in order to identify the amount of water that can be or needs to be developed in each year of the analysis.

Table 4.64: Offstream demand water supply availability in the Mattaponi planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	8058	7847	7465	6864	6396
$7Q_{10}$	-251	-258	-269	-287	-301
$1Q_{30}$	-386	-389	-394	-403	-409
Q_{90}	441	418	376	309	258
$10\%Q_{AM}$	351	330	292	232	185
$20\%Q_{AM}$	1207	1165	1089	969	875

Projected offstream demands are not expected to exceed 8% of annual mean flow in the planning area.

Water availability conditions may be significantly altered if a flow equivalent to the total $7Q_{10}$ condition was required to pass the mouth of the Mattaponi River.

Table 4.65: Total demand water supply availability in the Mattaponi planning (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	525	524	523	520	517
$7Q_{10}$	-34	-35	-37	-40	-42
$1Q_{30}$	-43	-44	-46	-49	-51
Q_{90}	13	12	10	7	4

The preceding preliminary assessment of water supply conditions specifies the amount of water that must be developed beyond the streamflow conditions in the Mattaponi River to meet projected water demands. The analysis does not include the availability of localized supplies and does not describe the potential for conflict between individual users. Groundwater is not included in the analysis of natural flow availability despite being a well-developed resource in the Mattaponi planning area. Municipalities in the regional area have recognized the potential for future water shortages and have initiated the planning process to build the King William Reservoir to capture water from a tributary of the Mattaponi River during times of excess flow. However, the US Army Corps of

Engineers has denied the initial federal permit application;[190] the future of the project is yet to be determined.

4.5.9 The Upper James/Maury Planning Area

4.5.9.1 The Upper James/Maury Planning Area and Its Population

The Upper James/Maury planning area (see Plate IX) consists of hydrologic units I01-I28 of the headwaters of the James River (see Plate 17) and hydrologic units I29-I38 defining the Maury River Basin (see Plate 18). The Upper James drainage area constitutes 2138.06 square miles of the 2976.03 square mile planning area, while the Maury River drains the remaining 837.97 square miles. Each portion of the planning area coincides with an USGS cataloging unit: the Upper James is designated 02080201, and the Maury is designated 02080202. Major tributaries to the flow estimate include the Jackson, Bullpasture and Cowpasture Rivers in the Upper James system and the Calfpasture, South and Poague Rivers in the Maury; numerous creeks (including Upper Potts, Cove and Sweet Springs Creeks shared with West Virginia) also contribute to each system (see Appendix A) before the convergence of the James and the Maury near Glasgow, Virginia. Portions of the cities of Buena Vista, Clifton Forge, Covington, and Lexington and Alleghany, Augusta, Bath, Botetourt, Craig, Giles, Highland, Montgomery, Nelson, Roanoke, and Rockbridge Counties are included in the planning area (see Appendix G.2). According to municipal population densities developed from 1998 Census Bureau population estimates (see Appendix F), approximately 170,685 people resided in the planning area in 1998, an average population density of about 58

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[190] "Corps weighs in against new peninsula reservoir; Area leaders vow to fight for water supply for 8 localities." Scott

people per square mile. Population projections for the planning area were made assuming growth within the planning area will be the same as the growth projected by the Census Bureau for the Commonwealth through 2025.

Table 4.66: Upper James/Maury planning area population projections (see Appendix H).

YEAR	Projected Population
2000	175,116
2005	183,300
2015	198,241
2025	211,881

The Upper James drainage area also includes a small portion of Monroe County, West Virginia. The exact land area is unknown; however, it is approximated to be about 60 to 80 square miles (less than 1% of the James River basin) and will be considered negligible.

4.5.9.2 The Supply Condition

Streamflow availability in the Upper James/Maury planning area was developed from flow data measurements made at USGS gage 02019500 on the James River at Buchanan, Virginia and 02024000 on the Maury River near Buena Vista, Virginia. The average cfs/mi^2 yield under each flow condition was developed for each of the contributing drainage areas and then summed to estimate the total flow at their confluence; the outlet of the planning area on the boundary of hydrologic units I28, I37 and H01 is about 2 miles downstream from the confluence. Supply conditions in the stream are not adjusted for upstream consumption because the Upper James/Maury planning area is considered a headwater planning area.

Harper. The Virginia Pilot, June 8, 1999, p. A1.

Gage 02019500 on the James River at Buchanan, Virginia measures and records flow from 2075 square miles of the 2138.06 square mile Upper James drainage area (63.06 square miles of ungaged area added to gaged area - 3.04% of ungaged area). Records at the station have been kept by the USGS since 1898; however, the completion of the US Army Corps of Engineers Lake Moomaw project behind the Gathright Dam on the Jackson River has regulated flow conditions in the stream since 1980. The compacted earth clay dam stores 20.54 billion gallons of water for flood control, low flow augmentation and recreation at the minimum conservation pool elevation of 1554 feet above sea level.[191] Table 4.67 reports Q_{AM}, Q_{90}, Q_{50} and Q_{10} flow values calculated from flows recorded between 1980 and 1998.[192] On an annual average basis, the dam has increased Q_{90} by 147 cfs, Q_{50} by 40 cfs and Q_{10} by 730 cfs.[193] Estimates for $7Q_{10}$, Q_{95} and the MBF_{est} were derived by Nelms, et. al from records at the station between 1912 and 1979;[194] the $1Q_{30}$ estimate was calculated by the Virginia State Water Control Board (1983) from gage measurements between 1898 and 1977.[195]

Table 4.67: Flow estimates on the James River at its confluence with the Maury River.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**2372.7**	100%
$7Q_{10}$	**232.5**	9.80%
$1Q_{30}$	**179.8**	7.58%
Q_{95}	**305.1**	12.86%
Q_{90}	**460.6**	19.41%
Q_{50}	**1185.7**	49.97%
MBF_{est}	**1274.8**	53.73%
Q_{10}	**5236.5**	220.70%

[191] See note 28, supra, p.244.
[192] Id.
[193] Id.

Gage 02024000 on the Maury River near Buena Vista, Virginia measures and records discharge from 646 square miles of the total 837.97 square mile drainage area (an addition of 191.97 ungaged square miles - 29.72% of the gaged area). Records for Q_{AM}, Q_{90}, Q_{50} and Q_{10} conditions were derived from the entire period of recorded gage data of 1939 through 1998 despite a minimal amount of regulation by Lake Merriweather on the Calfpasture River;[196] flows under $7Q_{10}$, Q_{95} and MBF_{est} conditions are from Nelms, et. al (1997) from records between 1940 and 1966;[197] and, $1Q_{30}$ estimates are from VSWCB analysis of records between 1938 and 1977.[198]

Table 4.68: Flow estimates for the Maury River at its confluence with the James River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**570.1**	100%
$7Q_{10}$	**52.0**	9.12%
$1Q_{30}$	**29.8**	5.23%
Q_{95}	**68.7**	12.04%
Q_{90}	**89.7**	15.74%
Q_{50}	**293.4**	51.47%
MBF_{est}	**334.5**	58.68%
Q_{10}	**1274.3**	223.53%

At the confluence of the two gaged areas, the total flow condition estimates for the entire 2976.03 square mile upstream planning area can be developed as a sum of the adjusted gage data. Of the 2976.03 square mile planning area, a total of 2721 square miles is gaged; while, 255.03 ungaged square miles are added to the total gaged area (9.37%). The similarity in hydrology and geology throughout the planning area, about 90% of the area lies in the Valley and Ridge province, enabled the estimates of flow conditions at the downstream point of hydrologic unit I28.

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[194] See note 121, supra.
[195] See note 123, supra, p. xiii.
[196] See note 28, p. 283.

Table 4.69: Supply estimates for the Upper James/Maury planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**2372.7**	100%
$7Q_{10}$	**232.5**	9.80%
$1Q_{30}$	**179.8**	7.58%
Q_{95}	**305.1**	12.86%
Q_{90}	**460.6**	19.41%
Q_{50}	**1185.7**	49.97%
MBF_{est}	**1274.8**	53.73%
Q_{10}	**5236.5**	220.70%

Although Table 4.69 does reflect the influence of Lake Moomaw on the flow patterns in the stream, it does not account for the water potentially yielded from stored surface water or spring and well access to groundwater in the Upper James/Maury planning area.
In 1982 and 1983-1984, an average daily withdrawal of about 79 MGD was supplied to the planning area by 74 springs, 42 wells, and artificial storage sources.[199] In 1995 the USGS reported that 16.34 MGD of groundwater was utilized in the Upper James/Maury planning area.

4.5.9.3 The Demand Condition

In 1995 in USGS demand cataloging units 02080201 and 02080202, an estimated 82.86 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Upper James/Maury planning area (see Appendix J). Based on the 1995 planning area population estimate of 119,430 people, the 1995 total daily per capita demand was 693.80 gpcd (82.86 MGD/119,430 people). The total offstream per capita freshwater estimate includes 65.27 MGD of industrial withdrawals (78.77% of the total offstream demand). Of the total daily offstream demand, 10.63 MGD (12.83% of the

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[197] See note 121, Appendix 1.
[198] See note 123, p. xiv.

partially consumed withdrawal) was estimated to have been consumed. Assuming the total daily per capita offstream demand and the percentage of that demand consumed will remain constant in each year of the planning period, projected demands through 2025 can be expected to be those values shown in Table 4.70 (see Appendix K).

Table 4.70: Total daily offstream demand for the Upper James/Maury planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	118.43	15.19
2000	121.48	15.59
2005	127.17	16.32
2015	137.51	17.64
2025	146.95	18.85

Table 4.71 indicates the total daily demand if an instream demand equivalent to $7Q_{10}$ is required to pass the downstream point of the planning area (see Appendix K).

Table 4.71: Total daily demand in the Upper James/Maury planning area.

YEAR	Total Demand (MGD)
1998	350.93
2000	353.98
2005	359.67
2015	370.01
2025	379.45

4.5.9.4 Water Supply Availability in the Upper James/Maury Planning Area

Upon comparing the projected total streamflow availability (Table 4.69) to the projected total daily offstream demand (Table 4.70), the following water balance conditions result:

[199] Virginia State Water Control Board. "James Water Supply Plan." Virginia Sate Water Control Board Planning Bulletin No. 337, March 1988, part 1, p. II-12 - II-16 and II-80 - II-82.

Table 4.72: Offstream demand water supply availability in the Upper James/Maury planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	2254	2251	2246	2235	2226
$7Q_{10}$	114	111	105	95	86
$1Q_{30}$	61	58	53	42	33
Q_{95}	187	184	178	168	158
Q_{90}	342	339	333	323	314
$10\%Q_{AM}$	119	116	110	100	90
$20\%Q_{AM}$	356	353	347	337	328

The preceding surpluses can also be expressed in terms of projected population in order to identify the amount of water available for development on a per capita basis in each year of the planning period.

Table 4.73: Offstream demand water supply availability in the Upper James/Maury planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	13,206	12,857	12,251	11,277	10,503
$7Q_{10}$	668	634	575	479	403
$1Q_{30}$	360	333	287	213	155
Q_{95}	1094	1049	971	846	746
Q_{90}	2005	1937	1819	1630	1480
$10\%Q_{AM}$	696	661	601	503	426
$20\%Q_{AM}$	2086	2016	1895	1700	1546

As indicated in Tables 4.72 and 4.73, projected offstream demands are not expected to exceed 10 or 20 percent of the annual mean flow. In fact, projected these demands in the Upper James/Maury planning area are not expected to exceed 7% of the estimated annual mean flow.

Water supply conditions could be significantly affected if a flow equivalent to the total estimated $7Q_{10}$ was required to remain instream at the downstream point of the Upper James River drainage basin.

Table 4.74: Total demand water supply availability in the Upper James/Maury planning (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	2022	2019	2013	2003	1993
$7Q_{10}$	-118	-121	-127	-138	-147
$1Q_{30}$	-171	-174	-180	-190	-200
Q_{95}	-46	-49	-55	-65	-74
Q_{90}	110	107	101	91	81

Despite the surpluses indicated in Tables 4.72 and 4.73, it is important to note that the future demand conditions have been projected as a function of population. Included in the projected offstream demand is the industrial demand that accounted for nearly 80% of the partially consumed demand in 1995. The preceding analysis of availability might be considered a conservative estimate because industrial growth does not necessarily accompany increases in population as it has been assumed in this case. Another limitation of the analysis is that the preliminary assessment at the partial-river basin scale does not describe potential for conflict between individual users during localized periods of low flow or the availability of water in existing storage facilities.

4.5.10 The Upper Middle James/Rivanna Planning Area

4.5.10.1 The Upper Middle James/Rivanna Planning Area and Its Population

The Upper Middle James/Rivanna planning area (see Plate X) includes hydrologic units H01-H32 of the Upper Middle James River basin (see Plate 19) and the Rivanna River basin (see Plate 20). The Upper Middle James/Rivanna planning area covers 2790.51 square miles represented by USGS cataloging units 02080203 and 02080204. Hydrologic units H01-H22 represent 2022.65 square miles of the Upper Middle James drainage area, and hydrologic units H23-H32 represent 767.86 square miles of the Rivanna drainage basin. Tributaries to the Upper Middle James include the Pedlar, Tye, Piney, Buffalo, Rockfish, Hardware and Slate Rivers and numerous creeks (see Appendix A). Tributaries to the Rivanna include the Mechums and Moormans Rivers and Buck Mountain, Ivy, Preddy, Moores, Buck Island, Mechunk, Ballinger and Cunningham Creeks (see Appendix A). The Upper Middle James/Rivanna planning area consists of portions of the Cities of Charlottesville and Lynchburg and Albemarle, Amherst, Appomattox, Bedford, Buckingham, Campbell, Cumberland, Fluvanna, Green, Louisa, Nelson and Orange Counties (see Appendix G.2). The 1998 population density estimates for each contributing municipality, based on Census Bureau estimates in the same year (see Appendix F), were used to develop the 1998 estimated population of 279,057 people. Table 4.75 portrays the projected population if the population within the planning area grows proportional to the Census Bureau projections for the Commonwealth.

Table 4.75: Upper Middle James/Rivanna planning area population projections (see Appendix H).

YEAR	Projected Population
2000	286,302
2005	299,683
2015	324,111
2025	346,411

4.5.10.2 The Supply Condition

Streamflow availability in the Upper Middle James/Rivanna planning area was developed from flow records kept at USGS gage 02029000 on the James River at Scottsville, Virginia and USGS gage 02034000 on the Rivanna River at Palmyra, Virginia. Within each drainage area, the average cfs/mi^2 yield at the gage was moved to the downstream point of the drainage basin and combined at the confluence of the two rivers near Columbia, Virginia.

Gage 02029000 on the James River at Scottsville, Virginia records streamflow data from 4584 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept between 1980 and 1998, despite record availability since 1925; the records were truncated in order to account for flow regulation introduced by the completion of Lake Moomaw in 1979.[200] Flow conditions for $7Q_{10}$, Q_{95} and the MBF_{est} were developed by Nelms, et al. from records kept between 1925 and 1979.[201] The $1Q_{30}$ estimate was developed by the VSWCB from records kept between 1924 and 1977.[202] By translating the gage data to the confluence of the James and the Rivanna at the outlet of hydrologic unit H20, the adjusted flow estimates include 414.69 square miles of ungaged land area (9.05% of the gaged area).

Table 4.76: Flow estimates for the James River from data at gage 02029000.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**4017.7**	100%
$7Q_{10}$	**358.0**	8.91%
$1Q_{30}$	**238.6**	5.94%
Q_{95}	**551.1**	13.72%
Q_{90}	**838.6**	20.87%
Q_{50}	**2339.7**	58.24%
MBF_{est}	**2200.2**	54.76%
Q_{10}	**8668.3**	215.75%

Gage 02034000 on the Rivanna River at Palmyra, Virginia records flow information from 664 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept from 1935 to 1998.[203] Flow conditions for $7Q_{10}$ and $1Q_{30}$ were developed by the VSWCB from records kept between

200 See note 28, p.294-295.
201 See note 121, Appendix 1.
202 See note 123, p. xv.
203 See note 28, p. 303.

1933 and 1977.[204] By translating the gage data to the downstream point of hydrologic unit H31 at the confluence with the James River, the adjusted flows include 103.66 square miles of ungaged land area (15.61% of the gaged land area).

Table 4.77: Flow estimates for the Rivanna River from data at gage 02034000.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**554.4**	100%
$7Q_{10}$	**21.2**	3.83%
$1Q_{30}$	**9.1**	1.63%
Q_{90}	**83.7**	15.09%
Q_{50}	**319.8**	57.68%
Q_{10}	**1075.9**	194.07%

Upon combining the supply estimates at the confluence of the two rivers, a single streamflow availability estimate can be expressed for the planning area. Of the total 5766.35 square miles of drainage area contributing to the planning area, 5248 square miles of the planning area are gaged. The remaining 518.35 square miles of ungaged area (9.88% of the gaged area) are added to the gaged area to provide the following flow estimates.

Table 4.78: Total flow estimates for the Upper Middle James/Rivanna planning area.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**4572.1**	100%
$7Q_{10}$	**379.2**	8.29%
$1Q_{30}$	**247.6**	5.42%
Q_{90}	**922.3**	20.17%
Q_{50}	**2659.5**	58.17%
Q_{10}	**9744.2**	213.12%

[204] See note 123, p. xv.

Because of the consumption of water withdrawn by upstream water users in the Upper James/Maury planning area, the streamflow availability estimates for the Upper Middle James/Rivanna planning area had to be adjusted for upstream consumption.

Table 4.79: Supply projections for the Upper Middle James/Rivanna planning area.

Flow	1998	2000	2005	2015	2025
Q_{AM}	4556.9	4556.5	4555.8	4544.5	4553.2
$7Q_{10}$	364.0	363.7	362.9	361.6	360.4
$1Q_{30}$	232.4	232.0	231.3	230.0	228.8
Q_{90}	907.1	906.7	906.0	904.7	903.5
Q_{50}	2644.3	2643.9	2643.2	2641.9	2640.7
Q_{10}	9744.2	9729.0	9728.6	9727.9	9725.3

The supply estimates do not account for 23.3 MGD of water developed from 45 wells, 1 spring, and stored water facilities in 1980 and 1983-1984.[205] In 1995 the USGS reported that 6.8 MGD of groundwater was utilized in the Upper Middle James/Rivanna planning area.

4.5.10.3 The Demand Condition

In 1995 in USGS demand cataloging units 02080203 and 02080204, an estimated 55.66 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Upper Middle James/Rivanna planning area (see Appendix J). Based on the 1995 population of 270,910 people, the total per capita daily offstream demand was 205.46 gpcd (55.66 MGD/270,910 people). The total offstream per capita freshwater estimate includes 20.21 MGD of industrial withdrawals (36.31% of the total offstream demand). Of the 55.66 MGD total daily offstream demand, 9.12 MGD (16.39% of the partially consumed offstream withdrawal) was estimated to have been consumed. Assuming that the total per capita daily offstream demand and the percentage of that demand consumed remains constant in each future year of the planning period, the demand through 2025 is shown in Table 4.80 (see Appendix K).

Table 4.80: Projected total daily offstream demand for the Upper Middle James/Rivanna planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	57.34	9.40
2000	58.82	9.64
2005	61.58	10.09
2015	66.59	10.91
2025	71.17	11.66

Table 4.81 shows total daily demand if an instream demand equivalent to the total $7Q_{10}$ is required to pass the confluence point of the James and the Rivanna (see Appendix J).

Table 4.81: Projected total daily demand in the Upper Middle James/Rivanna planning area.

YEAR	Total Demand (MGD)
1998	436.54
2000	438.02
2005	440.78
2015	445.79
2025	450.37

4.5.10.4 Water Supply Availability in the Upper Middle James/Rivanna Planning Area

Upon the comparison of the projected total streamflow availability (Table 4.79) and the projected total daily offstream demand (Table 4.80), the following water balance conditions result:

Table 4.82: Offstream demand water supply availability in the Upper Middle James/Rivanna planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4500	4498	4494	4488	4482
$7Q_{10}$	308	305	301	295	289
$1Q_{30}$	175	173	170	163	158
Q_{90}	850	848	844	838	832

[205] See note 199, supra, p. II-134 - II-137 and II-200 - II-202.

The preceding surpluses can also be expressed in terms of the projected population in order to identify the amount of estimated streamflow that may be available for future development on a per capita basis.

Table 4.83: Offstream demand water supply availability in the Upper Middle James/Rivanna planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	16,122	15,710	14,996	13,847	12,939
$7Q_{10}$	1099	1065	1006	910	835
$1Q_{30}$	627	605	566	504	455
Q_{90}	3045	2962	2818	2586	2403

Including the upstream projected offstream demands in the Upper James/Maury planning area, the cumulative withdrawals in the James River basin at the outlet of the Upper Middle James/Rivanna planning area are not expected to exceed 5% of the estimated annual mean flow.

Water supply conditions would be significantly affected if a flow equivalent to the estimated $7Q_{10}$ condition is required to pass the confluence of the James and Rivanna Rivers.

Table 4.84: Total demand water supply availability in the Upper Middle James/Rivanna planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4120	4118	4115	4109	4103
$7Q_{10}$	-73	-74	-78	-84	-90
$1Q_{30}$	-204	-206	-209	-216	-222
Q_{90}	471	469	465	459	453

The surpluses indicated in Tables 4.82 and 4.83 do not include the 115.71 MGD demanded in 1995 for nonconsumptive thermoelectric purposes or the 3189.52 MGD used instream for hydroelectricity generation. The large scope of the partial-river basin scale eliminates the analysis of potential conflict between individual users during periods of localized low flow or the condition of individual system treatment, storage or distribution facilities.

4.5.11 The Lower Middle James Planning Area

4.5.11.1 The Lower Middle James Planning Area and Its Population

The Lower Middle James planning area (see Plate XI) includes hydrologic units H33-H39 of the Lower Middle James River basin (see Plate 21). The Lower Middle James planning area covers a total of 945.49 square miles, and its boundaries are coincidental with USGS cataloging unit 02080205. Tributaries to the Lower Middle James include the Willis River and Deep, Muddy, Byrd, Big Lickinghole, Beaverdam, Fine, Tuckahoe and Norwood Creeks (see Appendix A). The Lower Middle James planning area includes portions of the City of Richmond and Buckingham, Chesterfield, Cumberland, Fluvanna, Goochland, Hanover, Henrico, Louisa and Powhatan Counties (see Appendix G.2). Developed as a function of 1998 Census Bureau population densities for each jurisdiction (see Appendix F), the 1998 population for the planning area was estimated as 172,475 people, an average population density of about 183 people per square mile. Table 4.85 indicates projected population in the planning area if the growth in the planning area occurs proportionally to growth expected in the Commonwealth by the Census Bureau.

Table 4.85: Lower Middle James planning area projected populations (see Appendix H).

YEAR	Projected Population
2000	176,953
2005	185,223
2015	200,321
2025	214,104

4.5.11.2 The Supply Condition

Streamflow availability in the Lower Middle James planning area was developed from streamflow records kept at USGS gage 02035000 on the James River at Cartersville, Virginia. The average cfs/mi^2 yield at the gaged was developed for each flow condition and adjusted to include the entire land area added by shifting the gage data to the downstream point of hydrologic unit H39 in Richmond, Virginia.

Gage 02035000 on the James River at Cartersville, Virginia records streamflow data from 6257 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept between 1899 and 1998.[206] Despite the regulation introduced by Lake Moomaw in the Upper James/Maury planning area, the streamflow regulation affects were considered "moderate";[207] hence, the period of record was not adjusted. Flow conditions for $7Q_{10}$, Q_{95} and the MBF_{est} were developed by Nelms, et al. based on USGS records kept between 1926 and 1979;[208] these conditions were truncated to account for the regulation induced by Lake Moomaw. The $1Q_{30}$ estimate was developed by the VSWCB from records kept between 1898 and 1977.[209] By translating the gage data downstream to the outlet of hydrologic unit H39, the adjusted flow estimates include 454.58 square miles of ungaged land area (7.27% of the gaged land area).

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[206] See note 28, supra, p.305.
[207] Id.
[208] See note 121, Appendix 1.
[209] See note 123, supra, p.xvi.

Table 4.86: Flow estimates on the James River from data at gage 02035000.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**4985.0**	100%
$7Q_{10}$	**404.8**	8.91%
$1Q_{30}$	**255.0**	5.94%
Q_{95}	**687.0**	13.72%
Q_{90}	**1005.2**	20.87%
Q_{50}	**3112.6**	58.24%
MBF_{est}	**2792.3**	54.76%
Q_{10}	**10467**	215.75%

Because of the consumption of water withdrawn by upstream water users in the Upper James/Maury and Upper Middle James/Rivanna planning areas, the streamflow availability estimates for the Lower Middle James planning area had to be adjusted for upstream consumption (see Appendix E).

Table 4.87: Supply projections for the Lower Middle James planning area.

Flow	1998	2000	2005	2015	2025
Q_{AM}	4960.4	4959.8	4958.6	4956.4	4954.5
$7Q_{10}$	380.2	379.6	378.4	376.3	374.3
$1Q_{30}$	230.4	229.7	228.6	226.4	224.4
Q_{95}	662.4	661.8	660.6	658.4	656.5
Q_{90}	980.6	979.9	978.8	976.6	974.7
Q_{50}	3088.0	3087.4	3086.2	3084.0	3082.1
MBF_{est}	2767.7	2767.1	2765.9	2763.8	2761.8
Q_{10}	10443.1	10442.5	10441.3	10439.1	10437.2

The supply estimates do not include 1 MGD of water developed from 31 wells and 1 stored water facility in 1984.[210] In 1995 the USGS reported that 4.31 MGD of groundwater was utilized in the Lower Middle James planning area.

[210] See note 199, supra, p. II-240 - II-244.

4.5.11.3 The Demand Condition

In 1995 in USGS demand cataloging unit02080205, an estimated 77.02 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Lower Middle James planning area (see Appendix J). Based on the 1995 population estimate of 249,150 people, the total per capita daily offstream demand was 309.13 gpcd (77.02 MGD/249,150 people). The total offstream per capita freshwater estimate includes 4.71 MGD of industrial withdrawals (6.12% of the total offstream demand). Of the 77.02 MGD total daily offstream demand, 5.52 MGD (7.17% of the partially consumed offstream withdrawal) was estimated as consumed. Assuming the total per capita daily offstream demand and the percentage of that demand consumed remains constant in each year of the planning period, the demand through 2025 can be expected to be as indicated in Table 4.88 (see Appendix K).

Table 4.88: Projected total daily offstream demand for the Lower Middle James planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	53.32	3.82
2000	54.72	3.92
2005	57.25	4.10
2015	61.92	4.44
2025	66.18	4.75

Table 4.89 portrays the total daily demand if an instream demand equivalent to $7Q_{10}$ is required to pass the outlet of hydrologic unit H39 (see Appendix K).

Table 4.89: Projected total daily demand in the Lower Middle James planning area.

YEAR	Total Demand (MGD)
1998	433.52
2000	434.92
2005	437.45
2015	442.12
2025	446.38

The total daily offstream demand includes 34.97 MGD reported as losses from cataloging unit 02080205 in 1995. Such a large loss value is likely to indicate the transfer of water within the Lower Middle James planning area to an adjacent jurisdiction. If such a transfer is taking place, the transferred demand has been projected to increase with the population of the Lower Middle James planning area. If the losses are, in fact, within the distribution systems within the planning area, they, too, may not increase with population. Another significant limitation to the projections is that the 1995 population estimate was 249,150 people, while the 1998 population estimate was 176,953 people as developed in Appendix G.2. Discrepancies in the population estimates are assumed the result of inhomogeneities in population distribution across the land area.

4.5.11.4 Water Supply Availability in the Lower Middle James Planning Area

Upon the comparison of the projected streamflow availability (Table 4.87) and the projected total daily offstream demand (Table 4.88), the following water balance conditions result:

Table 4.90: Offstream demand water supply availability in the Lower Middle James planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4907	4905	4901	4895	4888
$7Q_{10}$	327	325	321	314	308
$1Q_{30}$	177	175	171	165	158
Q_{95}	609	607	603	597	590
Q_{90}	927	925	922	915	908

The preceding surpluses can also be expressed in terms of the projected population in order to identify the amount of estimated streamflow that may be available for future development on a per capita basis.

Table 4.91: Offstream demand water supply availability in the Lower Middle James planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	28,447	27,712	26,465	24,436	22,832
$7Q_{10}$	1895	1836	1734	1569	1439
$1Q_{30}$	1026	989	925	821	739
Q_{95}	3531	3430	3258	2978	2757
Q_{90}	5375	5227	4976	4567	4243

Including the upstream projected offstream demands in planning areas 9 and 10, cumulative offstream demand in the James River basin at the outlet of the Lower Middle James planning area is not expected to exceed 6 percent of the annual mean flow (see Appendix L).

Water supply conditions would be significantly affected if a flow equivalent to the estimated $7Q_{10}$ is required to pass the outlet of hydrologic unit H39.

Table 4.92: Total demand water supply availability in the Lower Middle James planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4502	4500	4497	4490	4483
$7Q_{10}$	-78	-80	-84	-90	-97
$1Q_{30}$	-228	-230	-233	-240	-247
Q_{95}	204	202	197	192	185
Q_{90}	522	520	517	510	504

The preceding analysis of the water balance in the Lower Middle James planning area does not include individual water supply system analysis. Because of the large partial-river basin scale, the potential for conflict between individual users during localized periods of low flow and the condition of treatment, storage and distribution facilities has not been included in the analysis.

4.5.12 The Appomattox Planning Area

4.5.12.1 The Appomattox Planning Area and Its Population

The Appomattox planning area (see Plate XII) includes hydrologic units J01-J17 that collectively drain 1598.35 square miles of the Appomattox River Basin (see Plate 22) before converging with the James River near Hopewell, Virginia. The Appomattox planning area coincides with USGS cataloging unit 02080207 and includes the watersheds of the Sandy and Bush Rivers and Spring, Briery, Big Guinea, Flat, Nibbs, Deep, Namozine and Swift Creeks (see Appendix A). Headwaters of the Appomattox River form in Appomattox, Buckingham, Prince Edward and Cumberland Counties and flow due east to the River's mouth at the James River in Chesterfield and Dinwiddie Counties near the cities of Petersburg, Colonial Heights, and Hopewell. Population estimates in 1998 were developed for the planning area as a function of 1998 Census Bureau population density estimates for the cities of Colonial Heights, Hopewell, and Petersburg and Amelia, Appomattox, Buckingham, Charlotte, Chesterfield Cumberland, Dinwiddie, Lunenburg, Nottoway, Powhatan, Prince Edward, and Prince George Counties (see Appendix G.2). Based upon 1998 Census Bureau population density estimates (see Appendix F), the total 1998 population estimate for the planning area was 270,496 people, an average population density of 170 people per square mile. If the 1998 Census Bureau growth projections for the population of Virginia are applied to the planning area, the projected population in the planning area may take the form indicated in Table 4.93.

Table 4.93: Appomattox planning area population projections through 2025 (see Appendix H).

YEAR	Projected Population
2000	277,519
2005	290,498
2015	314,167
2025	335,783

4.5.12.2 The Supply Condition

Flow availability in the Appomattox planning area was developed from flow data measurements at USGS gage 02041500 on the Appomattox River near Petersburg, Virginia and from flow data measurements at USGS gage 02041650 on the Appomattox River at Matoaca, Virginia. Different flow parameters were available at each location; in order to have a complete are of flow conditions, the parameters available from each location were used to estimate supply at the outlet of the planning area. Supply estimates do not need to be adjusted for consumption because the Appomattox planning area is not affect by upstream consumption; it is a headwater planning area. Average cfs/mi^2 yield conditions at each location were developed and applied to the entire drainage area in order to estimate the flow conditions near the mouth of the Appomattox at its confluence with the James. Flow conditions Q_{AM}, Q_{90}, Q_{50} and Q_{10} were taken from records between 1970 and 1998 for drainage from 1344 mi^2 of gaged land area at gage 02041650 at Matoaca.[211] The adjusted flow values include 254.35 square miles of ungaged area (18.92% of the gaged area).

[211] See note 28, supra, p. 327.

Table 4.94: Flow estimates at the mouth of the Appomattox River from gage 02041650.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1079.9**	100%
Q_{90}	**123.7**	11.46%
Q_{50}	**540.3**	50.04%
Q_{10}	**2690.0**	249.11%

Flow conditions $7Q_{10}$, Q_{95} and the mean baseflow estimate (MBF_{est}) were taken from records between 1928 and 1966 for drainage from 1334 mi^2 of gaged land area at gage 02041500 near Petersburg;[212] the $1Q_{30}$ flow condition was taken from VSWCB records between 1928 and 1966 at the same station.[213] The adjusted flow values include 264.35 square miles of ungaged land area (19.82% of the gaged land area).

Table 4.95: Flow estimates at the mouth of the Appomattox River from gage 02041500.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
$7Q_{10}$	**44.9**	4.16%
$1Q_{30}$	**24.9**	2.31%
Q_{95}	**103.4**	9.57%
MBF_{est}	**475.4**	44.03%

The full array of flow conditions developed for the Appomattox planning area is indicated in Table 4.96.

Table 4.96: Supply estimates for the Appomattox planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1079.9**	100%
$7Q_{10}$	**44.9**	9.80%
$1Q_{30}$	**24.9**	7.58%
Q_{95}	**103.4**	12.86%
Q_{90}	**123.7**	19.41%
Q_{50}	**540.3**	49.97%
MBF_{est}	**475.4**	53.73%
Q_{10}	**2690.0**	220.70%

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[212] See note 121, supra, p. 37.
[213] See note 123, supra, p. xvii.

The Appomattox River Water Authority controls the downstream flow of the Appomattox at the Lake Chesdin dam that collects water from 1335 square miles of the upstream drainage area.[214] Lake Chesdin has stored 11.5 billion gallons of water for water supply and recreation purposes[215] since its installation at the end of the 1960's and beginning of the 1970's. Therefore, it is important to note that gage 02041500 indicates the flow conditions expected to occur under free-flowing conditions before the reservoir restricted flows; gage 02041650 measures the flow conditions available under controlled conditions. The supply estimates do not include 25.6 MGD developed from 38 wells and stored water systems in 1984.[216] In 1995 the USGS reported that 9.73 MGD of groundwater was utilized in the Appomattox planning area.

4.5.12.3 The Demand Condition

In 1995 in USGS demand cataloging unit 02080207, an estimated 78.38 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Appomattox planning area (see Appendix J). Based on the 1995 population estimate of 286,160 people, the total daily per capita offstream demand was 273.90 gpcd (78.38 MGD/286,160 people). The total offstream per capita freshwater estimate includes 2.74 MGD of industrial withdrawals (3.50% of the total offstream demand). Daily consumption was estimated as 7.59 MGD or 9.68% of the partially consumed offstream withdrawal. Table 4.97 indicates the projected total daily offstream demand assuming the per capita usage and the percentage of consumption remain constant in each future year of the planning period.

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[214] See note 199, supra, p. II-292.
[215] Id.

Table 4.97: Projected total daily offstream consumptive demand for the Appomattox planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	74.09	7.17
2000	76.01	7.36
2005	79.57	7.70
2015	86.06	8.33
2025	91.98	8.90

It is important to note that the USGS reported in 1995 that 28.35 MGD were considered as losses of water within the planning area. The consequences of such a significant loss figure within the distribution systems of individual users indicates that a portion of the unaccounted water may be lost to inter-basin transfers to surrounding municipalities and other users. Table 4.97 assumes that the 28.35 MGD of unaccounted water will increase with population growth in the Appomattox planning area, although it may not necessarily do so. Table 4.98 indicates the total daily demand if flow equivalent to $7Q_{10}$ is required to pass the mouth of the Appomattox (see Appendix K).

Table 4.98: Projected total daily demand in the Appomattox planning area.

YEAR	Total Demand (MGD)
1998	118.99
2000	120.91
2005	124.47
2015	130.96
2025	136.88

4.5.12.4 Water Supply Availability in the Appomattox Planning Area

Upon comparing the projected streamflow availability estimates (Table 4.96) to the projected total daily offstream demand (Table 4.97), the following water balance conditions result:

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[216] Id., p. II-288 - II-292.

Table 4.99: Offstream demand water supply availability in the Appomattox planning area (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1006	1004	1000	994	988
$7Q_{10}$	-29	-31	-35	-41	-47
$1Q_{30}$	-49	-51	-55	-61	-67
Q_{95}	29	27	24	17	11
Q_{90}	50	48	44	38	32
$10\%Q_{AM}$	34	32	28	22	16
$20\%Q_{AM}$	142	140	136	130	124

Water balance projections can also be expressed as a function of the projected population in order to determine the amount of water per person that can be or needs to be developed in the future.

Table 4.100: Offstream demand water supply availability in the Appomattox planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	3718	3618	3443	3163	2942
$7Q_{10}$	-108	-112	-119	-131	-140
$1Q_{30}$	-182	-184	-188	-195	-200
Q_{95}	108	99	82	55	34
Q_{90}	183	172	152	120	94
$10\%Q_{AM}$	125	115	98	70	48
$20\%Q_{AM}$	525	504	470	414	369

Although projected offstream demands are not expected to exceed 9% of the estimated annual flow, water balance conditions in the Appomattox planning area appear to be in jeopardy under $7Q_{10}$ and $1Q_{30}$ flow conditions. If an instream flowby requirement equivalent to the $7Q_{10}$ condition was instituted in the planning area, water balance conditions could be significantly affected.

Table 4.101: Total demand water supply availability in the Appomattox planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	961	959	955	949	943
$7Q_{10}$	-74	-76	-80	-86	-92
$1Q_{30}$	-94	-96	-100	-106	-112
Q_{95}	-16	-18	-21	-28	-34
Q_{90}	5	3	-1	-7	-13

The water balance conditions presented in Tables 4.99, 4.100 and 4.101 indicate the amount of water in surplus and deficit under each flow condition expected to occur in the stream. The analysis does not include water developments at the local level, potential conflict between individual users or surpluses and deficiencies in local systems that are the result of treatment and delivery infrastructure.

4.5.13 The Lower James Planning Area

4.5.13.1 The Lower James Planning Area and Its Population

The Lower James planning area (see Plate XIII) consists of hydrologic units G01-G15 of the Lower James River basin (see Plate 23). The Lower James planning area stretches from the City of Richmond and Hanover, Henrico and Chesterfield Counties in to the mouth of James in the Cities of Newport News, Hampton, Portsmouth and Norfolk and covers some 1925.85 square miles. The Lower James planning area shares boundaries with USGS cataloging unit 02080206. Tributaries include the Chickahominy (represented by hydrologic units G05-G09), Rumley, Pagen, Warwick, Hamptons and Elizabeth Rivers and Falling, Fourmile, Powell, Chippokes, Beaverdam, Diascund, Powhatan, Chuckatuck and Bennett Creek (see Appendix A). The Lower James planning area consists of portions of the Cities of Chesapeake, Hampton, Hopewell, Newport News, Norfolk, Portsmouth, Richmond, Suffolk, Virginia Beach, and Williamsburg and

Charles City, Chesterfield, Hanover, Henrico, Isle of Wight, James City, New Kent, Prince George, Surry, and York Counties (see Appendix G.2). The 1998 population density estimates (see Appendix F), developed from Census Bureau estimates in the same year, indicated that roughly 1,068,187 people resided in the planning area in 1998. Table 4.102 indicates the population in the planning area if the population within the planning area grows proportionally to the Census Bureau projections through 2025.

Table 4.102: Lower James planning area population projections (see Appendix H).

YEAR	Projected Population
2000	1,095,920
2005	1,147,137
2015	1,240,644
2025	1,326,006

4.5.13.2 The Supply Condition

Streamflow availability in the Lower James planning area was developed from flow records kept at USGS gage 02037500 on the James River near Richmond, Virginia, USGS gage 02041500 on the Appomattox River near Petersburg, Virginia, USGS gage 02041650 on the Appomattox River at Matoaca, Virginia and USGS gage 02042500 on the Chickahominy River near Providence Forge, Virginia. The average cfs/mi^2 yield under each flow condition at each gage location was developed and adjusted to the corresponding drainage area in order to estimate the freshwater streamflow availability within the planning area. The flow estimates from the Appomattox at its confluence with the James near Hopewell, from the Chickahominy at its confluence with the James in James City County and from the James River at the gage in Richmond were developed as the estimate of the supply condition. Such an analysis is partial because it does not include drainage from part of hydrologic unit G01 and all of hydrologic units G02, G03, G04, G10, G11, G12, G13, G14 and G15. The total land area contributed by these excluded drainage areas is over 1300 square miles; the neglected area is assumed to be under tidal influence and unable to yield potable surface waters. Although the neglected land area may in fact yield freshwater if impoundment and reservoir schemes were pursued, it will be assumed they cannot be in this case.

Flow availability from the Appomattox River was developed from gages 02041500 on the Appomattox River near Petersburg, Virginia and 02041650 on the Appomattox River at Matoaca, Virginia as described in *4.5.12.2*. The flows were not adjusted for consumption because no consumption took place upstream from the mouth in the Appomattox planning area. It is also important to note that the flows were not adjusted for withdrawals that are projected to take place over the planning period within the Appomattox planning area. However, the consumption will be accounted for in the Appomattox planning when the total flow availability for the Lower James planning area is described in the final paragraph of this section. The adjusted values for the Appomattox River basin include 256.35 square miles of ungaged area (19.82% of the gaged area for gage 02041500).

Table 4.103: Flow estimates at the mouth of the Appomattox planning area.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**1079.9**	100%
$7Q_{10}$	**44.9**	9.80%
$1Q_{30}$	**24.9**	7.58%
Q_{95}	**103.4**	12.86%
Q_{90}	**123.7**	19.41%
Q_{50}	**540.3**	49.97%
MBF_{est}	**475.4**	53.73%
Q_{10}	**2690.0**	220.70%

Gage 02037500 on the James River near Richmond, Virginia was chosen as the termination point of freshwater availability from the James River. The gage records streamflow data from 6758 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were from USGS records kept between 1937 and 1998.[217] Flow conditions for $7Q_{10}$ and $1Q_{30}$ were estimated by the SWCB from records kept between 1934 and 1977.[218] Because the gage location is coincidental with the termination point of the freshwater availability assumption, the flow conditions recorded at the gage are not adjusted and do not include ungaged land area.

Table 4.104: Gage flow conditions on the James River near Richmond, Virginia.

Flow	Gage flow (MGD)	$\%Q_{AM}$
Q_{AM}	**4489.0**	100%
$7Q_{10}$	**402.7**	8.97%
$1Q_{30}$	**206.2**	4.59%
Q_{90}	**614.0**	13.68%
Q_{50}	**2714.3**	60.47%
Q_{10}	**9694.1**	215.95%

Gage 02042500 on the Chickahominy River near Providence Forge, Virginia records streamflow data from 252 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept between 1942 and 1998.[219] Flow conditions for $7Q_{10}$ and $1Q_{30}$ were estimated by the VSWCB from records kept between 1942 and 1977.[220] By translating the gage data downstream to the outlet of hydrologic unit G08 at the confluence of the Chickahominy and the James, the adjusted flows include 217.22 square miles of ungaged land area (86.20% of the gaged land area).

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[217] See note 28, supra, p. 315.
[218] See note 123, supra, p. xvi (see footnote on page xvi).
[219] See note 28, supra, p. 333.

Table 4.105: Flow estimates at the mouth of the Chickahominy River.

Flow	Adjusted Flow (MGD)	$\%Q_{AM}$
Q_{AM}	**316.5**	100%
$7Q_{10}$	**6.0**	1.90%
$1Q_{30}$	**2.3**	0.73%
Q_{90}	**26.5**	8.37%
Q_{50}	**199.8**	63.12%
Q_{10}	**722.0**	228.14%

Upon combining the supply estimates developed at each of the three freshwater locations in the planning area, a single streamflow availability estimate can be expressed for the planning area. Of the total 8825.57 square miles of drainage area assumed to be contributing to freshwater availability in the planning area, 8344 square miles are gaged. The remaining 481.57 square miles of ungaged area (5.77% of the gaged area) are included in the flow estimates.

Table 4.106: Flow estimates for the freshwater portion of the Lower James planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**5885.3**	100%
$7Q_{10}$	**453.6**	7.71%
$1Q_{30}$	**233.5**	3.97%
Q_{90}	**764.2**	12.98%
Q_{50}	**3454.4**	58.70%
Q_{10}	**13,106.1**	222.69%

Because of the consumption of water withdrawn by upstream users in the Upper James/Maury, the Upper Middle James/Rivanna, the Lower Middle James, and the Appomattox planning areas, the freshwater streamflow availability estimates for the Lower James planning area had to be adjusted for upstream consumption.

Table 4.107: Supply projections for the Lower James planning area.

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[220] See note 123, supra, p. xvii.

Flow	1998	2000	2005	2015	2025
Q_{AM}	5849.7	5848.8	5847.1	5844.0	5841.1
$7Q_{10}$	418.0	417.1	415.4	412.3	409.4
$1Q_{30}$	197.9	197.0	195.3	192.2	189.3
Q_{90}	728.6	727.7	726.0	722.9	720.0
Q_{50}	3418.8	3417.9	3416.2	3413.1	3410.2
Q_{10}	13070.5	13069.6	13067.9	13064.8	13061.9

The supply estimates do not include an average of 122.5 MGD of water developed from 181 wells, 13 reservoirs and 1 stream intake between 1983 and 1986[221] or the 1300 square miles of Lower James land area eliminated from the gage data analysis. In 1995 the USGS reported that 15.74 MGD of groundwater was utilized in the Lower James planning area.

4.5.13.3 The Demand Condition

In 1995 in USGS demand cataloging unit 02080206 and 02080208, an estimated 440.83 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Lower James planning area (see Appendix J). Based on the 1995 population of 998,900 people, the total per capita daily offstream demand was 445.78 gpcd (440.83 MGD/988,900 people). The total offstream per capita freshwater estimate includes 240.79 MGD of industrial withdrawals (54.62% of the total offstream demand). Of the 440.83 MGD total daily offstream demand, 45.87 MGD (10.41% of the total daily offstream demand) was estimated to have been consumed. Table 3.108 indicates total daily offstream demand assuming that total per capita daily offstream demand and the percentage consumed remains constant in each year of the planning period (see Appendix K).

[221] See note 199, supra, p. II-240 - II-244, II-320 - II-323 and II-396 - II-398.

Table 4.108: Projected total daily offstream demand for the Lower James planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	476.18	49.57
2000	488.53	50.86
2005	511.35	53.23
2015	553.03	57.57
2025	591.10	61.53

Table 4.108 indicates the total daily demand if an instream demand equivalent to $7Q_{10}$ is required to pass each of the three basin outlets (see Appendix K).

Table 4.109: Projected total daily demand in the Lower James planning area.

YEAR	Total Demand (MGD)
1998	929.78
2000	942.13
2005	964.95
2015	1006.63
2025	1044.70

It is important to note that the preceding demand projections assume that industrial demand, accounting for 240.79 MGD (54.6% of the total daily offstream withdrawal) in 1995, will increase with population. The 1995 estimates reported that nearly 68 MGD of the water withdrawn in the planning area was not accounted for within the planning area. Such a large loss may have occurred with the older distribution systems in the planning area; however, it is possible that a portion of the water reported as lost was utilized in the adjacent planning areas. The preceding projections assume that the losses will increase proportionally with population in the Lower James planning area.

4.5.13.4 Water Supply Availability in the Lower James Planning Area

Upon comparison of the projected total freshwater streamflow availability (Table 4.107) and the total daily offstream demand (Table 4.108), the following water balance conditions result:

Table 4.110: Offstream demand water supply availability in the Lower James planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	5374	5360	5336	5291	5250
$7Q_{10}$	-58	-71	-96	-141	-182
$1Q_{30}$	-278	-292	-316	-361	-402
Q_{90}	252	239	215	170	129

The preceding deficits and surpluses can also be expressed in terms of the projected population in order to identify the amount of estimated freshwater streamflow than can be or needs to be developed under each flow condition in the future on a per capita basis.

Table 4.111: Offstream demand water supply availability in the Lower James planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	5030	4891	4652	4265	3959
$7Q_{10}$	-54	-65	-84	-113	-137
$1Q_{30}$	-261	-266	-276	-291	-303
Q_{90}	236	218	187	137	97

Including the upstream projected offstream demands in planning areas 9, 10, 11 and 12, cumulative offstream demand in the James River is not expected to exceed 17% percent of the annual mean flow (see Appendix L). The large percentage of the annual mean flow that has been developed may be an indication development potential reaching a maximum point in the Lower James planning area.

Water balance conditions might be significantly altered if an instream flowby equivalent to $7Q_{10}$ is required to pass the downstream point of each contributing river.

Table 4.112: Total demand water supply availability in the Lower James planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4920	4907	4882	4837	4796
$7Q_{10}$	-512	-525	-550	-594	-635
$1Q_{30}$	-732	-745	-770	-814	-855
Q_{90}	-201	-214	-239	-284	-325

The water balance conditions expressed in Tables 4.110, 4.111 and 4.112 do not include the 912.06 MGD nonconsumptive thermoelectric withdrawal or the 2305.34 MGD saline water withdrawn in 1995 for industrial and thermoelectric purposes. It also seems appropriate to mention again that nearly 1300 square miles of the planning area were assumed not to contribute to the freshwater availability estimate used in all supply calculations. The large partial-river basin scale does not permit the analysis of potential conflict between individual users during periods of localized low flow or of individual system treatment, storage or distribution facility conditions.

4.5.14 The Mainland Chesapeake Bay Planning Area

4.5.14.1 The Mainland Chesapeake Bay Planning Area and Its Population

The Mainland Chesapeake Bay/York planning area (see Plate XIV) includes hydrologic units C01-C08 and D07 which drain directly into the Chesapeake Bay (see Plate 25) and hydrologic units F26 and F27 which drain the tidal portion of the York River (see Plate 15). The planning area covers 1114.26 square miles and coincides with USGS cataloging units 02080102 and 02080107. Tributaries include the Great Wicomico, Piankatank, East, North, Ware, Severn, Back, Poquoson, Lynnhaven and Poropotank Rivers and Dragon Swamp and Little, Queen, Ware, Carter, and King Creeks (see Appendix A). The Mainland Chesapeake Bay/York planning area consists of portions of the Cities of Hampton, Newport News, Norfolk, Poquoson, Virginia Beach, and Williamsburg and Essex, Gloucester, James City, King and Queen, Lancaster, Mathews, Middlesex, New Kent, Northumberland, Richmond, and York Counties (see Appendix G.2). Developed as a function of Census Bureau population estimates in 1998 (see Appendix F), the population densities of each county and city were multiplied by the contributing land area to estimate the 1998 population to be 414,452 people. If population within the planning area is assumed to grow proportional to Census Bureau projections for the Commonwealth, the resulting projected population is shown in Table 4.113.

Table 4.113: Mainland Chesapeake Bay/York planning area population projections (see Appendix H).

YEAR	Projected Population
2000	425,212
2005	445,084
2015	481,364
2025	514,484

4.5.14.2 The Supply Condition

Streamflow availability in the Mainland Chesapeake Bay/York planning area was a difficult assessment because of the lack of reliable gage data and the tidal influence of all surface waters in the area. A partial surface water availability analysis was chosen to represent at least a partial availability assessment. Gage 01669520 on Dragon Swamp near Mascot, Virginia was chosen to represent the yield of the land area within the planning area. The average cfs/mi^2 was developed at the gage under each estimated condition and applied to the remaining ungaged area.

Gage 01669520 on Dragon Swamp near Mascot, Virginia records streamflow data from 108 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept between 1982 and 1998.[222] Flow conditions for $7Q_{10}$ were developed by Hayes from an undisclosed period of record.[223] By assuming that the conditions on Dragon Swamp depict the average cfs/mi^2 yield of all of the land

[222] See note 28, supra, p. 207.
[223] See note 34, supra, p. 31.

area in the planning area, about 1006 square miles of ungaged area (931.72% of the gaged area) are included in the estimates of flow conditions from the entire land area.

Table 4.114: Supply estimates for the Mainland Chesapeake Bay/York planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**793.5**	100%
$7Q_{10}$	**4.3**	0.54%
Q_{90}	**49.3**	6.22%
Q_{50}	**553.4**	69.75%
Q_{10}	**1766.9**	222.67%

Although consumption did take place in the upstream planning areas of the York River Basin, that is in the Mattaponi and Pamunkey planning areas, the streamflow availability estimates were not adjusted for upstream consumption. Consumption was considered negligible because the gage data was derived from the self-contained headwaters of the Dragon Swamp drainage basin. The supply estimates do not include an average 25 MGD withdrawn from 5 reservoir systems and 29 wells within the planning area between 1982 and 1985.[224] In 1995 the USGS reported that 8.07 MGD of groundwater was utilized in the Mainland Chesapeake Bay/York planning area.

4.5.14.3 The Demand Condition

In 1995 in USGS demand cataloging units 02080102 and 02080107, an estimated 47.61 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Mainland Chesapeake Bay/York planning area (see Appendix J). Based on the 1995 estimated population of 417,550 people, the total per capita daily offstream demand was 114.02 gpcd (47.61 MGD/417,550 people). The total offstream per capita freshwater estimate includes 3.77 MGD of industrial withdrawals (7.92% of the total offstream demand). Of the 47.61 MGD total daily offstream demand, 7.08 MGD (14.87% of the partially consumed offstream withdrawal) was estimated to have been consumed. Assuming that the total per capita daily offstream demand and the percentage of that demand consumed remains constant in each succeeding year of the planning period, the demand projections are indicated in Table 4.115 (see Appendix K).

Table 4.115: Projected total daily offstream demand for the Mainland Chesapeake Bay/York planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	47.26	7.03
2000	48.48	7.21
2005	50.75	7.55
2015	54.89	8.16
2025	58.66	8.72

If an instream demand equivalent to $7Q_{10}$ is required to flow out of the land area, the total daily demand would be as indicated in Table 4.116 (see Appendix K):

Table 4.116: Projected total daily demand in the Mainland Chesapeake Bay/York planning area.

YEAR	Total Demand (MGD)
1998	51.56
2000	52.78
2005	55.05
2015	59.19
2025	62.96

4.5.14.4 Water Supply Availability in the Mainland Chesapeake Bay/York Planning Area

Upon the comparison of the projected total streamflow availability estimates (Table 4.114) to the projected total daily offstream demand (Table 4.115), the following water balance conditions result:

[224] See note 180, supra, p. II-72 - II-73; note 173, supra, p. II-103 - II-104; and note 199, supra, p. II-320 - II-323 and p. II-396 - II-398.

Table 4.117: Offstream demand water supply availability in the Mainland Chesapeake/York planning area (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	746	745	743	739	735
$7Q_{10}$	-43	-44	-47	-51	-54
Q_{90}	2	1	-1	-6	-9
$10\%Q_{AM}$	32	31	29	24	21
$20\%Q_{AM}$	111	110	108	104	100

The preceding surpluses and deficits can also be expressed in terms of the projected population in order to identify the amount of water that must be developed beyond surface water availability in the future on a per capita basis.

Table 4.118: Offstream demand water supply availability in the Mainland Chesapeake/York planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1800	1752	1669	1534	1428
$7Q_{10}$	-104	-104	-104	-105	-105
Q_{90}	5	2	-3	-12	-18
$10\%Q_{AM}$	77	73	64	51	40
$20\%Q_{AM}$	269	259	243	216	194

Although water supply availability in the planning area may be in deficit under $7Q_{10}$ and Q_{90} flow conditions in the future, projected offstream demands are not expected to exceed 8% in the planning period.

Water balance conditions could be significantly altered if a flow equivalent to $7Q_{10}$ is required to flow from the land area in the Mainland Chesapeake Bay/York planning area.

Table 4.119: Total demand water supply availability in the Mainland Chesapeake/York planning area (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	742	741	738	734	731
$7Q_{10}$	-47	-48	-51	-55	-59
Q_{90}	-2	-3	-6	-10	-14

The surpluses and deficits indicated in Tables 4.117, 4.118 and 4.119 do not include the 490.07 MGD of saline water demanded for thermoelectric and industrial purposes in the planning area in 1995. The large scope of the partial-river basin scale does not permit the analysis of potential conflict between individual users during localized periods of low flow or of individual system treatment, storage or distribution facility conditions.

4.5.15 The Eastern Shore Planning Area

4.5.15.1 The Eastern Shore Planning Area and Its Population

The Eastern Shore planning area (see Plate XV) combines hydrologic units C09-C16 and D01-D06 into a single 1105.30 square mile planning area. Virginia's Eastern Shore includes USGS cataloging units 02060009, 02060010, 02080109 and 02080110. Units 02060009 and 02080109 send surface water runoff into the Chesapeake Bay (see Plate 25) via several small surface water tributaries to the Bay including Pitts, Holdens, Onancock, Pungoteague and Nasawadox Creeks (see Appendix A). Units 02060010 and 02080110 drain surface waters to the Atlantic Ocean (see Plate 26) through direct Tributaries including the Machipongo River and Little Mosquito and Assawoman Creeks (see Appendix A). All of these surface water drainage systems are considered tidal, brackish water streams that are unfit for surface water development. The VSWCB reported the land area of the Eastern Shore as 940 square miles; the remaining 165.30 square miles are assumed water area included in the jurisdictional boundaries of Northampton and Accomack Counties.

Population on the Eastern Shore was developed as a function of 1998 Census Bureau estimates (see Appendix F). Based on the population estimates, the 1998 population of the planning area was 44,954 people, an average population density of 41 people per square mile. If the Census Bureau growth projections for the Commonwealth are applied to the planning area, population through 2025 can be expected to be as indicated in Table 4.120.

Table 4.120: Eastern Shore planning area population projections through 2025 (see Appendix H).

YEAR	Projected Population
2000	46,121
2005	48,277
2015	52,212
2025	55,804

4.5.15.2 The Supply Condition

Water supply availability on the Eastern Shore cannot be estimated by the natural flow availability measured in surface water streams. Therefore, a simplified estimate of the groundwater aquifer safe yield was performed based on the procedure used by the VSWCB (1988) for the same planning area.[225] Because surface water streams were assumed unusable, with the exception of "a portion of irrigation water" which is derived from surface water ponds,[226] groundwater is the sole supply of water for the planning area. Therefore, the recharge of the shallow aquifer system was quantified in order to estimate the supply. In the 1988 study, 70 percent of the average annual rainfall was assumed lost to evapotransporative processes, and the remaining 30 percent of the rainfall was assumed divided between recharge and surface runoff into the Chesapeake bay and the Atlantic Ocean.[227] The geology of the Coastal Plain physiographic province indicates

[225] Virginia State Water Control Board. "Eastern Shore Water Supply Plan." Virginia State Water Control Board Planning Bulletin No. 342, March 1988.
[226] Id., p. III-4.
[227] Id.

that recharge within the Coastal Plain "ranges from one [to] fifteen percent of the total precipitation."[228] Based on "limited gage data," the VSWCB estimated that recharge in the Eastern Shore planning area was approximately four percent of annual precipitation.[229] With the average annual rainfall determined to be 43 inches over the 960 square mile land area, the safe yield of the aquifer system was determined to be 78 MGD.[230]

In order to account for the potential discrepancies in the recharge estimate, the following analysis includes three supply scenarios similar to the 1988 VSWCB Eastern Shore safe yield estimate procedure. The first scenario assumes that 41 inches of rainfall falls over the 960 square mile area and that recharge can be anywhere from two to fourteen percent of the 41 inches of average annual rainfall.

Table 4.121: Safe yield estimate of the aquifer formation underlying the Eastern Shore planning area for Scenario A (see Appendix D.15).

Avg Rainfall (inches)	**41**
recharge (as % precip)	recharge (MGD)
2	37.48
3	56.22
4	74.96
6	112.44
8	149.91
10	187.39
12	224.87
14	262.35

The second scenario assumes that 42 inches of rainfall is distributed evenly over the 960 square mile land area and that recharge varies from two to fourteen percent.

[228] Id.
[229] Id.
[230] Id., p. III-6.

Table 4.122: Safe yield estimate of the aquifer formation underlying the Eastern Shore planning area for Scenario B (see Appendix D.15).

Avg Rainfall (inches)	**42**
recharge (as % precip)	recharge (MGD)
2	38.39
3	57.59
4	76.78
6	115.18
8	153.57
10	191.96
12	230.35
14	268.75

The third scenario assumes that 43 inches of annual precipitation is evenly distributed over the 960 square mile land area and that recharge varies from two to fourteen percent of the average precipitation.

Table 4.123: Safe yield estimate of the aquifer formation underlying the Eastern Shore planning area for Scenario C (see Appendix D.15).

Avg Rainfall (inches)	**43**
recharge (as % precip)	recharge (MGD)
2	39.31
3	58.96
4	78.61
6	117.92
8	157.23
10	196.53
12	235.84
14	275.15

The resulting conclusion is that the Eastern Shore groundwater aquifer system could potentially yield anywhere from 37 to 275 MGD depending upon the amount of precipitation over the course of a year and the amount of that precipitation that recharges the shallow groundwater system. In 1995 the USGS reported that 12.01 MGD of groundwater was utilized in the Eastern Shore planning area.

4.5.15.3 The Demand Condition

In 1995 in USGS demand cataloging units 02060009, 02060010, 02080109 and 02080110, 16.00 MGD of partially consumed water (i.e., total daily demand) was withdrawn from the Eastern Shore planning area (see Appendix J). Based on the 1995 population estimate of 45,130 people, the total daily per capita demand was 354.53 gpcd (16.00 MGD/45,130 people). The total offstream per capita freshwater estimate includes 3.53 MGD of industrial withdrawals (22.06% of the total offstream demand). Daily consumption was estimated as 6.09 MGD or 38.06% of the partially consumed groundwater withdrawal. Table 4.124 displays projected total daily offstream demand assuming the per capita usage and the percentage of consumption remain constant in each year of the planning period (see Appendix K).

Table 4.124: Projected total daily demand for the Eastern Shore planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	15.95	6.07
2000	16.34	6.22
2005	17.12	6.52
2015	18.51	7.04
2025	19.78	7.53

The projected demand within the Eastern Shore planning area assumes that irrigation demand will increase proportional to population growth. In 1995, 6.82 MGD or 43% of the partially consumed withdrawal was attributed to agricultural demand for irrigation; Table 4.124 assumes that the irrigation demand will increase with population, although it may not necessarily do so. Because the surface water streams are not considered a viable source of supply, an instream demand requirement has not been developed; however, the lack of an instream demand analysis does not alleviate the need to protect aquatic ecosystems in the coastal environment.

4.5.15.4 Water Supply Availability in the Eastern Shore Planning Area

Upon comparing the projected safe yield estimates for each average rainfall scenario (Table 4.121, 4.122 and 4.123) to the projected total daily demand (Table 4.124), the following water balance conditions result under each safe yield scenario:

SCENARIO A: 41 Inches Average Annual Rainfall

Table 4.125: Offstream demand water supply availability in the Eastern Shore planning area for Scenario A (all values expressed in MGD).

Recharge	1998	2000	2005	2015	2025
2%	22	21	20	19	18
3%	40	40	39	38	36
4%	59	59	58	57	55
6%	96	96	95	94	93
8%	134	134	133	131	130
10%	171	171	170	169	168
12%	209	209	208	206	205
14%	246	246	245	244	243

SCENARIO B: 42 Inches Average Annual Rainfall

Table 4.126: Offstream demand water supply availability in the Eastern Shore planning area for Scenario B (all values expressed in MGD).

Recharge	1998	2000	2005	2015	2025
2%	22	22	21	20	19
3%	42	41	40	39	38
4%	61	60	60	58	57
6%	99	99	98	97	95
8%	138	137	136	135	134
10%	176	176	175	173	172
12%	214	214	213	212	211
14%	253	252	252	250	249

SCENARIO C: 43 Inches Average Annual Rainfall

Table 4.127: Offstream demand water supply availability in the Eastern Shore planning area for Scenario C (all values expressed in MGD).

Recharge	1998	2000	2005	2015	2025
2%	23	23	22	21	20
3%	43	43	42	40	39
4%	63	62	61	60	59
6%	102	102	101	99	98
8%	141	141	140	139	137
10%	181	180	179	178	177
12%	220	220	219	217	216
14%	259	259	258	257	255

Even under the minimum recharge percentage of 2% and precipitation of 41 inches, water supply on the Eastern Shore appears to be in surplus. However, the preceding analysis does not include an analysis of any potential water quality deficiencies in the planning area or any of the potential taste and odor problems that may occur in a low lying coastal marine environment. Conflict between local groundwater withdrawals and deficiencies in treatment and storage infrastructure have not been considered.

The surpluses may be expressed in terms of the projected population in order to determine the amount of water per person that can be developed in the future.

SCENARIO A: 41 Inches Average Annual Rainfall

Table 4.128: Offstream demand water supply availability in the Eastern Shore planning area for Scenario A (all values expressed in gpcd).

Recharge	1998	2000	2005	2015	2025
2%	478	458	421	363	317
3%	895	865	809	722	653
4%	1311	1271	1197	1081	989
6%	2144	2084	1973	1799	1660
8%	2977	2897	2749	2517	2332
10%	3810	3710	3525	3235	3004
12%	4643	4523	4301	3953	3675
14%	5475	5336	5077	4671	4347

SCENARIO B: 42 Inches Average Annual Rainfall

Table 4.129: Offstream demand water supply availability in the Eastern Shore planning area for Scenario A (all values expressed in gpcd).

Recharge	1998	2000	2005	2015	2025
2%	499	478	440	381	334
3%	925	895	838	749	678
4%	1352	1311	1235	1116	1022
6%	2205	2144	2030	1852	1710
8%	3058	2977	2825	2587	2398
10%	3911	3810	3620	3323	3086
12%	4764	4642	4415	4058	3774
14%	5618	5475	5210	4794	4462

SCENARIO C: 43 Inches Average Annual Rainfall

Table 4.130: Offstream demand water supply availability in the Eastern Shore planning area for Scenario C (all values expressed in gpcd).

Recharge	1998	2000	2005	2015	2025
2%	499	478	440	381	334
3%	925	895	838	749	678
4%	1352	1311	1235	1116	1022
6%	2205	2144	2030	1852	1710
8%	3058	2977	2825	2587	2398
10%	3911	3810	3620	3323	3086
12%	4764	4642	4415	4058	3774
14%	5618	5475	5210	4794	4462

4.5.16 The Meherrin Planning Area

4.5.16.1 The Meherrin Planning Area and Its Population

The Meherrin planning area (see Plate XVI) includes hydrologic units K01-K13, covering a total of 1115.53 square miles, of the Virginia portion of the Meherrin River Basin (see Plate 28) in the larger Chowan River Basin (see Plate 27). The Meherrin planning area coincides with USGS cataloging unit 03010204 and includes drainage contributions from tributaries such as Fontaine, Great, Roses, Reedy, and Rattlesnake Creeks and Mill and Flat Swamps (see Appendix A). The Meherrin river stretches from its headwaters in Charlotte, Lunenburg and Mecklenburg Counties and flows southeast into North Carolina through Southampton County. Population was developed as a function of the population densities in the City of Emporia and Brunswick, Charlotte, Greensville, Lunenburg, Mecklenburg, Prince Edward and Southampton Counties (see Appendix G.2). Based on estimates made by the Census Bureau in 1998 (see Appendix F), the total population of the 1115.53 square mile area was 40,595 people, a total average population density of about 37 people per square mile. If Census Bureau population projections through 2025 are assumed to represent the growth in the planning area, the population growth pattern can be expected to be as shown in Table 4.131.

Table 4.131: Meherrin planning area population projections (see Appendix H).

YEAR	Projected Population
2000	41,649
2005	43,596
2015	47,149
2025	50,393

4.5.16.2 The Supply Condition

Flow availability in the Nottoway planning area was developed from flow data measurements made at USGS gage 02052000 on the Meherrin River at Emporia, Virginia (see Appendix D.16). The average cfs/mi^2 yield was developed for the gaged area and applied to the entire Virginia portion of the drainage area in order to estimate the amount of flow in the stream under each flow condition before the river enters North Carolina. Mean annual flow (Q_{AM}), Q_{90}, Q_{50} and Q_{10} estimates are derived from the entire period of record, 1952-1998, and taken from 1998 USGS records at Virginia gaging stations.[231] Flow conditions for $7Q_{10}$, Q_{95} and the MBF_{est} were derived from gage data from the years 1967-1984 by Nelms, et. al.[232] The $1Q_{30}$ flow was developed by the VSWCB from records measured from 1953-1977.[233] Adjusted flow values for the entire planning area include a 368.33 square mile ungaged land area in the 747 square mile gaged area (an addition of 49.31% of the gaged area).

[231] See note 28, supra, p. 357.
[232] See note 121, supra, Appendix 1.

Table 4.132: Supply estimates for the Meherrin planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**675.5**	100%
$7Q_{10}$	**22.2**	3.29%
$1Q_{30}$	**8.9**	1.32%
Q_{95}	**9.9**	1.46%
Q_{90}	**68.5**	10.14%
Q_{50}	**347.4**	51.43%
MBF_{est}	**359.0**	53.14%
Q_{10}	**1389.5**	205.71%

Supply in the Meherrin River was not adjusted for consumption because the Meherrin planning area is a headwater planning area. The supply estimates do not include supplies developed from 11 wells and stored water systems that contributed 3 MGD of water to the Meherrin planning area in 1984.[234] In 1995 the USGS reported that 2.11 MGD of groundwater was utilized in the Meherrin planning area.

4.5.16.3 The Demand Condition

In 1995 in USGS demand cataloging unit 03010204, an estimated 9.12 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Meherrin planning area (see Appendix J). Based on the 1995 population estimate of 40,090 people for the planning area, the 1995 total daily per capita offstream demand was 227.49 gpcd (9.12 MGD/40,090 people). The total offstream per capita freshwater estimate includes 1.07 MGD of industrial withdrawals (11.73% of the total offstream demand). Of the total daily offstream demand, 1.69 MGD (18.53% of the total demand) was estimated to have been consumed. Assuming that the per capita usage and the

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[233] See note 123, supra, p. xviii.
[234] Virginia State Water Control Board. "Chowan Water Supply Plan." Virginia State Water Control Board Planning Bulletin No. 340, March 1988, p. II-51 - II-53.

percentage of consumption remain steady in each future year of the planning period, projected demands through 2025 are shown in Table 4.133 (see Appendix K):

Table 4.133: Projected total daily offstream demand for the Meherrin planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	9.24	1.71
2000	9.46	1.75
2005	9.92	1.84
2015	10.71	1.99
2025	11.47	2.12

Table 4.134 indicates total daily demand if an instream demand requirement equivalent to $7Q_{10}$ is required to pass the downstream boundary of the planning area (see Appendix K).

Table 4.134: Projected total daily demand in the Meherrin planning area.

YEAR	Total Demand (MGD)
1998	31.44
2000	31.66
2005	32.12
2015	32.91
2025	33.67

4.5.16.4 Water Supply Availability in the Meherrin Planning Area

Upon comparing the projected total natural flow availability (Table 4.132) to the projected total daily offstream demand (Table 4.133), the following water balance conditions result:

Table 4.135: Offstream demand water supply availability in the Meherrin planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	666	666	666	665	664
$7Q_{10}$	13	13	12	11	11
$1Q_{30}$	-1	-1	-1	-2	-3
Q_{95}	1	0	0	-1	-2
Q_{90}	59	59	59	58	57
$10\%Q_{AM}$	58	58	58	57	56
$20\%Q_{AM}$	126	126	125	124	124

The anticipated water balance conditions can also be expressed in terms of the projected population in order to identify the amount of water that can be or needs to be developed in the future.

Table 4.136: Offstream demand water supply availability in the Meherrin planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	16,409	16,009	15,265	14,113	13,174
$7Q_{10}$	319	306	282	244	213
$1Q_{30}$	-8	-13	-23	-38	-51
Q_{95}	16	10	-1	-18	-32
Q_{90}	1460	1419	1344	1227	1132
$10\%Q_{AM}$	1436	1396	1322	1207	1113
$20\%Q_{AM}$	3100	3020	2871	2641	2453

Although water supply availability may be deficient under $1Q_{30}$ and Q_{95} flow conditions in the future, projected offstream demands are not expected to exceed 2% of the annual mean flow in the planning period.

Water supply conditions could be significantly altered if a flowby requirement equivalent to the total $7Q_{10}$ estimate is instituted at the downstream point.

Table 4.137: Total demand water supply availability in the Meherrin planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	644	644	643	643	642
$7Q_{10}$	-9	-9	-10	-10	-11
$1Q_{30}$	-23	-23	-23	-24	-25
Q_{95}	-22	-22	-22	-23	-24
Q_{90}	37	37	36	36	35

Because of the large scale of a partial-river basin planning area analysis, the preliminary assessment of water supply availability in the Meherrin planning area does not account for the potential conflict between individual users during localized low flow conditions or the insufficiencies of infrastructure in local water distribution systems.

4.5.17 The Nottoway Planning Area

4.5.17.1 The Nottoway Planning Area and Its Population

The Nottoway planning area (see Plate XVII) consists of hydrologic units K14-K30 that collects drainage from 1722.63 square miles of the Virginia portion of the Nottoway River Basin (see Plate 29). The Nottoway planning area coincides with USGS cataloging unit 03010201 and includes waters from Big Hounds, Waqua, Sturgeon, Sappony, Rowanty, Raccoon, Spring and Three Creeks as well as Harris, Southwest, Jones Hole, Otterdam, Poplar and Assamoosick Swamps (see Appendix A). The Nottoway River headwaters are located in Prince Edward, Lunenburg and Nottoway Counties and flows southeast into North Carolina through Southampton County. Current population estimates were developed as a function of 1998 Census Bureau population density estimates in the portions of the cities of Emporia, Franklin and Petersburg and Brunswick, Dinwiddie, Greensville, Lunenburg, Nottoway, Prince Edward, Prince George, Southampton and Sussex Counties included in the planning area (see Appendix G.2). Based on population densities developed from 1998 Census Bureau population estimates in each municipality, the total 1998 population estimate for the planning area was 63,295 people, an average population density of 37 people per square mile over the 1722.63 square mile area. Population projection in the planning area indicate the values included in Table 4.138 and have been made assuming the growth in the planning area will be proportional to the growth projected by the Census Bureau for the Commonwealth.

Table 4.138: Nottoway planning area population projections through 2025 (see Appendix H).

YEAR	Projected Population
2000	64,938
2005	67,973
2015	73,514
2025	78,572

4.5.17.2 The Supply Condition

Natural flow availability in the Nottoway planning area was developed from flow data measurements made at USGS gage 02047000 on the Nottoway River near Sebrell, Virginia (see Appendix D.17). The average cfs/mi^2 yield was developed for the gaged area and applied to the entire Virginia portion of the drainage area in order to estimate the amount of flow in the stream under each flow condition before flowing into North Carolina. Flow conditions Q_{AM}, Q_{90}, Q_{50} and Q_{10} were developed as a function of gage measurements at the site from 1941-1998, the full period of record, and were reported by the USGS.[235] The $7Q_{10}$ and $1Q_{30}$ flows were developed by the VSWCB from records accumulated between 1941-1977.[236] Adjusted flows for the planning area include a 301.63 square mile ungaged land area addition to the 1421 square mile gaged land area (21.23% of the gaged land area).

Table 4.139: Supply estimates for the Nottoway planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1065.5**	100%
$7Q_{10}$	**23.2**	3.29%
$1Q_{30}$	**12.6**	1.32%
Q_{90}	**79.9**	10.14%
Q_{50}	**581.3**	51.43%
Q_{10}	**2648.1**	205.71%

[235] See note 28, supra, p. 347.
[236] See note 123, supra, p. xvii.

Natural supply availability in the Nottoway River was not adjusted for consumption because the Nottoway planning area is a headwater planning area. The supply estimates do not include 3.6 MGD developed from 31 wells and stored water systems in 1984.[237] In 1995 the USGS reported that 9.71 MGD of groundwater was utilized in the Nottoway planning area.

4.5.17.3 The Demand Condition

In 1995 in USGS cataloging unit 03010201, an estimated 33.30 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Nottoway planning area (see Appendix J). Based on the 1995 population estimate of 58,280 people, the total daily per capita offstream demand was 571.38 gpcd (33.30 MGD/58,280 people). The total offstream per capita freshwater estimate includes 7.67 MGD of industrial withdrawals (23.03% of the total offstream demand). Daily consumption was reported to be 4.02 MGD or 12.07% of the total daily offstream demand. Assuming the per capita usage and the percentage of consumption remain steady in each future year of the planning period, projected demands are shown in Table 4.140 (see Appendix K).

Table 4.140: Projected total daily offstream demand for the Nottoway planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	36.17	4.37
2000	37.08	4.48
2005	38.85	4.69
2015	42.00	5.07
2025	44.91	5.42

[237] See note 234, supra, p. II-80, II-85 - II-86.

However, it is important to note that the City of Norfolk operates a significant pump station on the Nottoway River, a 13.64 MGD withdrawal in 1984,[238] that is an inter-basin transfer and is not used in or returned to the Nottoway planning area. The projected demands include this withdrawal as a function of population growth with the Nottoway planning area, although it is not the case. Therefore, the inter-basin transfer may present the demands as artificially high for the Nottoway planning area; likewise, the supply estimates for the planning area may be artificially low because of the transfer. Table 4.141 indicates the total daily demand if an instream demand requirement equivalent to $7Q_{10}$ is required to flow into North Carolina (see Appendix K).

Table 4.141: Projected total daily demand in the Nottoway planning area.

YEAR	Total Demand (MGD)
1998	59.37
2000	60.28
2005	62.05
2015	65.20
2025	68.11

4.5.17.4 Water Supply Availability in the Nottoway Planning Area

Upon comparing the projected total natural flow availability (Table 4.139) to the projected total daily offstream demand (Table 4.140), the following water balance conditions result:

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[238] Id.

Table 4.142: Offstream demand water supply availability in the Nottoway planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1029	1028	1027	1024	1021
$7Q_{10}$	-13	-14	-16	-19	-22
$1Q_{30}$	-24	-25	-26	-29	-32
Q_{90}	44	43	41	38	35
$10\%Q_{AM}$	70	69	68	65	62
$20\%Q_{AM}$	177	176	174	171	168

Anticipated water balance conditions can also be expressed in terms of the projected population in order to determine the amount of water that can be or needs to be developed in the future.

Table 4.143: Offstream demand water supply availability in the Nottoway planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	16,621	15,846	15,098	13,925	12,985
$7Q_{10}$	-205	-214	-230	-256	-276
$1Q_{30}$	-373	-378	-387	-401	-412
Q_{90}	691	660	604	516	445
$10\%Q_{AM}$	1112	1070	996	878	784
$20\%Q_{AM}$	2795	2712	2562	2328	2140

Although deficits of water supply availability may occur under $7Q_{10}$ and $1Q_{30}$ flow conditions, projected offstream demands are not expected to exceed 5% of the average annual mean in the planning period.

Water supply conditions will be significantly altered if a flowby requirement equivalent to the total $7Q_{10}$ estimate instituted at the downstream point.

Table 4.144: Total demand water supply availability in the Nottoway planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1006	1005	1003	1000	997
$7Q_{10}$	-36	-37	-39	-42	-45
$1Q_{30}$	-47	-48	-50	-53	-56
Q_{90}	21	20	18	15	12

Again, it is important to recognize that the Norfolk withdrawal is included in the future demand estimates and the future water balance conditions. Water availability analysis at the partial-river basin scale is preliminary in nature because it does not include information about conflict between individual users during times of localized low flow or about the infrastructure of those individual systems.

4.5.18 The Blackwater/Southeast Coastal Planning Area

4.5.18.1 The Blackwater/Southeast Coastal Planning Area and Its Population

The Blackwater/Southeast Coastal planning area (see Plate XVIII) includes hydrologic units K31-K38 of the Blackwater River Basin (see Plate 30) and hydrologic units K39-K42 of the Southeastern Coastal portion of the Chowan River drainage area (see Plate 31). The planning area covers 1413.37 square miles and shares boundaries with USGS cataloging units 03010202, 03010203 and 03010205. Major waterbodies within the planning area include the Blackwater, Northwest and North Landing Rivers, Somerton and Buckhorn Creeks, and Blackwater, Warwick, Cypress, Rattlesnake, Mill, Seacock, Kingsdale, Corrowaugh and Dismal Swamps (see Appendix A). The planning area consists of portions of the Cities of Chesapeake, Franklin, Petersburg, Suffolk and Virginia Beach and Dinwiddie, Isle of Wight, Prince Edward, Prince George, Southampton, Surry and Sussex Counties (see Appendix G.2). Developed as a function of 1998 Census Bureau population estimates (see Appendix F), the 1998 planning area population was estimated to be 525,780 people. If the planning area population grows proportional to the Census Bureau projections for the Commonwealth, the population projections for the planning area through 2025 are indicated in Table 4.145.

Table 4.145: Blackwater/Southeast Coastal planning area population projections (see Appendix H).

YEAR	Projected Population
2000	539,431
2005	564,641
2015	610,666
2025	652,683

4.5.18.2 The Supply Condition

Streamflow availability in the Blackwater/Southeast Coastal planning area was developed from flow records kept as USGS gage 02049500 on the Blackwater River near Franklin, Virginia. The average cfs/mi^2 yield was developed at the gage and distributed over the entire planning area. Despite an extraordinary amount of ungaged land being added to the gaged land, all land lies within the Coastal Plain physiographic province, and it has been assumed that the gage data is representative of flow conditions in the entire planning area. The availability of freshwater in the Southeast Coastal portion of the planning is indicated by the City of Chesapeake's new treatment plant on the Northwest River.[239]

Gage 02049500 on the Blackwater River near Franklin, Virginia records streamflow information from 617 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept between 1944 and 1998.[240] Flow conditions for $7Q_{10}$ and $1Q_{30}$ were estimated by the VSWCB from records kept between 1944 and 1977.[241] By applying the gage data to the entire planning area, the adjusted flow estimates include 796.37 square miles of ungaged land area (129.07% of the gaged area).

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[239] "Dedication of the Northwest River water treatment plant." Supplement to The Virginia-Pilot, June 17, 1999.
[240] See note 28, supra, p. 351.

Table 4.146: Supply estimates for the Blackwater/Southeast Coastal planning area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**929.7**	100%
$7Q_{10}$	**2.9**	0.32%
$1Q_{30}$	**0.9**	0.09%
Q_{90}	**12.1**	1.31%
Q_{50}	**555.2**	59.71%
Q_{10}	**2427.9**	261.15%

The supply availability estimates were not adjusted for consumption because the planning area is a headwater planning area with no upstream consumption. The supply estimate does not include the supply of 55 MGD of water transferred from Lake Gaston or over 40 MGD of water developed from 61 wells in 1983.[242] In 1995 the USGS reported that 44.32 MGD of groundwater was utilized in the Blackwater/Southeastern Coastal planning area.

4.5.18.3 The Demand Condition

In 1995 in USGS demand cataloging units 03010202, 03010203, and 03010205, an estimated 89.11 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Blackwater/Southeast Coastal planning area (see Appendix J). Based on the 1995 population estimate of 508,150 people, the total per capita daily offstream demand was 175.36 gpcd (89.11 MGD/508,150 people). The total offstream per capita freshwater estimate includes 40.7 MGD of industrial withdrawals (45.67% of the total offstream demand). Of the 89.11 MGD total daily offstream demand, 10.91 MGD (12.24% of the partially consumed offstream demand) was estimated to have been consumed. Assuming that the total per capita daily offstream demand and the percentage

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[241] See note 123, supra, p.xviii.
[242] See note 234, supra, p. II-15, II-17 and note 199, supra, p. II-396 - II-398.

of that demand consumed remains constant in each future year of the planning period, the projected demand through 2025 can be expected to be as shown in Table 4.147 (see Appendix K):

Table 4.147: Projected total daily offstream demand for the Blackwater/Southeast Coastal planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	92.20	11.29
2000	94.59	11.58
2005	99.01	12.12
2015	107.09	13.11
2025	114.46	14.01

Table 4.148 indicates total daily demand if an instream demand requirement equivalent to $7Q_{10}$ is required to flow from the planning area (see Appendix K).

Table 4.148: Projected total daily demand in the Blackwater/Southeast Coastal planning area.

YEAR	Total Demand (MGD)
1998	95.10
2000	97.49
2005	101.91
2015	109.99
2025	117.36

It is important to note that the City of Norfolk operates a significant pump station on the Blackwater River, a 12 MGD withdrawal in 1986,[243] that is an inter-basin transfer and is not used in or returned to the Blackwater/Southeast Coastal planning area. Therefore, demands presented for the Blackwater/Southeast Coastal planning area maybe artificially high and supply estimates maybe artificially low. It is also important to recognize that the preceding demand projections assume that industrial demands will increase with population growth; in 1995, 40.7 MGD (45.7% of the total daily offstream demand) was withdrawn for industrial use.

4.5.18.4 Water Supply Availability in the Blackwater/Southeast Coastal Planning Area

Upon the comparison of the projected total streamflow availability (Table 4.146) to the projected total daily offstream demand (Table 4.147), the following water balance conditions result:

Table 4.149: Offstream demand water supply availability in the Blackwater/Southeast Coastal planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	838	835	831	823	815
$7Q_{10}$	-89	-92	-96	-104	-112
$1Q_{30}$	-91	-94	-98	-106	-114
Q_{90}	-80	-82	-87	-95	-102
$10\%Q_{AM}$	1	-2	-6	-14	-21
$20\%Q_{AM}$	94	91	87	79	71

The preceding surpluses and deficits can also be expressed in terms of the projected population in order to identify the amount of water that can be needs to be developed in excess of streamflow availability on a per capita basis.

Table 4.150: Offstream demand water supply availability in the Blackwater/Southeast Coastal planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1593	1548	1471	1347	1249
$7Q_{10}$	-170	-170	-170	-171	-171
$1Q_{30}$	-174	-174	-174	-174	-174
Q_{90}	-152	-153	-154	-155	-157
$10\%Q_{AM}$	1	-3	-11	-23	-33
$20\%Q_{AM}$	178	169	154	129	110

Projected offstream water demands are expected to exceed 12% of estimated annual mean for the planning area in 2025. The water supply availability seems to be approaching its maximum development potential because of the projected deficits in Tables 4.149 and 4.150 under $7Q_{10}$, $1Q_{30}$ and Q_{90} flow conditions. However, the supply

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[243] See note 234, supra, p. II-15 and II-17.

estimates do not include water delivered by the water withdrawals that are treated and distributed to municipalities in the planning area via the Norfolk waterworks system.

Water supply conditions would be altered if a flow equivalent to $7Q_{10}$ was required to flow from the planning area into North Carolina.

Table 4.151: Total demand water supply availability in the Blackwater/Southeast Coastal planning area (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	835	832	828	820	812
$7Q_{10}$	-92	-95	-99	-107	-114
$1Q_{30}$	-94	-97	-101	-109	-117
Q_{90}	-83	-85	-90	-98	-105

The surpluses and deficits in Tables 4.149, 4.150 and 4.151 do not include a significant amount of water developed from groundwater sources in the planning area. Therefore, deficits may be severely overestimated in the planning area. The large scope of the partial-river basin scale eliminates the analysis of potential conflict between individual users during periods of localized low flow or of individual system treatment, storage and distribution facility conditions.

4.5.19 The Upper Roanoke Planning Area

4.5.19.1 The Upper Roanoke Planning Area and Its Population

The Upper Roanoke planning area (see Plate XIX) consists of hydrologic units L01-L29 that collect drainage from 2191.30 square miles of the Upper Roanoke River drainage basin (see Plate 33). The Upper Roanoke planning area is coincidental to USGS cataloging unit 03010101 and includes drainage from the Roanoke, Blackwater, Pigg, Big Otter, and Little Otter Rivers. Minor tributaries include Elliot, Mason, Tinker, Carvin, Glade, Back, Beaverdam, Maggodee, Gills, Old Womans, Goose, Buffalo, and Flat

Creeks (see Appendix A). The Upper Roanoke planning area stretches from the Roanoke River headwaters in Montgomery, Floyd, Roanoke, and Botetourt Counties to the confluence of the Roanoke and Big Otter Rivers on the border between Campbell and Pittsylvania Counties in hydrologic units L19 and L28, respectively. Population estimates in 1998 were developed as a function of Census Bureau population density estimates in the same year for the contributing portions of the cities of Bedford, Roanoke and Salem and Bedford, Botetourt, Campbell, Floyd, Franklin, Henry, Montgomery, Pittsylvania, and Roanoke Counties (see Appendix G.2). Based on 1998 Census Bureau population density estimates (see Appendix F), the resulting population estimate for the planning area was 351,028 people, an average population density of 161 people per square mile of the 2191.30 square mile planning area. If population growth in the planning area is assumed to match the growth projected for Virginia by the Census Bureau, the populations in Table 4.152 can be expected in the planning area.

Table 4.152: Upper Roanoke planning area population projections through 2025 (see Appendix H).

YEAR	Projected Population
2000	360,141
2005	376,972
2015	407,700
2025	435,752

4.5.19.2 The Supply Condition

Streamflow availability in the Upper Roanoke planning area was developed from flow data records kept at USGS gage 02060500 on the Roanoke River at Altavista, Virginia that captures 1789 square miles of the upstream watershed. The average cfs/mi^2 was developed for the gaged land area and applied to the remaining ungaged land area at the confluence of the Roanoke and Big Otter Rivers; the streamflow estimates were not adjusted for upstream consumption because the Upper Roanoke planning area is a headwater planning area. Records at the gaging station were first kept by the USGS in 1931 and continue to be kept presently. In 1962 and 1963, Smith Mountain Lake and Leesville Lake were completed by the Appalachian Power Company[244] and significantly altered the streamflow patterns in the River. Consequently, the USGS records used to develop Q_{AM}, Q_{90}, Q_{50} and Q_{10} were from data recorded between 1963 and 1998.[245] The $7Q_{10}$, Q_{95} and MBF_{est} flow conditions were developed by Nelms, et al. from records between 1932 and 1962[246] in order to represent the conditions without regulation, i.e., the natural streamflow characteristics. The VSWCB developed the $1Q_{30}$ flow condition based on records kept between 1930 and 1977.[247] The dam's regulation of flow has decreased Q_{AM}, Q_{90}, Q_{50} and Q_{10} conditions by 217 cfs, 275 cfs, 280 cfs and 150 cfs annually, respectively.[248] When the 400.9 square mile ungaged land area is included in the adjusted flow estimates (an addition of 22.41% to the gaged land area), the flow conditions in Table 4.153 can be expected in the stream (see Appendix D.19).

Table 4.153: Supply estimates for the Upper Roanoke planning area.

Flow	Adjusted flow	%Q_{AM}
Q_{AM}	**1363.1**	100%
$7Q_{10}$	**210.4**	15.44%
$1Q_{30}$	**38.8**	2.84%
Q_{95}	**39.6**	2.90%
Q_{90}	**211.2**	211.2%
Q_{50}	**814.8**	59.78%
MBF_{est}	**815.6**	59.84%
Q_{10}	**2721.4**	199.65%

244 See note 82, supra, p. I-13.
245 See note 28, supra, p. 385.
246 See note 121, supra, Appendix 1.
247 See note 123, supra, p. xx.
248 See note 28, supra, p. 385.

The supply estimates in the Upper Roanoke drainage area do not include 26.39 MGD withdrawn in 1982 from 8 springs, 157 wells, and surface water withdrawals from artificial storage structures.[249] In 1995 the USGS reported that 12.52 MGD of groundwater was utilized in the Upper Roanoke planning area.

4.5.19.3 The Demand Condition

In 1995 in USGS demand cataloging unit 03010101, an estimated 57.10 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Upper Roanoke planning area (see Appendix J). Based on the 1995 estimated population of 345,840 people, the 1995 total daily per capita offstream demand was 165.11 gpcd (57.10 MGD/345,840 people). The total offstream per capita freshwater estimate includes 9.5 MGD of industrial withdrawals (16.64% of the total offstream demand). Of the 57.10 MGD partially consumed offstream withdrawal, 12.60 MGD was reported as consumed (22.07% of the withdrawal). If the total per capita daily offstream demand and the percentage of that demand consumed remains constant in each future year of the planning period, projected demands through 2025 may be as indicated in Table 4.154 (see Appendix K).

Table 4.154: Projected total daily offstream demand for the Upper Roanoke planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	57.95	12.79
2000	59.46	13.12
2005	62.25	13.74
2015	67.32	14.86
2025	71.95	15.88

[249] See note 82, supra, p. II-15 - II-17.

Table 4.155 shows the total daily demand if an instream demand equivalent to $7Q_{10}$ is required (see Appendix K).

Table 4.155: Total daily demand in the Upper Roanoke planning area.

YEAR	Total Demand (MGD)
1998	268.35
2000	269.86
2005	272.65
2015	277.72
2025	282.35

4.5.19.4 Water Supply Availability in the Upper Roanoke Planning Area

Upon comparing the projected total streamflow availability (Table 4.153) to the projected total daily offstream demand (Table 4.154), the following water balance conditions result:

Table 4.156: Offstream demand water supply availability in the Upper Roanoke planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1305	1304	1301	1296	1291
$7Q_{10}$	152	151	148	143	138
$1Q_{30}$	-19	-21	-23	-29	-33
Q_{95}	-18	-20	-23	-28	-32
Q_{90}	153	152	149	144	139
$10\%Q_{AM}$	78	77	74	69	64
$20\%Q_{AM}$	215	213	210	205	201

Table 4.156 indicates that projected instream flow conditions may not satisfy total projected daily offstream demand without additional supply developments within the planning area under $1Q_{30}$ and Q_{95} flow conditions. However, it is important to note that the $1Q_{30}$ and Q_{95} estimates were developed from records that do not reflect the flow pattern changes resulting from the installation of the Leesville and Smith Mountain Lake hydroelectric facilities (see *4.5.19.2*). The streamflow availability estimates less the

projected partially consumed demand can also be expressed as a function of projected population in order to identify the amount water that be or needs to be developed in the future on a per capita per day basis.

Table 4.157: Offstream demand water supply availability in the Upper Roanoke planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	3718	3620	3450	3178	2963
$7Q_{10}$	434	419	393	351	318
$1Q_{30}$	-55	-57	-62	-70	-76
Q_{95}	-52	-55	-60	-68	-74
Q_{90}	437	421	395	353	320
$10\%Q_{AM}$	223	213	196	169	148
$20\%Q_{AM}$	612	592	558	504	460

Despite potential water supply deficits under $1Q_{30}$ and Q_{95} flow conditions, projected offstream demands are not expected to exceed 6% of annual mean flow in the planning period.

Surface water availability conditions may be significantly altered if a flow equivalent to the $7Q_{10}$ estimate was required to pass the confluence of the Roanoke and Big Otter Rivers.

Table 4.158: Total demand water supply availability in the Upper Roanoke planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1095	1093	1090	1085	1081
$7Q_{10}$	-58	-59	-62	-67	-72
$1Q_{30}$	-230	-231	-234	-239	-244
Q_{95}	-229	-230	-233	-238	-243
Q_{90}	-57	-59	-61	-66	-71

The preceding analysis indicates the amount of water that must be developed beyond the available streamflow quantities that is unable to meet specified projected demand conditions in the Upper Roanoke planning area through 2025. It does not include the storage potentially available from existing upstream surface water impoundments or the instream demand requirements of upstream hydroelectric facilities. The analysis is preliminary and does not attempt to describe the water available from municipally owned water supply facilities, the potential conflicts between individual users under localized low flow conditions or the infrastructure characteristics of local supply systems.

4.5.20 The Lower Roanoke Planning Area

4.5.20.1 The Lower Roanoke Planning Area and Its Population

The Lower Roanoke planning area (see Plate XX) includes hydrologic units L30-L41 and L75-L82 in the Lower Roanoke River portion of the Roanoke River basin (see Plate 34). The Lower Roanoke planning area covers 1811.01 square miles of the Commonwealth and includes drainage from the Upper Roanoke, Martinsville, and Danville planning areas and from the Upper and Lower Dan cataloging units in North Carolina. USGS cataloging units 03010102 and 03010106 are coincidental to the planning area. Within hydrologic units L30-L41 (1151.76 mi^2) of the planning area, free flowing drainage is collected and drained into the Roanoke River via the Seneca and Falling River systems and Straightstone, Childrey, Molleys, Turnip, Catawba, Cub, Hunting, Horsepen, and Sandy Creeks (see Appendix A). Hydrologic units L75-L82 represent 659.25 square miles of the planning area that are impounded and ponded waters behind the Kerr Reservoir and Lake Gaston dams on the Roanoke River. Tributaries to the reservoir systems include Butcher, Buffalo, Bluestone, Allen, Cox, Miles, Flat, Smith, Great, Poplar, and Peahill Creeks (see Appendix A). The Lower Roanoke planning area includes portions of Appomattox, Brunswick, Campbell, Charlotte, Halifax, Mecklenburg, Pittsylvania, and Prince Edward Counties (see Appendix G.2). Developed as a function of 1998 Census Bureau estimated population densities (see Appendix F), the 1998 population of the planning area was estimated to be 89,220 people. If the population within the planning area grows according to the Census Bureau projections for Virginia, the projected population can be expected to be as shown in Table 4.159.

Table 4.159: Lower Roanoke planning area population projections through 2025 (see Appendix 2-H).

YEAR	Projected Population
2000	91,536
2005	95,814
2015	103,624
2025	110,754

4.5.20.2 The Supply Condition

Streamflow availability in the Lower Roanoke planning area was developed from flow records kept at USGS gage 02075500 on the Dan River at Paces, Virginia, USGS gage 02077000 on the Banister River at Halifax, Virginia and USGS gage 02066000 on the Roanoke River at Randolph, Virginia. At each gage, the average cfs/mi^2 yield at the gage was moved to the downstream point of the drainage basin. Flow data on the Dan and Banister Rivers were adjusted to reflect the ungaged land area drained just before the confluence of the Dan and Banister Rivers as described in *3.3.22.2* and combined with the adjusted flow data from gage 02066000 at the downstream point of L40. The combined adjusted flow yields in average cfs/mi^2 were then assumed to be yielded from the land area represented by hydrologic units L75-L82 (659.25 mi^2).

The Dan River contribution to average flow conditions in the Roanoke River was developed as a function of the flow data recorded at USGS gages 02075500 and 02077000 on the Dan and Banister Rivers, respectively. Following the procedure described in *4.5.22.2*, the adjusted flows at each gage were combined to estimate the flow available at the confluence of the two rivers. However, it is important to note that flow contributions from the Hyco River and Aarons Creek, a drainage area of about 460 square miles, were not included in the estimates because of the lack of reliable gage data. Therefore, the total streamflow estimate for the Dan River contribution to the Lower Roanoke River was estimated as the combined adjusted flows from the Banister and Dan Rivers as developed in *4.5.22.2* and displayed in Table 4.160.

Table 4.160: Flow estimates at the mouth of the Dan River.

Flow	Adjusted (MGD)	$\%Q_{AM}$
Q_{AM}	**2265.4**	100%
$7Q_{10}$	**308.9**	13.64%
$1Q_{30}$	**100.7**	4.45%
Q_{90}	**704.9**	31.12%
Q_{50}	**1509.0**	66.61%
Q_{10}	**4077.2**	179.98%

Gage 02066000 on the Roanoke River near Randolph, Virginia records flow information from 2997 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were taken from USGS records kept between 1963 and 1998[250]; previous records kept between 1928 and 1962 were eliminated from the analysis in order to account for flow regulation incurred by the construction of Lake Leesville and Smith Mountain Lake upstream in 1963. Flow conditions for $7Q_{10}$, Q_{95} and the MBF_{est} were developed by Nelms, et al. from records kept between 1902 and 1962.[251] The $1Q_{30}$ flow condition was estimated by the VSWCB from records kept between 1900 and 1906, 1927 and 1930 and 1950 and 1977.[252] By translating the data to the downstream point of L40,

[250] See note 28, supra, p. 395.
[251] See note 121, supra, Appendix 1.
[252] See note 123, supra, p. xx.

the adjusted flow estimates include 364.66 square miles of ungaged land area (12.25% of the gaged area).

Table 4.161: Flow estimates on the Roanoke River at the outlet of hydrologic unit L40.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**2192.3**	100%
$7Q_{10}$	**309.0**	14.10%
$1Q_{30}$	**126.2**	5.76%
Q_{95}	**560.8**	25.58%
Q_{90}	**627.5**	28.62%
Q_{50}	**1313.0**	59.89%
MBF_{est}	**1414.6**	64.53%
Q_{10}	**4207.5**	191.93%

The adjusted flows for the Dan River and free-flowing portion of the Roanoke River in the Lower Roanoke planning area were combined and adjusted again to include the pooled water portion of the Roanoke River (hydrologic units L75-L82). Adjusting the combined data over the pooled water land area assumes that the average cfs/mi^2 yield of the combined Dan River and Roanoke River flows will be the average yield of the 659.25 square mile pooled water drainage basin. Including the ungaged areas added to all three gages and the reservoir portion of the planning area, 1193.83 square miles of ungaged area (19.65% of the gaged area) is added to a total gaged area of 6074 square miles.

Table 4.162: Total flow estimates for the Roanoke River at the Virginia/North Carolina border.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**5047.5**	100%
$7Q_{10}$	**699.1**	13.85%
$1Q_{30}$	**255.0**	5.05%
Q_{90}	**1512.4**	29.96%
Q_{50}	**3205.2**	63.50%
Q_{10}	**9363.7**	185.51%

Although the pooled area average yield assumption may introduce considerable error, the VSWCB kept flow data records on the Roanoke River between 1934 and 1952 at USGS gage 02079000 at Clarksville, Virginia. Before the installation of the Smith Mountain Lake, Leesville Lake, Kerr Reservoir and Lake Gaston, the Roanoke River yielded an annual mean flow of 8,375 cfs from 7320 square miles of upstream watershed, an average Q_{AM} yield of 1.144 cfs/mi^2.[253] The Q_{AM} average cfs/mi^2 yield in Table 4.162 is 1.075 cfs/mi^2.

Because of the consumption of water withdrawn from upstream water users in the Martinsville, Danville and Upper Roanoke planning areas and in the Upper and Lower Dan cataloging units in North Carolina, the streamflow availability estimates for the Lower Roanoke planning area had to be adjusted for upstream consumption. The projected consumption estimates in each year of the planning period for each upstream planning area were summed and subtracted from the streamflow availability estimates in Table 4.162.

Table 4.163: Supply projections for the Lower Roanoke planning area.

Flow	1998	2000	2005	2015	2025
Q_{AM}	4976.9	4974.8	4970.9	4965.0	4959.9
$7Q_{10}$	628.5	626.4	622.5	616.6	611.5
$1Q_{30}$	184.4	182.3	178.4	172.5	167.4
Q_{90}	1441.8	1439.7	1435.8	1429.9	1424.8
Q_{50}	3134.6	3132.5	3128.6	3122.7	3117.6
Q_{10}	9293.1	9291.0	9287.1	9281.2	9276.1

The supply estimates do not account for 6.4 MGD of supply developed from 44 wells, 1 spring, and stored water facilities in 1984 or the potential water supply allocation of a

[253] Id. p.xxii.

combined 1273.2 billion gallons stored water in the Kerr Reservoir and Lake Gaston.[254] In 1995 the USGS reported that 4.75 MGD of groundwater was utilized in the Lower Roanoke planning area.

4.5.20.3 The Demand Condition

In 1995 in USGS demand cataloging units 03010102 and 03010106, an estimated 17.63 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Lower Roanoke planning area (see Appendix J). Based on the 1995 population estimate of 85,890 people, the total per capita daily offstream demand was 205.26 gpcd (17.63 MGD/85,890 people). The total offstream per capita freshwater estimate includes 7.17 MGD of industrial withdrawals (40.67% of the total offstream demand). Of the 17.63 MGD total daily offstream demand, 4.12 MGD (23.37% of the partially consumed withdrawal) was assumed to have been consumed. If the total per capita daily offstream demand and the percentage of that demand consumed stay constant in each succeeding year of the planning area, the demand through 2025 can be expected as indicated in Table 4.164 (see Appendix K).

Table 4.164: Projected total daily offstream demand for the Lower Roanoke planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	18.31	4.28
2000	18.78	4.39
2005	19.66	4.60
2015	21.26	4.97
2025	22.74	5.31

If an instream demand requirement equivalent to is required to pass into North Carolina, the total daily demand would be as shown in Table 4.165 (see Appendix J).

[254] See note 82, supra, p. II-202 - II-205.

Table 4.165: Projected total daily demand in the Lower Roanoke planning area.

YEAR	Total Demand (MGD)
1998	717.41
2000	717.88
2005	718.76
2015	720.36
2025	721.84

The demand projections indicated in Tables 4.164 and 4.165 do not include the City of Virginia Beach's withdrawal of 55 MGD from the mouth Pea Hill Creek into Lake Gaston that began in 1996.

4.5.20.4 Water Supply Availability in the Lower Roanoke Planning Area

Upon comparison of the projected total streamflow availability (Table 4.163) to the projected total daily offstream demand (Table 4.164), the following water balance conditions result:

Table 4.166: Offstream demand water supply availability in the Lower Roanoke planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4959	4956	4951	4944	4937
$7Q_{10}$	610	608	603	595	589
$1Q_{30}$	166	164	159	151	145
Q_{90}	1423	1421	1416	1409	1402

The preceding surpluses can also be expressed in terms of the projected population in order to identify the amount of estimated streamflow that may be available for future development on a per capita basis.

Table 4.167: Offstream demand water supply availability in the Lower Roanoke planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	56,381	54,959	52,483	48,516	45,350
$7Q_{10}$	7632	7435	7092	6542	6104
$1Q_{30}$	2653	2582	2457	2256	2096
Q_{90}	16,750	16,324	15,582	14,393	13,445

Although projected offstream demands in the Lower Roanoke planing area account for less than 1% of the annual mean flow, the cumulative effect of the offstream withdrawal in all planning areas contributing to the Roanoke River basin may exceed the feasibility of capture threshold. Including the withdrawal of 670 MGD of water for thermoelectric use in North Carolina's portion of the Lower Dan demand cataloging unit (of which 31 MGD or 4.62% is consumed) (see *4.5.22*), nearly 22% of the annual mean flow will be developed by 2025. However, if the thermoelectric withdrawal is not included in the offstream demand projection, projected offstream demands will not exceed 5% of the annual mean flow (see Appendix L).

Water supply conditions would be significantly affected if a flow equivalent to $7Q_{10}$ is required to pass into North Carolina.

Table 4.168: Total demand water supply availability in the Lower Roanoke planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	4219	4217	4212	4204	4198
$7Q_{10}$	-129	-132	-137	-144	-151
$1Q_{30}$	-573	-576	-581	-588	-595
Q_{90}	684	682	677	669	663

The surpluses indicated in Tables 4.166, 4.167 and 4.168 do not include the nonconsumptive hydroelectric demand of 4788 MGD reported in the planning area in 1995. The large planning area does not permit the analysis of the potential conflict between individual users during periods of localized low flow or the condition of individual system treatment, storage or distribution facilities.

4.5.21 The Martinsville Planning Area

4.5.21.1 The Martinsville Planning Area and Its Population

The Martinsville planning area (see Plate XXI) consists of hydrologic units L42-L57 in the Upper Dan River portion of the Roanoke River basin (see Plate 35) and hydrologic units M01-M03 in the Ararat River Basin (see Plate 37). The Martinsville planning area covers 910.05 square miles of the Dan River drainage area and includes drainage from the Dan, Smith, North Mayo, and South Mayo Rivers and Horse Pasture, Matrimony, Renet Bag, Blackberry, Beaver, Lower Smith, Marrowbone, and Leatherwood Creeks (see Appendix A). It also includes 118.32 square miles of the Upper Ararat drainage area and includes flow contributions from the Upper Ararat, Little Fisher, and Fisher Rivers and Stewarts, Pauls, and Lovills Creeks (see Appendix A). The USGS has designated the Upper Dan portion of the Roanoke River Basin as cataloging unit 03010103 and the Upper Ararat River Basin as cataloging unit 03040101. However, the USGS designation for cataloging unit 03010103 includes hydrologic units L57 and L58; these hydrologic units have been included in the Danville planning area (see *4.5.22*). A different boundary was drawn for the Martinsville planning area for two main reasons: first, the USGS designation separated the City of Danville into two sections along a hydrologic unit. Secondly, hydrologic unit L57 captures drainage that flows into the Dan River upon its return into the Commonwealth from North Carolina. The result of the distinction of boundary is that the population of Danville is not attributed to population density estimates by land area distribution; but, the 1995 demand data must be distributed according to land area weighting.

Population in the planning area was estimated in 1998 by developing population densities as a function of municipal jurisdiction from 1998 Census Bureau estimates (see Appendix F) and estimating the portion of the jurisdiction population residing in the hydrologic planning area (see Appendix G.2). Portions of the City of Martinsville and Carroll, Floyd, Franklin, Grayson, Henry, and Patrick Counties indicated 96,076 people in the planning area in 1998, an average population density of nearly 94 people per square mile. Assuming expected growth in the Commonwealth (as projected by the Census Bureau) would occur in the planning area, projected population might be expected to be as displayed in Table 4.169.

Table 4.169: Martinsville planning area population projections through 2025 (see Appendix H).

YEAR	Projected Population
2000	98,570
2005	103,177
2015	111,587
2025	119,265

4.5.21.2 The Supply Condition

Flow availability in the Martinsville planning area was developed from flow data measurements at USGS gage 02068500 on the Dan River near Francisco, North Carolina, USGS gage 05073000 on the Smith River at Martinsville, Virginia, USGS gage 02070000 on the North Mayo River near Spencer, Virginia and USGS gage 02069700 on the South Mayo River near Nettleridge, Virginia. Average cfs/mi^2 yield conditions at each location were developed and applied to the entire drainage area of each of the four major subbasins before flowing into North Carolina. The supply availability estimate for each drainage basin was then combined to develop a total availability quantity of surface water in the planning area. Because the Martinsville planning area is a headwater planning area, supply estimates were not adjusted for consumption.

Gage 02068500 on the Dan River near Francisco, North Carolina records flow information from 129 square miles of the upstream watershed. Of the 129 square miles, 119.8 square miles of the drainage are lies in Virginia (hydrologic unit L42). Flows under Q_{AM}, Q_{90}, Q_{50} and Q_{10} conditions are derived from USGS records over the entire period of measurement between 1938 and 1998.[255] Flows under $7Q_{10}$ and $1Q_{30}$ conditions were developed by the VSWCB for records kept between 1924 and 1977.[256] The Upper Ararat drainage area of 118.3 square miles is added to the gage on the Dan because there are no continuous record gage measurements available on Ararat tributaries in Virginia, and because both drainage areas are headwater drainage areas that lie partially in the Blue Ridge and Piedmont physiographic provinces. Adding the Ararat drainage area to the Dan River gage increases the 129 square mile gaged area to 238.1 square miles, an addition of 91.73% to the total gaged area.

Table 4.170: Flow estimates for the Upper Dan and Ararat drainage areas.

Flow	**Adjusted flow (MGD)**	**%Q_{AM}**
Q_{AM}	**236.2**	100%
$7Q_{10}$	**51.1**	21.63%
$1Q_{30}$	**32.6**	13.79%
Q_{90}	**101.4**	42.93%
Q_{50}	**188.5**	79.80%
Q_{10}	**383.0**	162.12%

Gage 02073000 on the Smith River at Martinsville, Virginia records flow information from 380 square miles of the upstream watershed. Flows under Q_{AM}, Q_{90},

[255] See note 28, supra, p. 398-399.
[256] See note 123, supra, p. xxi.

Q_{50} and Q_{10} conditions are derived from USGS records between 1951 and 1998.[257] The full period of record at the gage is from 1930 and 1998; however, records between 1930 and 1950 were not regulated by the Philpott Reservoir 19.6 miles upstream and the records reflect the effect of the regulated flow in the River. Flows under $1Q_{30}$ and $7Q_{10}$ conditions were developed by the VSWCB from records between 1929 and 1977 and were not adjusted to reflect the flow regulation introduced by the Philpott Reservoir.[258] The Smith River drainage area covers 541.29 square miles of the Martinsville planning area with an ungaged land area of 161.29 square miles or 42.44% of the gaged land area.

Table 4.171: Flow estimates for the Smith River drainage area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**448.3**	100%
$7Q_{10}$	**101.3**	22.59%
$1Q_{30}$	**17.4**	3.89%
Q_{90}	**154.7**	34.50%
Q_{50}	**335.1**	74.74%
Q_{10}	**843.3**	188.09%

Gage 02070000 on the North Mayo River near Spencer, Virginia records flow information from 108 square miles of the upstream watershed. Flows under Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from records kept at the station between 1929 and 1935 and 1937 and 1998.[259] Flows conditions for $7Q_{10}$, Q_{95} and the MBF_{est} were developed by Nelms, et al. for records between 1930 and 1984;[260] the $1Q_{30}$ estimate was developed by the VSWCB from records between 1928 and 1977.[261] The North Mayo River drainage area covers 123 square miles of the Martinsville planning area with an ungaged land area of 15 square miles or 13.89% of the gaged land area.

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257 See note 28, supra, p. 413.
258 See note 123, supra, p. xxi.
259 See note 28, supra, p. 403.
260 See note 121, supra, Appendix 1.
261 See note 123, supra, p. xxi.

Table 4.172: Flow estimates for the North Mayo River drainage area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**96.4**	100%
$7Q_{10}$	**18.4**	19.08%
$1Q_{30}$	**13.1**	13.57%
Q_{95}	**29.6**	30.69%
Q_{90}	**38.3**	39.69%
Q_{50}	**70.7**	73.28%
MBF_{est}	**69.0**	71.53%
Q_{10}	**148.7**	154.20%

Gage 02069700 on the South Mayo River near Nettleridge, Virginia records flow information from 84.6 square miles of the upstream watershed. Flows under Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from records kept at the station between 1963 and 1998.[262] Flows under $7Q_{10}$, Q_{95} and the MBF_{est} were developed by Nelms, et al. for records between 1964 and 1984;[263] the $1Q_{30}$ estimate was developed by the VSWCB from records between 1962 and 1977.[264] The South Mayo River drainage area covers 125.98 square miles of the Martinsville planning area with an ungaged land area of 41.38 square miles or 48.91% of the gaged land area.

Table 4.173: Flow estimates for the South Mayo River drainage area.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**96.4**	100%
$7Q_{10}$	**18.4**	19.08%
$1Q_{30}$	**13.1**	13.57%
Q_{95}	**29.6**	30.69%
Q_{90}	**38.3**	39.69%
Q_{50}	**70.7**	73.28%
MBF_{est}	**69.0**	71.53%
Q_{10}	**148.7**	154.20%

Combining the four major river basins into a single estimate, the total flow condition estimates for the 1028.4 square mile area can be developed for the planning area. Of the total land area, 692.4 square miles are gaged, while 336 square miles are

[262] See note 28, supra, p. 401.

added to the total gaged area (48.52%). Assuming the large percentage of ungaged land area is an acceptable estimate of the total flow availability, the estimates in Table 4.174 can represent the streamflow at the Virginia border with North Carolina.

Table 4.174: Supply estimates for the Martinsville planning area.

Flow	Estimated flow (MGD)	$\%Q_{AM}$
Q_{AM}	**907.6**	100%
$7Q_{10}$	**196.7**	21.67%
$1Q_{30}$	**83.3**	9.18%
Q_{90}	**344.4**	37.95%
Q_{50}	**690.5**	76.08%
Q_{10}	**1583.8**	174.50%

Although Table 4.174 does reflect the influence of Lake Philpott on the flow patterns of the Smith River, it does not account for the water potentially yield from stored surface water or spring and well access to groundwater in the Martinsville planning area. In 1982, an average daily withdrawal of 8.1 MGD was supplied to facilities in the planning area by 1 spring, 110 wells, and stored water developments.[265] In 1995 the USGS reported that 5.67 MGD of groundwater was utilized in the Martinsville planning area.

4.5.21.3 The Demand Condition

In 1995 in USGS demand cataloging units 03040101 and 03010103, an estimated 49.73 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Martinsville planning area (see Appendix J). However, the demand had to account for the variation in the planning area boundary from the cataloging unit boundary. The methodology applied was to assume that the reported values were evenly distributed over the cataloging unit and to assume that the portion of land area in the

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[263] See note 121, supra, Appendix 1.
[264] See note 123, supra, p. xxi.

planning area accounted for the same portion of the reported values. Hence, the 1995 USGS estimates for cataloging unit 03010103 were multiplied by the land area ratio of .8382198. Based on the estimated 1995 planning area population of 109,637 people, the 1995 total daily per capita offstream demand was 453.57 gpcd (49.73 MGD/109,637 people). The total offstream per capita freshwater estimate includes 39.57 MGD of industrial withdrawals (59.46% of the total offstream demand). Of the total daily offstream demand, 6.34 MGD, 12.74% of the withdrawal, was estimated to have been consumed. Assuming that the total daily per capita offstream demand and the percentage of that demand will remain constant in each succeeding year of the planning period, projected demands through 2025 can be expected to take the form in Table 4.174 (see Appendix K).

Table 4.175: Total daily offstream consumptive demand for the Martinsville planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	43.59	5.55
2000	44.72	5.70
2005	46.81	5.96
2015	50.62	6.45
2025	54.11	6.89

Table 4.176 indicates the total daily demand if an instream demand requirement equivalent to $7Q_{10}$ was required to flow out of the planning area (see Appendix K).

Table 4.176: Total daily demand in the Martinsville planning area.

YEAR	Total Demand (MGD)
1998	240.29
2000	241.42
2005	243.51
2015	247.32
2025	250.81

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[265] See note 82, supra, p. II-122 - II-123, II-125.

4.5.21.4 Water Supply Availability in the Martinsville Planning Area

Upon comparing the projected total streamflow availability (Table 4.174) to the projected total daily offstream consumptive demand (Table 4.175), the following water balance conditions result:

Table 4.177: Offstream demand water supply availability in the Martinsville planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	864	863	861	857	853
$7Q_{10}$	153	152	150	146	143
$1Q_{30}$	40	39	36	33	29
Q_{90}	301	300	298	294	290
$10\%Q_{AM}$	47	46	44	40	37
$20\%Q_{AM}$	138	139	134	131	127

The preceding surpluses can also be expressed in terms of projected population in order to identify the amount of water available for development on a per capita basis in each year of the planning period.

Table 4.178: Offstream demand water supply availability in the Martinsville planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	8991	8751	8341	7679	7154
$7Q_{10}$	1593	1541	1452	1309	1195
$1Q_{30}$	413	391	354	293	245
Q_{90}	3130	3039	2884	2632	2433
$10\%Q_{AM}$	491	467	426	360	307
$20\%Q_{AM}$	1435	1387	1305	1173	1068

Projected offstream demands are not expected to exceed 6% of the annual mean flow in the planning period.

Water supply conditions could be significantly affected if a flow equivalent to $7Q_{10}$ is required to remain instream at the outlet of the planning area.

Table 4.179: Total demand water supply availability in the Martinsville planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	667	666	664	660	657
$7Q_{10}$	-44	-45	-47	-51	-54
$1Q_{30}$	-157	-158	-160	-164	-168
Q_{90}	104	103	101	97	94

Despite the conditions indicated in Tables 4.177 and 4.178, it is important to note that the future demand conditions have been projected as a function of population. Included in the projected total offstream demand is the industrial demand that accounted for nearly 80% of the partially consumed demand in 1995. The preceding analysis of streamflow availability might be considered conservative because industrial growth does not necessarily accompany increases in population. Another important factor in the analysis is the distribution of the USGS 1995 estimates according to land area. Such an assumption does not account for the heterogeneities associated with population distribution or the concentration of water use in demand centers. The large scale of the analysis does not permit the assessment of potential conflict between users during times of localized low flow, of individual system infrastructure deficiencies or of the water available from underground or stored water developments.

4.5.22 The Danville Planning Area

4.5.22.1 The Danville Planning Area and Its Population

The Danville planning area (see Plate XXII) includes hydrologic units L57-L74 in the Lower Dan River portion of the Roanoke River basin (see Plate 36). The Danville planning area drains water from 1361.23 square miles of the Commonwealth and includes drainage from the Dan, Sandy, Stinking, Banister, and Hyco Rivers (see

Appendix 3-A). It also includes minor tributaries such as Cascade, Sandy, Cane, Winns, Birch, Lawsons, Miry, Cherrystone, Elkhorn, Whitehorn, Polecat, Terrible, Aarons, and Big Bluewig Creeks (see Appendix A). The planning area consists of USGS cataloging units 03010104, 03010105 and the remaining portion of 03010103 not included in the Martinsville planning area (see *4.5.21.1*). Upstream from the Danville planning area is the Martinsville planning area and the Upper and Lower Dan River USGS cataloging units in North Carolina before the Dan flows back into Virginia in Pittsylvania County near Cascade, Virginia. The Danville planning area consists of portions of the City of Danville and Halifax, Henry, Mecklenburg, and Pittsylvania Counties. From the Census Bureau population estimates in 1998 (see Appendix F), population densities within each jurisdiction were developed and applied to the contributing land areas of the planning area. Population within the planning area in 1998 was estimated as 121,436 people, an average population density of 90 people per square mile. Table 4.180 specifies the population in the planning area if population within the planning area grows proportional to Census Bureau projections for Virginia.

Table 4.180: Danville planning area population projections through 2025 (see Appendix H).

YEAR	Projected Population
2000	124,588
2005	130,411
2015	141,041
2025	150,745

4.5.22.2 The Supply Condition

Streamflow availability in the Danville planning area was developed from flow data records kept at USGS gage 02075500 on the Dan River at Paces, Virginia and USGS gage 02077000 on the Banister River at Halifax, Virginia. The average cfs/mi^2 yield for each condition was developed at each gage location and applied to the entire upstream watershed at the outlet point of the drainage area. The Dan River gage data was applied to the outlet of hydrologic unit L64; the Banister River gage data was applied to the outlet of the hydrologic unit L71; the outlet of hydrologic units L64 and L71 is the confluence of the Dan and Banister Rivers. Estimates of supply for each drainage basin in the planning area were combined at the confluence to express the total supply availability as a single estimate for each condition in the stream. The combined supply availability estimates had to be adjusted for consumption projected to take place in the upstream Martinsville planning area and Upper and Lower Dan cataloging units in North Carolina (see Appendix J).

Gage 02075500 on the Dan River at Paces, Virginia records streamflow characteristics from 2550 square miles of the upstream watershed. Of the 2669.88 square mile river basin, 1522.51 square miles are in Virginia (hydrologic units L42-L64) and 1147.37 square miles are in North Carolina. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept from 1951 to 1998.[266] Flow conditions for $7Q_{10}$ and $1Q_{30}$ were developed by the VSWCB from records kept between 1950 and 1977.[267] By translating the gage data to the downstream point, the adjusted flow estimates include 119.88 square miles of ungaged land area (4.70% of the gaged area).

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[266] See note 28, supra, p. 421.
[267] See note 123, supra, p. xxii.

Table 4.181: Flow estimates for the Dan River at its confluence with the Banister River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1901.4**	100%
$7Q_{10}$	**280.8**	14.77%
$1Q_{30}$	**92.9**	4.89%
Q_{90}	**625.2**	32.88%
Q_{50}	**1292.4**	67.97%
Q_{10}	**3403.6**	179.00%

Gage 02077000 on the Banister River at Halifax, Virginia records flow information from 547 square miles of the upstream watershed. Flow conditions for Q_{AM}, Q_{90}, Q_{50} and Q_{10} were derived from USGS records kept from 1905 to 1906 and 1929 to 1998.[268] Flow conditions for $7Q_{10}$ and $1Q_{30}$ were developed by the VSWCB from records kept between 1928 and 1977.[269] By translating the gage data to the downstream point, the adjusted flow estimates include 50.04 square miles of ungaged land area (5.49% of the gaged area).

Table 4.182: Flow estimates for the Banister River at its confluence with the Dan River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**364.0**	100%
$7Q_{10}$	**28.1**	7.72%
$1Q_{30}$	**7.8**	2.15%
Q_{90}	**79.7**	21.90%
Q_{50}	**216.6**	59.50%
Q_{10}	**673.7**	185.08%

Combining the two river basin supply estimates into a single availability estimate, the total flow availability can be expressed for the planning area. Of the total 3266.92 square miles of drainage area contributing to the flow estimate at the confluence of the Dan and Banister Rivers, 3097 square miles are gaged; the remaining 169.92 square miles of ungaged area (5.49% of the total gaged area) are added to the gaged area.

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[268] See note 28, supra, p. 423.
[269] See note 123, supra, p. xxii.

Table 4.183: Supply estimates for the Danville planning area.

Flow	Estimated flow (MGD)	%Q_{AM}
Q_{AM}	**2265.4**	100%
$7Q_{10}$	**308.9**	13.64%
$1Q_{30}$	**100.7**	4.45%
Q_{90}	**704.9**	31.12%
Q_{50}	**1509.0**	66.61%
Q_{10}	**4077.2**	179.98%

Table 4.183 represents the flow availability at the confluence of the Dan and Banister Rivers in the Danville planning area. However, hydrologic units L73 and L74 have not been included in the surface water availability analysis. Hydrologic units L73 and L74 represent 60.73 square miles of the Aarons Creek and 90.98 square miles of the Hyco River drainage areas that are in Virginia, respectively. The flow contribution from these two tributaries to the Dan River and the Kerr Reservoir were considered negligible and are not accounted for in the preceding analysis.

The total streamflow availability estimate must be adjusted for upstream consumption in the Martinsville planning area and the Upper and Lower Dan cataloging units in North Carolina. The projections for consumption were developed as a total of the projected consumption for each upstream portion of the drainage basin, and Table 4.184 depicts the supply availability less the projected upstream consumption (see Appendix I, J and K for the development of the North Carolina estimates).

Table 4.184: Supply projections for the Danville planning area.

Flow	1998	2000	2005	2015	2025
Q_{AM}	2211.9	2210.3	2207.2	2202.8	2199.1
$7Q_{10}$	255.5	253.8	250.7	246.3	242.6
$1Q_{30}$	47.3	45.6	42.5	38.1	34.5
Q_{90}	651.5	649.8	646.7	642.3	638.7
Q_{50}	1455.5	1453.9	1450.7	1446.4	1442.7
Q_{10}	4023.7	4022.1	4019.0	4014.6	4010.9

The supply estimates do not include 1.27 MGD of water developed 16 wells and stored water facilities in 1982.[270] In 1995 the USGS reported that 3.92 MGD of groundwater was utilized in the Danville planning area.

4.5.22.3 The Demand Condition

In 1995 in USGS demand cataloging units 03010103, 03010104, and 03010105, 23.40 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Danville planning area (see Appendix J). The demand was developed as the sum of the values reported for cataloging unit 03010104, 03010105 and the land portion of cataloging unit 03010103 contributing to the planning area. Demand values for cataloging unit 03010103 were multiplied by the land area ratio of .1617802 in order to account for the boundary discrepancy. Based on the 1995 population estimate of 123,420 people, the total per capita daily offstream demand was 189.60 gpcd (23.40 MGD/123,420 people). The total offstream per capita freshwater estimate includes 11.53 MGD of industrial withdrawals (48.24% of the total offstream demand). Of the total daily offstream demand, 9.74 MGD (41.62% of the partially consumed withdrawal) was estimated as consumed in 1995. Table 4.185 displays offstream demand assuming that the total per capita daily offstream demand and that percentage of that demand consumed will remain constant in each year of the planning period (see Appendix K).

Table 4.185: Projected total daily offstream demand for the Danville planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	25.35	10.55
2000	26.02	10.83
2005	27.23	11.33
2015	29.44	12.25
2025	31.47	13.10

[270] See note 82, supra, p.II-123 - II-124.

Table 4.186 specifies projected total daily demand if an instream demand requirement equivalent to $7Q_{10}$ was required to pass the confluence of the Dan and Banister Rivers (see Appendix K).

Table 4.186: Projected total daily demand in the Danville planning area.

YEAR	Total Demand (MGD)
1998	334.25
2000	334.92
2005	336.13
2015	338.34
2025	340.37

4.5.22.4 Water Supply Availability in the Danville Planning Area

Upon comparing the projected total streamflow availability (Table 4.184) to the projected total daily offstream demand (Table 4.185), the following water balance conditions result:

Table 4.187: Offstream demand water supply availability in the Danville planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	2187	2184	2180	2173	2168
$7Q_{10}$	230	228	223	217	211
$1Q_{30}$	22	20	15	9	3
Q_{90}	626	624	619	613	607

The preceding surpluses can also be expressed in terms of the projected population in order to identify the amount of streamflow available for development on a per capita basis in each year of the planning period.

Table 4.188: Offstream demand water supply availability in the Danville planning area (all values in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	18,011	17,530	16,717	15,414	14,384
$7Q_{10}$	1895	1828	1714	1538	1401
$1Q_{30}$	180	157	117	61	20
Q_{90}	5157	5007	4751	4347	4029

Although projected offstream demands in the Danville planing area account for less than 2% of the annual mean flow, the cumulative effect of offstream withdrawal on the Dan River indicates that the feasibility of capture restraint may be exceed. If the withdrawal of 670 MGD of water for thermoelectric use in North Carolina's portion of the Lower Dan demand cataloging unit is included in the offstream withdrawal estimate (of which 31 MGD or 4.62% is consumed), over 44% of the annual mean flow will be developed by 2025. However, if the thermoelectric withdrawal is not included in the offstream demand projection, projected offstream demands will not exceed 6% of the annual mean flow (see Appendix L).

Water supply conditions would be significantly affected if a flow equivalent to the total estimated $7Q_{10}$ was required to pass the outlet of the planning area.

Table 4.189: Total demand water supply availability in the Danville planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1878	1875	1871	1864	1859
$7Q_{10}$	-79	-81	-85	-92	-98
$1Q_{30}$	-287	-289	-294	-300	-306
Q_{90}	317	315	311	304	298

The surpluses indicated in Tables 4.187 and 4.188 do not include the nonconsumptive thermoelectric demand of 934 MGD reported in 1995. The land area distribution assumption applied to the USGS 1995 estimates has the potential to create a degree of discrepancy in the projections even beyond those included in the methodology because of the inability to account for population and demand centers. The large partial-river basin scale does not include analysis of the potential conflict between individual users during localized periods of low flow or the condition of individual system treatment, storage or distribution facilities.

4.5.23 The Upper New Planning Area

4.5.23.1 The Upper New Planning Area and Its Population

The Upper New planning area covers 1455.80 square miles formed by hydrologic units N01-N15 (see Plate XXIII and Plate 39) that are a part of USGS cataloging unit 05050001. It includes the New River and its tributaries including Wilson, Brush, Cripple, Reed, Big Reed Island, and Little Reed Island Creek (see Appendix A). The cataloging unit boundary was truncated to form the planning area in order to reduce the upstream to downstream distance to about 75 miles and to capture the "free-flowing" characteristics of the New River before ponding behind the Claytor Lake Dam. Portions of Bland, Carroll, Floyd, Grayson, Patrick, Smyth, and Wythe Counties are contained in the planning area as well as the City of Galax (see Appendix G.2). Based on 1998 US Census Bureau county and city population estimates (see Appendix F), the 1998 population of the planning area was estimated to be 80,714 people; over the 1455.80 square mile area, the population is distributed at about 56 people per square mile. Based on Census estimates for population growth in Virginia through 2025, population projections for the planning area can be expected to take the form in Table 4.190.

Table 4.190: Upper New planning area projected population (see Appendix H).

YEAR	Projected Population
2000	82,809
2005	86,679
2015	93,745
2025	100,195

4.5.23.2 The Supply Condition

Supply availability was developed for the Upper New planning area as a function of USGS gage 03016800 on the New River. The gage location was coincidental with the downstream planning area boundary, and consequently, the real gage data was used to represent the natural flow availability in the planning area. Based on the actual gage data, the flows in Table 4.191 can be expected to occur at the downstream point of the planning area (for development of the streamflow availability estimates see Appendix D.23; for the period of record used to develop each flow characteristic see Appendix C).

Table 4.191: Gage flow measurements at the downstream point of the Upper New planning area.

Flow	Gage flow (MGD)	%Q_{AM}
Q_{AM}	**2101.7**	100%
$7Q_{10}$	**468.5**	22.29%
$1Q_{30}$	**329.2**	15.66%
Q_{95}	**616.5**	29.34%
Q_{90}	**717.4**	34.13%
Q_{50}	**1576.9**	75.03%
MBF_{est}	**1393.4**	66.30%
Q_{10}	**3787.2**	180.20%

To account for the diminishing effects of the amount of water consumed upstream in the headwaters of the New River basin in North Carolina, the flows were adjusted to reflect the amount of water expected to be consumed by upstream users (see Appendix E).

Table 4.192: Supply projections for the Upper New planning area (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	2094.3	2094.0	2093.6	2093.0	2092.5
$7Q_{10}$	461.1	460.9	460.5	459.9	459.4
$1Q_{30}$	321.8	321.6	321.1	320.5	320.0
Q_{95}	609.1	608.9	608.5	607.9	607.4
Q_{90}	709.9	709.7	709.3	708.7	708.2
Q_{50}	1569.5	1569.3	1568.8	1568.2	1567.7
MBF_{est}	1386.0	1385.7	1385.3	1384.7	1384.2
Q_{10}	3779.7	3779.5	3779.1	3778.5	3778.0

Because of the large scale of the partial river basin planning area, the analysis of the individual water supply systems is not included in the preceding supply estimates. The supply estimate does not account for the 18 wells and 6 springs that collectively provided an average of about 9.5 MGD to the planning area between 1982-1984.[271] In 1995 the USGS reported that 4.2 MGD of groundwater was utilized in the Upper New planning area.

4.5.23.3 The Demand Condition

In 1995, 28.32 MGD of partially consumed water (i.e. total daily offstream demand) was withdrawn from the Upper New planning area (see Appendix J). The 1995 estimate was developed by multiplying the 1995 USGS totals by the percentage of the land area included in the Upper New planning area (1455.8 mi^2). When compared to the whole land area of cataloging unit 05050001 (2186.59 mi^2), a land ratio of .6659 (66.59%) was developed. The 1995 total per capita daily offstream demand (28.32 MGD/ 111,705 people) was 253.52 gpcd. The total offstream per capita freshwater estimate includes 10.97 MGD of industrial withdrawals (38.74% of the total offstream demand). Of the 28.32 MGD withdrawn, 2.8 MGD, or 9.89% of the original withdrawal, was consumed. Table 4.193 indicates the projected offstream demand assuming that the total per capita daily offstream withdrawal and the percentage of consumption remain at a level equivalent to the 1995 level in each future year (see Appendix K).

Table 4.193: Total daily offstream demand for the Upper New planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	20.46	2.02
2000	20.99	2.08
2005	21.88	2.17
2015	23.75	2.35
2025	25.40	2.51

Table 4.194 indicates the total daily demand if an instream demand equivalent to $7Q_{10}$ is included in the total daily demand estimate (see Appendix K).

Table 4.194: Total daily demand in the Upper New planning area.

YEAR	Total Demand (MGD)
1998	488.96
2000	489.49
2005	490.48
2015	492.25
2025	493.90

Instream hydroelectric demand for the Upper New planning area was developed as a function of the amount of water needed to produce a single GW-hr of electricity. In 1995, the USGS reported that three hydroelectric facilities in the USGS cataloging unit 05050001 produced 105.9 GW-hrs of electricity and used a total of 2627.66 MGD of instream water; the index value per GW-hr is 24.81 MGD/GW-hrs. Two of these facilities, namely the Byllesby and Buck plants on the New River in Carroll County, are located in the Upper New planning area and have a combined capacity of 30,105 KW of

[271] Virginia State Water Control Board. "New River Basin Water Supply Plan." Virginia State Water Control Board Planning Bulletin No. 344, March 1988, p. II-18 - II-27.

the 105,105 kW capacity in cataloging unit 05050001.[272] If 30,105 represents 28.64% of the total installed 105,105 kW capacity in cataloging unit 05050001, then the two facilities might be assumed to produce 28.64% of the 105.9 GW-hrs produced in 1995, a production quantity of 30.33 GW-hrs in 1995. The resulting total instream hydroelectric demand in the Upper New planning area is 30.33 GW-hrs multiplied by 24.81 MGD/GW-hr or 752.55 MGD.

4.5.23.4 Water Supply Availability in the Upper New Planning Area

Upon comparing the projected natural supply availability adjusted for upstream consumption (Table 4.192) to the projected total daily offstream demand (Table 4.193), the following surpluses under each flow condition result:

Table 4.195: Offstream total water supply availability in the Upper New planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	2074	2073	2072	2069	2067
$7Q_{10}$	441	440	439	436	434
$1Q_{30}$	301	301	299	297	295
Q_{95}	589	588	586	584	582
Q_{90}	689	689	687	685	683
$10\%Q_{AM}$	190	189	188	186	185
$20\%Q_{AM}$	400	399	398	397	395

Based on the surpluses listed in the preceding table, it can be concluded that no shortages are expected to occur at the partial-river basin scale in the planning period. The surpluses can also be expressed in terms of the amount of water available for development per capita per day in each year of the planning period.

[272] Id., p. I-13.

Table 4.196: Offstream demand water supply availability in the Upper New planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	25,698	25,037	23,894	22,084	20,630
$7Q_{10}$	5461	5313	5058	4654	4331
$1Q_{30}$	3734	3630	3451	3167	2940
Q_{95}	7295	7100	6765	6234	5808
Q_{90}	8544	8318	7927	7310	6814
$10\%Q_{AM}$	2342	2276	2161	1980	1835
$20\%Q_{AM}$	4937	4805	4576	4214	3923

Projected offstream demands are not expected to exceed 2% of the annual mean flow in the planning period.

Although the Upper New planning area does not appear to face any potential supply and offstream demand conflict at the regional scale, instream demand requirements may change the nature of supply availability locally and regionally. If a flow equivalent to the $7Q_{10}$ was designated as a flowby requirement at the downstream point of the planning area, the set of conditions indicated in Table 4.197 might be expected to occur.

Table 4.197: Total demand water supply availability in the Upper New planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1605	1605	1603	1600	1599
$7Q_{10}$	-28	-29	-30	-32	-35
$1Q_{30}$	-167	-168	-169	-172	-174
Q_{95}	120	119	118	116	113
Q_{90}	221	220	219	216	214

The partial-river basin scale eliminates the potential water supply conflicts that may arise between individual users during localized times of low flow and the potential deficiencies of infrastructure in treatment, storage and distribution systems. It is also important to note that the hydroelectric instream demands are not included in the demand for which the surpluses have been developed. Despite hydroelectric demands being instream, potential conflicts may arise under low flow conditions unless sufficient flowby conditions are specified by permit at each facility.

4.5.24 The Lower New Planning Area

4.5.24.1 The Lower New Planning Area and Its Population

The Lower New planning area covers hydrologic units N16-N35 (see Plate XXIV and Plate 40) and includes USGS cataloging unit 05050002 and part of cataloging unit 05050001. It includes the New River and Claytor Lake as well as their tributaries including the Little, Bluestone, and East Rivers and Wolf, Walker, Little Stony, Stony, Sinking, and Peak Creeks (see Appendix A). The total planning area drains 1609.54 square miles of the lower portion of the New River. According to 1998 Census Bureau population density estimates (see Appendix F), approximately 126,522 people from portions of Bland, Craig, Floyd, Giles, Montgomery, Pulaski, Tazewell, and Wythe counties and the City of Radford live within the planning area; the average basin population density is about 79 people per square mile. Assuming population growth in the Commonwealth as projected by the US Census Bureau proportional to population growth within the planning area, the projected population for the Lower New planning area might be distributed as indicated in Table 4.198.

Table 4.198: Lower New planning area projected population (see Appendix H).

YEAR	Projected Population
2000	82,809
2005	86,679
2015	93,745
2025	100,195

4.5.24.2 The Supply Condition

Supply availability for the Lower New planning area was developed as a function of the flow measurements taken at USGS gage 03176500 on the New River at Glen Lyn. The gage captures flow from 3768 square miles of the upstream river basin. Approximately 43.54 square miles of ungaged area (1.16% of the original gaged area) were added to the gage data (for the development of the supply estimates see Appendix D.24; for the period of record used to develop flow characteristics see Appendix C).

Table 4.199: Flow estimates at the downstream point of the Lower New planning area.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**3322.3**	100%
$7Q_{10}$	**736.1**	22.16%
$1Q_{30}$	**571.8**	17.21%
Q_{95}	**806.7**	24.28%
Q_{90}	**1019.8**	30.70%
Q_{50}	**2425.4**	73.00%
MBF_{est}	**2096.5**	63.11%
Q_{10}	**6380.5**	192.05%

In order to account for the effects of upstream consumption in the North Carolina and Upper New portions of the New River Basin, the natural flow supply estimates were adjusted to reflect the effect of upstream consumption (see Appendix E).

Table 4.200: Supply projections for the Lower New planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	3312.9	3312.6	3312.1	3311.3	3310.6
$7Q_{10}$	726.7	726.4	725.9	725.1	724.4
$1Q_{30}$	562.3	562.0	561.5	560.7	560.1
Q_{95}	797.3	797.0	796.5	795.7	795.0
Q_{90}	1010.4	1010.1	1009.6	1008.8	1008.1
Q_{50}	2415.9	2415.7	2415.1	2414.4	2413.7
MBF_{est}	2087.1	2086.8	2086.3	2085.5	2084.9
Q_{10}	6371.1	6370.8	6370.3	6369.5	6368.8

Because of the large scale of the partial-river basin regional planning areas, the analysis of individual water supply systems is not included in the preceding supply estimates. The supply estimate does not account for an average of 11.703 MGD withdrawn from 11 springs, 32 wells, reservoir sources, and 1 mine runoff source between 1982-1984 within the planning area.[273] In 1995 the USGS reported that 8.36 MGD of groundwater was utilized in the Lower New planning area.

4.5.24.3 The Demand Condition

In 1995, 23.24 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Lower New planning area (see Appendix 2-J). The 1995 estimated was developed by adding the totals from USGS cataloging unit to 33.42% of the totals from cataloging unit 05050001. The 1995 total per capita daily offstream demand was 244.70 gpcd (23.24 MGD/94,975 people). The total offstream per capita freshwater estimate includes 10.45 MGD of industrial withdrawals (44.97% of the total offstream demand). Of the 23.24 MGD withdrawn, 2.56 MGD, or 11.02% of the original withdrawal was consumed. Assuming that the total per capita daily offstream demand and the percentage of consumption remain at a constant level in each year of the planning period, projected demands through 2025 might be expected to be those values in Table 4.201(see Appendix K).

Table 4.201: Total daily offstream demand for the Lower New planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	30.95	3.41
2000	31.76	3.50
2005	33.25	3.66
2015	35.95	3.96
2025	38.44	4.24

[273] See note 271, supra.

If an instream demand equivalent to $7Q_{10}$ is included as a portion of the total demand, the demand values in Table 4.202 might be expected to exist (see Appendix K).

Table 4.202: Total daily demand in the Lower New planning area.

YEAR	Total Demand (MGD)
1998	767.05
2000	767.86
2005	769.35
2015	772.05
2025	774.54

Instream hydroelectric demand for the Lower New planning area was developed based on the MGD/GW-hr index value developed in *4.3.23.4*. The Claytor Lake hydroelectric plant has an installed capacity of 75,000 kW, or 71.35% of the total installed capacity of USGS cataloging unit 05050001. Therefore, 71.35% of the total 105.9 GW-hr of electricity produced in 05050001 in 1995 can be assumed to be from the Claytor Lake facility, or 75.56 GW-hr of electricity. The resulting 1874.82 MGD from 05050001 is the total estimated amount of hydroelectric instream demands in the planning area. The thermoelectric demand at the Glen Lyn steam electric plant is not considered part of the total daily offstream withdrawal because none of the water withdrawn is consumed in the process.

4.5.24.4 Water Supply Availability in the Lower New Planning Area

Upon comparing the projected natural supply availability adjusted for upstream consumption (Table 4.200) to the projected daily offstream demand (Table 4.201), the following surpluses can be expected under each flow condition:

Table 4.203: Offstream demand water supply availability in the Lower New planning (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	3282	3281	3279	3275	3272
$7Q_{10}$	696	695	693	689	686
$1Q_{30}$	531	530	528	525	522
Q_{95}	766	765	763	760	757
Q_{90}	979	978	976	973	970

Based on the surpluses in the preceding table, it can be concluded that no shortages are expected to occur in the Lower New planning area over the planning period at the regional partial-river basin scale. The surpluses can also be expressed in terms of the amount of water available for development per capita per day in each year of the planning period.

Table 4.204: Offstream demand water supply availability in the Lower New planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	25,944	25,276	24,127	22,296	20,829
$7Q_{10}$	5500	5352	5096	4691	4367
$1Q_{30}$	4201	4085	3887	3572	3320
Q_{95}	6058	5895	5616	5172	4816
Q_{90}	7743	7537	7184	6623	6173

Although partially consumed withdrawals in the Lower New planning area are expected to increase to just over 1% of the annual mean flow estimate at the outlet of the planning area, the cumulative effect of all withdrawals made form the New River basin may rise to nearly 3% in 2025.

Without instream protection requirements, the Lower New planning area is not expected to face any water supply shortages in the near future; however, instream demand requirements could change the availability of local and regional water supplies. If an instream demand equivalent to $7Q_{10}$ was a flowby requirement at the downstream point of the Lower New planning area, the set of conditions in Table 4.205 might be expected to occur.

Table 4.205: Total demand water supply availability in the Lower New planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	2546	2545	2543	2539	2536
$7Q_{10}$	-40	-41	-43	-47	-50
$1Q_{30}$	-205	-206	-208	-211	-214
Q_{95}	30	29	27	24	20
Q_{90}	243	242	240	237	234

The partial-river basin scale does not describe the potential for water supply shortages that may arise in individual systems during periods of localized low flow or in the absence of sufficient infrastructure developments. Another short-coming of the preceding analysis is that is does not include instream hydroelectric or non-consumptive offstream thermoelectric demands in the quantification of the water balance. However, each of these large demands has the potential to create conflict under low flow conditions unless appropriate flowby conditions are specified by permit at each facility.

4.5.25 The Holston Planning Area

4.5.25.1 The Holston Planning Area and Its Population

The Holston planning area consists of hydrologic units O01-O15 that include USGS cataloging units 06010101 and 06010102 and drains 1322.04 square miles of the Holston River before flowing into Tennessee (see Plate XXV, Plate 42, Plate 43 and Plate 44). Tributaries to the system include the North, Middle, and South Forks of the Holston and Whitetop Laurel, Fifteenmile, Beaver, Reedy, and Big Moccasin Creeks (see Appendix A). Approximately 100 square miles of the South Fork drainage area is located in Tennessee; however, the Tennessee portion of the land area was considered negligible and not accounted for in the analysis of supply and demand. The planning area includes portions of the City of Bristol and Grayson, Wythe, Bland, Russell, Scott, Smyth, Tazewell, and Washington Counties (see Appendix G.2). Population in the planning area in 1998 was estimated to be 113,122 people based on 1998 Census Bureau figures for counties and cities within Virginia (see Appendix F), an average population density of about 87 people per square mile. Population projections were developed for the planning area from Census Bureau projections for the entire Commonwealth through 2025.

Table 4.206: Holston planning area projected population (see Appendix H).

YEAR	Projected Population
2000	116,060
2005	121,480
2015	131,390
2025	140,430

4.5.25.2 The Supply Condition

Streamflow availability was developed for the Holston planning area as a function of USGS gages 03490000, 03473000, 03047500 and 03047840 on the North Fork, South Fork and Middle Fork of the Holston River and Beaver Creek, respectively. The yield in cfs/mi^2 under each flow condition was used to develop the flow of each tributary to the system at the downstream point of each smaller drainage basin, and the flows were then summed to approximate the total amount of water naturally available from the entire planning area (see Appendix D.25; for the period of record used to develop each flow condition see Appendix C).

The North Fork flows are measured and recorded at USGS gage 03490000 near Gate City, Virginia that captures 672 square miles of the upstream drainage area. Table 4.207 indicates the amount of flow that can be expected to be in the stream before its entrance into Tennessee, an addition of 43.25 ungaged square miles (6.44% of the gaged area).

Table 4.207: Flow estimates for the Virginia portion of North Fork of the Holston River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**617.0**	100%
$7Q_{10}$	**38.5**	6.24%
$1Q_{30}$	**30.6**	4.96%
Q_{95}	**70.2**	11.37%
Q_{50}	**365.9**	59.31%
MBF_{est}	**380.4**	61.65%

The South Fork flows are measured and recorded at USGS gage 03473000 near Damascus, Virginia that captures 301 square miles of the upstream watershed including 100 square miles in Tennessee. Table 4.208 estimates the amount of water that can be expected to be in the stream under average conditions, including about 20 square miles of ungaged area (5.96% of the gaged area) before flowing into Holston Lake.

Table 4.208: Flow estimates for the Virginia portion of South Fork of the Holston River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**310.9**	100%
$7Q_{10}$	**47.2**	15.18%
$1Q_{30}$	**38.8**	12.47%
Q_{95}	**61.6**	19.81%
Q_{50}	**198.4**	63.83%
MBF_{est}	**215.2**	69.23%

The Middle Fork flows are measured and recorded at USGS gage 03475000 near Meadowview, Virginia that captures 211 square miles of the upstream drainage area.

Table 4.209 indicates the estimates of the flow at the downstream point of the watershed, an addition of 30.78 square miles of ungaged area (14.59% of the gaged area).

Table 4.209: Flow estimates for the Virginia portion of Middle Fork of the Holston River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	182.9	100%
$7Q_{10}$	37.0	20.24%
$1Q_{30}$	4.9	2.68%
Q_{95}	51.5	28.18%
Q_{50}	108.9	59.51%
MBF_{est}	141.4	77.33%

Beaver Creek flows are measured and recorded at USGS gage 03478400 at Bristol, Virginia that captures 27.7 square miles of the upstream watershed. The yields developed within the small gaged area is used an approximation of the flows that are generated in hydrologic units O06 and O07 that are not included in the other three planning area watersheds. Applying the gage data to the two hydrologic units adds 119.37 square miles of ungaged area to 27.7 square miles of gaged area, an increase in land area of over 430 percent.

Table 4.210: Flow estimates for hydrologic units O06 and O07 in the Holston River system.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	119.8	100%
$7Q_{10}$	29.2	24.36%
$1Q_{30}$	24.9	20.80%
Q_{95}	35.7	29.80%
Q_{50}	92.6	77.36%
MBF_{est}	106.0	88.54%

The four USGS gaging stations describe flow conditions in 1211.7 square miles of the 1422.04 square mile drainage basin that is included in the 1322.04 square mile Holston planning area. Therefore, the ungaged area added to the gages is about 210 square miles, 17.44% of the gaged area.

Table 4.211: Supply estimates for the Holston planning area.

Flow	Estimated flow (MGD)	%Q_{AM}
Q_{AM}	**1230.5**	100%
$7Q_{10}$	**151.9**	12.34%
$1Q_{30}$	**99.2**	8.06%
Q_{95}	**219.0**	17.80%
Q_{50}	**765.9**	62.24%
MBF_{est}	**843.1**	68.51%

Despite a small portion of the South Fork drainage area being inside Tennessee, the flows are not adjusted for the consumption within that area. The Tennessee portion of the drainage area is only about 100 square miles (7.02% of the entire drainage area) and is considered negligible. The supply estimate does not include the average withdrawal of 12.5 MGD from 14 springs, 1 mine, and reservoirs in 1982.[274] In 1995 the USGS reported that 1.75 MGD of groundwater was utilized in the Holston planning area.

4.5.25.3 The Demand Condition

In 1995 in USGS demand cataloging units 06010101 and 06010102, an estimated 16.94 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Holston planning area (see Appendix J). Based upon the estimated population of 113,400 people, the 1995 total per capita daily offstream demand was 149.38 gpcd (16.94 MGD/113,400 people). The total offstream per capita freshwater estimate includes 3.03 MGD of industrial withdrawals (17.89% of the total offstream demand). Total consumption was estimated in 1995 to be 10.21% of the total offstream withdrawal (1.73 MGD). Table 4.212 indicates offstream demand assuming the total per

[274] Virginia State Water Control Board. "Tennessee Basin Water Supply Plan." Virginia State Water Control Board Planning Bulletin No. 341, p. II-12.

capita daily offstream withdrawal and the percentage of that withdrawal consumed will remain constant through 2025.

Table 4.212: Total daily offstream demand for the Holston planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	16.89	1.86
2000	17.34	1.91
2005	18.15	2.00
2015	19.63	2.16
2025	20.97	2.31

Table 4.213 indicates the total daily demand if an instream demand equivalent to $7Q_{10}$ is required as part of the total daily demand (see Appendix K).

Table 4.213: Total demand in the Holston planning area.

YEAR	Total Demand (MGD)
1998	168.79
2000	169.24
2005	170.05
2015	171.53
2025	172.87

4.5.25.4 Water Supply Availability in the Holston Planning Area

Upon comparing the projected total natural flow availability (Table 4.211) to the projected total daily offstream demand (Table 4.212), the following surpluses result:

Table 4.214: Offstream demand water supply availability in the Holston planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1214	1213	1212	1211	1210
$7Q_{10}$	135	135	134	132	131
$1Q_{30}$	82	82	81	80	78
Q_{95}	202	202	201	199	198
$10\%Q_{AM}$	106	106	105	103	102
$20\%Q_{AM}$	229	229	228	226	225

According to the results of the preceding table, it can be concluded that no water supply shortages are anticipated for the Holston planning area at the partial-river basin scale through 2025. The surpluses can also be expressed in gpcd available for development based on population projections.

Table 4.215: Offstream demand water supply availability in the Holston planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	10,731	10,450	9979	9215	8615
$7Q_{10}$	1194	1159	1101	1007	932
$1Q_{30}$	728	705	667	606	557
Q_{95}	1787	1737	1653	1517	1410
$10\%Q_{AM}$	939	911	863	787	727
$20\%Q_{AM}$	2027	1970	1876	1724	1604

The projected offstream demands are not expected to exceed 2% in the planning period.

If an instream demand requirement equivalent to $7Q_{10}$ was included as a recognized portion of the daily demand, the Holston planning area might face the of surpluses and deficits in Table 4.216.

Table 4.216: Total demand water supply availability in the Holston planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1062	1061	1060	1059	1058
$7Q_{10}$	-17	-17	-18	-20	-21
$1Q_{30}$	-70	-70	-71	-72	-74
Q_{95}	50	50	49	47	46

The large regional assessment of water supply availability does not include the potential conflicts that may arise between individual users during localized low flow conditions.

4.5.26 The Clinch/Powell Planning Area

4.5.26.1 The Clinch/Powell Planning Area and Its Population

The Clinch/Powell planning area (see Plate XXVI) includes hydrologic units P01-P14 (1148.24 mi^2, see Plate 43) of the Clinch River basin and hydrologic units P15-P24 (662.57 mi^2, see Plate 44) of the Powell River basin for a total drainage area of 1810.81 square miles of the Virginia portion of the Tennessee River basin headwaters. Cataloging units 06010205 and 06040204 are the USGS designations for the Clinch and Powell River basins, respectively. Tributaries to the Clinch River include the Little and Guest Rivers and Indian, Big Cedar, Lick, and Stony Creeks (see Appendix A). Powell River tributaries include the Blackwater River, Roaring Fork, and Camp, Hardy, and Wallen Creeks (see Appendix A). The planning area includes portions of the City of Norton and Dickenson, Russell, Tazewell, Lee, Scott, and Wise Counties (see Appendix G.2). Based on 1998 Census Bureau county and city population estimates (see Appendix F), the total population in the planning area in 1998 was estimated to be 121,676 people. Assuming the population to be homogeneously distributed over the 1810.81 square mile area, the population density was about 68 people per square mile in 1998. Population projections were developed for the planning area from Census Bureau projections for Virginia through 2025.

Table 4.217: Clinch/Powell planning area projected population (see Appendix H).

YEAR	Projected Population
2000	124,835
2005	130,669
2015	141,321
2025	151,044

4.5.26.2 The Supply Condition

Streamflow availability was developed for the Clinch/Powell planning area as a function of USGS gage 03527000 on the Clinch River and USGS gage 03532000 on the Powell River. The average cfs/mi^2 yield for each flow condition was developed for each basin, applied to the entire land area of each basin to express total flow under each condition and the two estimates were summed to estimate the total flow availability in the planning area (see Appendix D.26; for the period of record used to develop each flow condition see Appendix C).

Gage 03527000 at Speers Ferry, Virginia on the Clinch River measures and records flow from 1126 square miles of the upstream watershed. Table 4.218 indicates the amount of flow that can be expected to be in the stream at the downstream point in the planning area (an addition of 22.24 mi^2 to the gaged area (1.98% of the gaged area)).

Table 4.218: Flow estimates for the Virginia portion of the Clinch River.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**1048.5**	100%
$7Q_{10}$	**65.9**	6.29%
$1Q_{30}$	**53.0**	5.06%
Q_{95}	**99.5**	9.49%
Q_{50}	**569.4**	54.31%
MBF_{est}	**600.4**	57.26%

Gage 03532000 just over the border in Tennessee on the Powell River measures and records flow from 685 square mile of the upstream watershed. Table 4.219 indicates the amount of water that can be expected to be in the stream at the downstream point in the planning area (because the gage data was moved upstream, no land area was added to the gage).

Table 4.219: Flow estimates for the Virginia portion of the Powell River.

Flow	Adjusted flow (MGD)	$\%Q_{AM}$
Q_{AM}	**713.9**	100%
$7Q_{10}$	**50.5**	7.07%
$1Q_{30}$	**42.7**	5.98%
Q_{90}	**86.3**	12.08%
Q_{50}	**368.8**	51.66%
Q_{10}	**1606.5**	225.04%

In combination, the estimates of flow from each river basin can be used to estimate a total flow leaving the 1810.81 square mile planning area. Upstream consumption was not included in the analysis because the Clinch/Powell planning area is a headwater planning area. Only 22.24 square miles of the total area is ungaged, 1.24% of the gaged drainage area.

Table 4.220: Supply estimates for the Clinch/Powell planning area.

Flow	Estimated flow (MGD)	$\%Q_{AM}$
Q_{AM}	**1762.4**	100%
$7Q_{10}$	**116.4**	6.60%
$1Q_{30}$	**95.7**	5.43%
Q_{50}	**938.2**	53.23%

Yield from hydrologic units P16 (the Blackwater River, 26.96 mi^2 of Virginia drainage area) and P24 (Indian Creek, 54.87 mi^2 of Virginia drainage area) are not included in the supply estimates. The supply estimates also do not include the average withdrawal of 9.5 MGD from 39 wells, 18 springs, artificial storage sites, and 4 mines in 1982.[275] In 1995 the USGS reported that 5.28 MGD of groundwater was utilized in the Clinch/Powell planning area.

[275] Id., p. II-62, II-63 and II-150.

4.5.26.3 The Demand Condition

In 1995 in USGS demand cataloging units 06010204 and 06010205, an estimated 29.74 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn form the Clinch/Powell planning area (see Appendix A). Based upon the 1995 estimate of 46,280 people, the 1995 total daily per capita offstream demand was 642.61 gpcd (29.74 MGD/46,280 people). The total offstream per capita freshwater estimate includes .53 MGD of industrial withdrawals (1.78% of the total offstream demand). The total amount of water consumed in 1995 was 11 MGD (36.99% of the total daily offstream withdrawal). Table 4.221 indicates the offstream demand assuming the total per capita daily offstream withdrawal and the percentage of that withdrawal consumed will remain constant through 2025.

Table 4.221: Total daily offstream demand for the Clinch/Powell planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	78.21	28.93
2000	80.20	29.67
2005	83.99	31.07
2015	90.80	33.59
2025	97.3	35.89

If an instream demand equivalent to the total estimated $7Q_{10}$ flow condition of 116.4 MGD is required to remain instream, the total daily demand could be to Table 4.222.

Table 4.222: Total demand in the Clinch/Powell planning area.

YEAR	Total Demand (MGD)
1998	194.61
2000	196.60
2005	200.39
2015	207.20
2025	213.43

An important distinction about the Clinch/Powell demand conditions is that the 1995 thermoelectric demand was consumptive; and, as a result, it was included as part of the total daily offstream demand. The inclusion of the large withdrawal and consumption in the total daily offstream consumptive demand leads to a large per capita use in 1995, and, therefore, it leads to large projected demand values over the planning period. Thermoelectric demands for offstream waters will not necessarily increase proportionally to population, but they are assumed to do so in this case.

4.5.26.4 Water Supply Availability in the Clinch/Powell Planning Area

Upon comparing the projected total natural flow availability (Table 4.220) to the projected total daily offstream demand (Table 4.221), the following water balance conditions result:

Table 4.223: Offstream demand water supply availability in the Clinch/Powell planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1684	1682	1678	1672	1665
$7Q_{10}$	38	36	32	26	19
$1Q_{30}$	17	16	12	5	-1.3
$10\%Q_{AM}$	98	96	92	85	79
$20\%Q_{AM}$	274	272	268	262	255

The supply conditions can also be expressed as a function of the projected population in order to identify how much water will be available to be or needs to be developed on a per capita basis.

Table 4.224: Offstream demand water supply availability in the Clinch Powell planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	13,839	13,479	12,842	11,830	11,029
$7Q_{10}$	314	290	248	181	128
$1Q_{30}$	144	124	90	35	-9
$10\%Q_{AM}$	806	770	706	605	525
$20\%Q_{AM}$	2254	2182	2054	1852	1692

According to the comparison in the preceding table, it can be concluded that water supply shortages are anticipated for the Clinch/Powell planning area in 2025 under $1Q_{30}$ flow conditions. Projected offstream demands are not expected to exceed 6% of the annual mean flow in the planning period.

Although the preceding water balance conditions appear predominantly favorable over the planning period, water balance conditions might change if a flow equivalent to the total estimated $7Q_{10}$ flow was required to pass the outlet of the planning area.

Table 4.225: Total demand water supply availability in the Clinch/Powell planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	1568	1566	1562	1555	1549
$7Q_{10}$	-78	-80	-84	-91	-97
$1Q_{30}$	-99	-101	-105	-112	-118

This water supply availability assessment of the Clinch and Powell River basins is a large regional analysis at the partial-river basin scale that does not include the potential for water supply conflicts between individual users during periods of localized low flow.

4.5.27 The Big Sandy Planning Area

4.5.27.1 The Big Sandy Planning Area and Its Population

The Big Sandy planning area (see Plate XXVII) includes hydrologic units Q01-Q14 of the headwaters of the Big Sandy River Basin (see Plate 45) which drains 998.81 square miles of the Commonwealth. The USGS has divided the Big Sandy basin into cataloging unit 05070201 that drains the Tug Fork portion of the basin (hydrologic units Q01-Q03) and cataloging unit 05070202 that drains the Levisa Fork (hydrologic units Q04-Q08) and Russell Fork (hydrologic units Q09-Q14) within the planning area. Tributaries to the Tug Fork include Dry and Jacobs Forks and Horsepen and Knox Creeks; tributaries to the Levisa Fork include Garden, Dismal, Prater, Slate and Bull Creeks; and, tributaries to the Russell Fork include the Pound, McClure and Cranesnest Rivers and Lick, Fryingpan and Caney Creeks (see Appendix A). Population in the planning area is contributed by land areas in Buchanan, Dickenson, Tazewell and Wise Counties (see Appendix G.2). Based on 1998 Census Bureau population estimates in Virginia cities and counties (see Appendix F), the 1998 population within the planning area was approximately 61,182 people, an overall per capita density of about 62 people per square mile. Population projections were developed for the planning area based on anticipated growth indicated by Census Bureau projections in Virginia through 2025.

Table 4.226: Big Sandy planning area projected population (see Appendix H).

YEAR	Projected Population
2000	62,770
2005	65,704
2015	71,059
2025	75,949

4.5.27.2 The Supply Condition

Streamflow availability was developed for the Big Sandy planning area as a function of data measurements at USGS gage 03209200 on the Russell Fork at Bartlick, Virginia and USGS gage 03207500 on the Levisa Fork near Grundy, Virginia. The average cfs/mi^2 yield for each flow condition was developed for each minor basin, applied to the entire land area of each basin to express flow conditions at the downstream point and the two estimates were summed to estimate the total flow availability in the planning area (see Appendix D.27; for the period of record used to develop each flow characteristic see Appendix C).

Gage 03209200 at Bartlick, Virginia on the Russell Fork measures and records flow from 526 square miles of the upstream watershed. Table 4.227 indicates the amount of flow that can be expected to be in the stream before flowing into Kentucky (an addition of 20.69 mi^2 of ungaged area to the gaged area (3.93% of the gaged area)):

Table 4.227: Flow estimates for the Virginia portion of the Russell Fork.

Flow	Adjusted flow (MGD)	%Q_{AM}
Q_{AM}	**458.8**	100%
$7Q_{10}$	**7.7**	1.68%
$1Q_{30}$	**2.8**	0.62%

Gage 03207500 near Grundy, Virginia on the Levisa Fork measures and records flow from 235 square miles of the upstream watershed. The lack of gages on the Tug Fork required the gage data from the Levisa Fork gage to serve as an estimate of the cfs/mi^2 yield in hydrologic units Q01-Q03. The result is an addition of 217.11 square miles of ungaged land area to the 235 square mile gaged area (an addition of nearly 92.39%). However, the lack of gage data and the similarity in geology and hydrology may justify the application of Levisa Fork data to the Tug Fork drainage area.

Table 4.228: Flow estimates for the Virginia portion of the Levisa and Tug Forks.

Flow	Adjusted flow	%Q_{AM}
Q_{AM}	**355.6**	100%
$7Q_{10}$	**1.6**	0.45%
$1Q_{30}$	**0.4**	0.12%

Once the two estimates were added together, each of the three estimated flow conditions could be expressed as a function of the total 998.81 square mile watershed. Upstream consumption was not included in the analysis, despite a portion of the Tug Fork drainage lying in West Virginia, because the Big Sandy planning area is a headwater planning area. Nearly 240 square miles of ungaged area was added to the 761 square mile gaged area, 31.25% of the gaged land area.

Table 4.229: Supply estimates for the Big Sandy planning area.

Flow	Estimated flow (MGD)	%Q_{AM}
Q_{AM}	**814.4**	100%
$7Q_{10}$	**9.3**	1.14%
$1Q_{30}$	**3.2**	0.39%

The preceding estimate of supply does not include average daily withdrawals of 3.2 MGD from 26 wells, 1 spring, artificial storage sites, and 2 mines in 1982.[276] The natural flow availability analysis also does not consider the potential to increase water supply designations from the US Army Corps of Engineers facilities on the Pound River, namely the John Flannagan and North Fork of the Pound River Reservoirs. In 1995 the USGS reported that 2.74 MGD of groundwater was utilized in the Big Sandy planning area.

[276] Virginia State Water Control Board. "Big Sandy Water Supply Plan." Virginia State Water Control Board Planning Bulletin No. 346, March 1988, p. II-16 - II-18.

4.5.27.3 The Demand Condition

In 1995 in USGS demand cataloging units 05070101 and 05070102, an estimated 71.75 MGD of partially consumed water (i.e., total daily offstream demand) was withdrawn from the Big Sandy planning area (see Appendix J). Based on the 1995 population estimate of 62,220 people, the 1995 total daily per capita offstream demand was 1153.17 gpcd (71.75 MGD/62,220 people). Of the 71.75 MGD withdrawn, 62.17 MGD (86.65% of the total offstream demand) was withdrawn for industrial purposes; the following projections assume that portion of the demand will grow with population, which is not necessarily the case. Of the total 71.75 MGD withdrawn in 1995, 8.30 MGD (11.57% of the total daily offstream withdrawal) was estimated to have been consumed. Assuming the total per capita daily offstream withdrawal and the percentage of that withdrawal consumed will remain constant over the planning period, the projected demands through 2025 are indicated in Table 4.230 (see Appendix K).

Table 4.230: Total daily offstream demand for the Big Sandy planning area.

YEAR	Daily Consumptive Offstream Demand (MGD)	Consumed (MGD)
1998	70.57	8.17
2000	72.42	8.38
2005	75.76	8.77
2015	81.99	9.49
2025	87.53	10.13

If an instream demand equivalent to $7Q_{10}$ is required to remain instream, the total daily demand would be as indicated in Table 4.231 (see Appendix K).

Table 4.231: Total demand in the Big Sandy planning area.

YEAR	Total Demand (MGD)
1998	79.87
2000	81.72
2005	85.06
2015	91.29
2025	96.83

Again, it is important to note that nearly 87% of the total daily offstream demand in 1995 was for industrial applications. The projected demand estimates are a result of the assumption that all consumptive withdrawals will increase with an increase in population. The result of this growth assumption may be an overestimate of future demand, because industry may not increase with population.

4.5.27.4 Water Supply Availability in the Big Sandy Planning Area

Upon comparing the projected total natural flow availability (Table 4.229) to the projected total daily offstream demand (Table 4.230), the following water balance conditions result:

Table 4.232: Offstream demand water supply availability in the Big Sandy planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	744	742	739	732	727
$7Q_{10}$	-61	-63	-66	-73	-78
$1Q_{30}$	-67	-69	-73	-79	-84
$10\%Q_{AM}$	11	9	6	-1	-6
$20\%Q_{AM}$	92	90	87	81	75

The supply availability conditions can also be expressed as a function of the projected population in order to identify the amount of water that must be developed per person under each projected condition.

Table 4.233: Offstream demand water supply availability in the Big Sandy planning area (all values expressed in gpcd).

Flow	1998	2000	2005	2015	2025
Q_{AM}	12,154	11,815	11,243	10,301	9577
$7Q_{10}$	-1001	-1005	-1012	-1022	-1031
$1Q_{30}$	-1101	-1102	-1104	-1108	-1111
$10\%Q_{AM}$	178	144	86	-8	-80
$20\%Q_{AM}$	1508	1440	1326	1138	993

According to Table 4.232 and 4.233, it can be concluded that water supply deficits may occur in the Big Sandy planning area under $7Q_{10}$ and $1Q_{30}$ natural flow conditions throughout the planning period. Projected demands may approach 11% of the annual mean flow in 2025.

Water supply conditions may be significantly affected if a flow equivalent to $7Q_{10}$ is required to pass the downstream point of the watershed.

Table 4.234: Total demand water supply availability in the Big Sandy planning area (all values expressed in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	735	733	729	723	718
$7Q_{10}$	-71	-72	-76	-82	-88
$1Q_{30}$	-77	-79	-82	-88	-94

The preceding analysis of water supply availability in the Big Sandy planning area is at the partial-river basin scale, and therefore, it does not include the analysis of individual water developments in the region. Individual systems may have resources such as groundwater withdrawals and artificial surface water reservoirs that could affect the preliminary analysis if pursued at a smaller, more in-depth scale. For instance, the potential availability of water from the John Flannagan and North Fork of the Pound River Reservoirs have not been included. As a result, a combined water supply storage allocation of 139.202 million gallons of water and low flow augmentation allocation have not been included in the water balance descriptions of Tables 4.232 and 4.233.

4.6 Water Supply Availability in the Commonwealth of Virginia

Water balance conditions in the twenty-seven planning areas indicate that projected surface water streamflow should be able to sustain projected demands under all flow conditions in thirteen of those planning areas. The water balance conditions in the remaining fourteen planning areas suggest a need for additional water supply development beyond available streamflows (again, existing storage has not been taken into account). Those planning areas that indicate potential water supply shortages are recommended for further study on a smaller scale that includes the analysis of individual water supply systems within the planning area. The 1998 water supply availability condition for all the planning areas is shown in Table 4.235. The 2025 water supply availability condition for all the planning areas is shown in Table 4.236. The planning areas that indicate deficit in 1998 also indicate deficit in 2025 under at least one flow condition.

Table 4.235: Comparison of offstream demand and $1Q_{30}$ and $7Q_{10}$ as an expression of water supply availability in 1998.

Planning Area	$1Q_{30}$	$7Q_{10}$	Off. Demand	$1Q_{30}$ WSA	$7Q_{10}$ WSA
1	**3.2 MGD**	**12.8 MGD**	**194 MGD**	**- 61 MGD***	**- 51 MGD***
2	**1.4 MGD**	**5.5 MGD**	**20 MGD**	**- 19 MGD**	**- 15 MGD**
3	89 MGD	108 MGD	45 MGD	+44 MGD	+63 MGD
4	148 MGD	230 MGD	42 MGD	+106 MGD	+188 MGD
5	**8 MGD**	**28 MGD**	**14 MGD**	**- 6 MGD**	**+14 MGD**
6	**14 MGD**	**50 MGD**	**18 MGD**	**- 4 MGD**	**+32 MGD**
7	**15 MGD**	**33 MGD**	**37 MGD**	**- 23 MGD**	**- 4 MGD**
8	**8 MGD**	**17 MGD**	**34 MGD**	**- 26 MGD**	**- 17 MGD**
9	180 MGD	233 MGD	118 MGD	+62 MGD	+115 MGD
10	232 MGD	364 MGD	57 MGD	+175 MGD	+307 MGD
11	230 MGD	380 MGD	53 MGD	+177 MGD	+327 MGD
12	**25 MGD**	**45 MGD**	**74 MGD**	**- 49 MGD**	**- 29 MGD**
13	**198 MGD**	**418 MGD**	**476 MGD**	**- 278 MGD**	**- 58 MGD**
14	**------**	**4 MGD**	**47 MGD**	**------**	**- 43 MGD**
15	------	------	------	------	------
16	**8 MGD**	**22 MGD**	**9 MGD**	**- 1 MGD**	**+13 MGD**
17	**13 MGD**	**23 MGD**	**36 MGD**	**- 24 MGD**	**- 13 MGD**
18	**1 MGD**	**3 MGD**	**92 MGD**	**- 91 MGD**	**- 89 MGD**
19	**39 MGD**	**210 MGD**	**58 MGD**	**- 19 MGD**	**+152 MGD**
20	184 MGD	629 MGD	18 MGD	+166 MGD	+611 MGD
21	83 MGD	197 MGD	44 MGD	+39 MGD	+153 MGD
22	47 MGD	256 MGD	25 MGD	+22 MGD	+231 MGD
23	322 MGD	461 MGD	20 MGD	+302 MGD	+441 MGD
24	562 MGD	727 MGD	31 MGD	+531 MGD	+696 MGD
25	99 MGD	152 MGD	17 MGD	+82 MGD	+135 MGD
26	96 MGD	116 MGD	78 MGD	+18 MGD	+38 MGD
27	**3 MGD**	**9 MGD**	**71 MGD**	**- 68 MGD**	**- 62 MGD**

* includes 130 MGD of artificial storage in the Upper Potomac planning area.

Table 4.236: Comparison of offstream demand and $1Q_{30}$ and $7Q_{10}$ as an expression of water supply availability in 2025.

Planning Area	$1Q_{30}$	$7Q_{10}$	Off. Demand	$1Q_{30}$ WSA	$7Q_{10}$ WSA
1	**3 MGD**	**13 MGD**	**241 MGD**	**- 108 MGD***	**- 98 MGD***
2	**1 MGD**	**6 MGD**	**25 MGD**	**- 24 MGD**	**- 19 MGD**
3	89 MGD	108 MGD	56 MGD	+33 MGD	+52 MGD
4	146 MGD	228 MGD	52 MGD	+94 MGD	+176 MGD
5	**8 MGD**	**28 MGD**	**18 MGD**	**- 10 MGD**	**+10 MGD**
6	**14 MGD**	**50 MGD**	**23 MGD**	**- 10 MGD**	**+27 MGD**
7	**15 MGD**	**33 MGD**	**47 MGD**	**- 32 MGD**	**- 14 MGD**
8	**8 MGD**	**17 MGD**	**42 MGD**	**- 34 MGD**	**- 25 MGD**
9	180 MGD	233 MGD	147 MGD	+33 MGD	+86 MGD
10	229 MGD	360 MGD	71 MGD	+158 MGD	+289 MGD
11	224 MGD	374 MGD	66 MGD	+158 MGD	+308 MGD
12	**25 MGD**	**45 MGD**	**92 MGD**	**- 67 MGD**	**- 47 MGD**
13	**189 MGD**	**409 MGD**	**591 MGD**	**- 402 MGD**	**- 182 MGD**
14	**------**	**4 MGD**	**59 MGD**	**------**	**- 55 MGD**
15	------	------	------	------	------
16	**8 MGD**	**22 MGD**	**11 MGD**	**- 3 MGD**	**+11 MGD**
17	**13 MGD**	**23 MGD**	**45 MGD**	**- 32 MGD**	**- 22 MGD**
18	**1 MGD**	**3 MGD**	**114 MGD**	**- 114 MGD**	**- 112 MGD**
19	**39 MGD**	**210 MGD**	**72 MGD**	**- 33 MGD**	**+138 MGD**
20	167 MGD	612 MGD	23 MGD	+144 MGD	+589 MGD
21	83 MGD	197 MGD	54 MGD	+29 MGD	+143 MGD
22	35 MGD	243 MGD	31 MGD	+4 MGD	+212 MGD
23	320 MGD	459 MGD	25 MGD	+295 MGD	+434 MGD
24	560 MGD	724 MGD	38 MGD	+522 MGD	+686 MGD
25	99 MGD	152 MGD	21 MGD	+78 MGD	+131 MGD
26	96 MGD	116 MGD	97 MGD	- 1 MGD	+19 MGD
27	**3 MGD**	**9 MGD**	**88 MGD**	**-85 MGD**	**- 79 MGD**

* includes 130 MGD of artificial storage in the Upper Potomac planning area.

All planning areas in Virginia are expected to incur a water supply deficit if a flow equivalent to $7Q_{10}$ is required as the instream portion of the total demand under $7Q_{10}$ and $1Q_{30}$ flow conditions. The instream demand of $7Q_{10}$ is hypothetical and presented only as an indication of the effect of a statewide instream demand policy.

4.6.1 Planning Areas without Anticipated Water Supply Availability Deficits

Streamflow availability projections are expected to meet projected demands in the following planning areas of Virginia: the Upper Shenandoah/Laurel, the Lower Shenandoah/Opequon, the Upper James/Maury, the Upper Middle James/Rivanna, the Lower Middle James, the Eastern Shore, the Lower Roanoke, the Martinsville, the Danville, the Upper New, the Lower New, the Holston, and the Clinch/Powell planning areas. Assuming the projected water balance conditions are conservative in nature, the surpluses of water supply may be even greater than those shown in each planning area. Although quantity may be in surplus, the quality of available water was not assessed in the procedure and could reduce the availability of some of the waters included in the supply estimate.

4.6.2 Planning Areas Indicating Potential Water Supply Availability Deficits

Remembering that short-term groundwater availability and artificial surface water storage have not been included in supply availability estimates, fourteen planning areas in Virginia are expected to experience streamflow availability deficits before 2025 under at least one streamflow condition and are recommended for further study. Streamflow availability in the Upper Potomac planning area is not expected to meet projected demands for $7Q_{10}$, $1Q_{30}$ and Q_{95} estimated streamflow conditions and exceeds 10 and 20 percent of the estimated annual mean flow in 1998, 2000, 2005, 2015 and 2025. Demands in the Lower Potomac planning area are expected to exceed streamflow availability for $7Q_{10}$, $1Q_{30}$ and Q_{95} estimated flow conditions in each year of the analysis. Demands in the Upper and Lower Rappahannock planning areas are expected to exceed streamflow availability for the estimated $1Q_{30}$ flow condition in each year of the planning period. Demands in the Pamunkey, Mattaponi, Appomattox, Lower James and Nottoway planning areas have been projected to exceed streamflow estimates for $7Q_{10}$ and $1Q_{30}$ flow conditions throughout the planning period. Streamflow availability projections in the Mainland Chesapeake Bay/York planning area will not satisfy projected demands for the estimated $7Q_{10}$ flow condition throughout the planning period and for estimated Q_{90} flow conditions in 2005, 2015 and 2025. Demands in the Meherrin planning area are expected to exceed streamflow availability for the estimated $7Q_{10}$ flow condition in each year of the analysis and the estimated Q_{95} flow condition in 2005, 2015 and 2025. Streamflow availability in the Blackwater/Southeast Coastal planning area is not expected to meet projected demands for the estimated $7Q_{10}$, $1Q_{30}$ and Q_{90} estimated flow conditions throughout the planning period; projected demands are expected to exceed 10 percent of the estimated annual mean flow condition in 2000, 2005, 2015 and 2025. Demand conditions are expected to exceed streamflow availability in the Upper Roanoke planning area for estimated $1Q_{30}$ and Q_{95} flow conditions in each year of the planning period. And, finally, projected demands are expected to exceed streamflow availability estimates in the Big Sandy planning area for $7Q_{10}$ and $1Q_{30}$ flow conditions throughout the planning period and to exceed 10 percent of the estimated annual mean flow condition in 2015 and 2025.

4.6.3 Comprehensive Assessment of Water Supply Availability in the Commonwealth

As a final step in the procedure for preliminary assessment, it seems appropriate to consider the supply conditions, demand conditions and water balance conditions across the Commonwealth as a whole. Summing the adjusted streamflow estimates in each of the planning areas that exit the boundaries of the state, the streamflow availability conditions are indicated in Table 4.237 (does not include the Eastern Shore).

Table 4.237: Total flow estimates for waters exiting the Commonwealth of Virginia.

Flow	Total flow (MGD)	% Q_{AM}
Q_{AM}	**29132.8**	100.00%
$7Q_{10}$	**2772.7**	9.52%
$1Q_{30}$	**1561.2**	5.36%
$10\%Q_{AM}$	**2913.3**	10.00%
$20\%Q_{AM}$	**5826.6**	20.00%

The statewide total projected consumption is indicated in Table 4.238 (includes Eastern Shore consumption).

Table 4.238: Total projected consumption in the Commonwealth of Virginia.

YEAR	CONSUMED (MGD)
1998	244.64
2000	250.95
2005	262.71
2015	284.10
2025	303.64

Adjusting the streamflow availability for the total amount of expected consumption, the projected streamflow estimates are shown in Table 4.239.

Table 4.239: Supply projections for the Commonwealth of Virginia (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	28,888.2	28,881.8	28,870.1	28,848.7	28,829.2
$7Q_{10}$	2528.1	2521.7	2510.0	2488.6	2469.1
$1Q_{30}$	1316.6	1310.2	1298.5	1277.1	1257.6
$10\%Q_{AM}$	2668.6	2662.3	2650.6	2629.2	2609.6
$20\%Q_{AM}$	5581.9	5575.6	5563.8	5542.5	5522.9

Upon summing the total daily offstream demand for each planning area, the total daily statewide offstream demands are (includes demands for the Eastern Shore) shown in Table 4.240.

Table 4.240: Projected total daily offstream demand for the Commonwealth of Virginia.

YEAR	OFF. DEMAND (MGD)
1998	1747.90
2000	1793.13
2005	1877.04
2015	2029.94
2025	2169.54

Comparing the supply and demand projections, water balance conditions in the Commonwealth through 2025 are shown in Table 4.241.

Table 4.241: Water supply availability in the Commonwealth of Virginia (all values in MGD).

Flow	1998	2000	2005	2015	2025
Q_{AM}	27,140	27,134	27,122	27,101	27,081
$7Q_{10}$	735	729	717	695	676
$1Q_{30}$	-560	-567	-579	-600	-619
$10\%Q_{AM}$	639	632	621	599	580
$20\%Q_{AM}$	3412	3406	3394	3373	3353

Recalling the limitations of the analysis (see *4.4*), projected streamflow availability in the Commonwealth as a whole should meet projected demands through 2025 except under the estimated $1Q_{30}$ flow condition.

4.7 Limitations of the Procedure for Preliminary Assessment of Water Supply Availability in Virginia

The assumptions made in applying the procedure for preliminary assessment of water supply availability to Virginia limit the validity of the conclusions. The intention of applying the preliminary assessment to Virginia is to identify those areas in the Commonwealth that could potentially face water supply shortages through 2025. Within each planning area, the general procedure was applied to define the boundaries of the planning area, estimate and project population within the planning area, estimate and project streamflow availability yield by the hydrology of the planning area, estimate and project demand, and compare the estimates and projections of supply and demand. The accuracy of the results is dependent on the validity of the assumptions contained in the general procedure.

For instance, the general procedure may break down in the Coastal Plain of Virginia, and consequently, the limitations of the analysis may be more evident in this physiographic province. The hydrologically defined cataloging unit was used as the starting place for every planning area boundary, and the Coastal Plain was not an exception. In the coastal Plain of Virginia, wide, tidally influenced water bodies define three peninsulas: (1) the Northern Neck peninsula between the Potomac and Rappahannock estuaries, (2) the Middle Peninsula between the Rappahannock and York estuaries, and (3) the York-James Peninsula between the York and James estuaries. Because the procedure for preliminary assessment of water supply availability was developed to be consistently applied to the entire state, the peninsulas were not used as the planning area boundaries. However, future analyses of the Commonwealth might benefit from the use of boundaries other than demand cataloging unit boundaries (see 4.7.2 for a further discussion of limitations of the analysis in the Coastal Plain) to perform an analysis similar to that done in the Eastern Shore planning area.

4.7.1 Limitations of the Planning Area Boundary Designations

Each planning area was chosen based on naturally occurring hydrologic boundaries in order to limit the size of each planning area to a reasonable size and enable the supply availability analysis along one or more major drainage basins. The planning areas were determined based on two key components of the nature of the local drainage basin as identified in Section 4.2.1: (1) the measured distance from the upstream limit of the boundary to the outlet of the drainage are was limited to 75 miles and (2) the location of stream gages along the mainstream. Another important element of the decision for planning area boundaries was the USGS cataloging unit boundaries. The cataloging unit boundaries were also based on hydrologic boundaries within Virginia, and the 1995 demand estimates were made for users within these boundaries. Changing the planning area boundaries from the cataloging unit boundaries was avoided as much as possible; however, the 75 mile distance restriction and the stream gage locations were given precedence in the decision making process.

The measured distance from headwater boundaries to the identified outlet point was restricted to 75 miles because in theory the analysis of the streamflow availability at the downstream point could provide water that could be transferred to meet demand in the upstream headwater areas. The 75 mile distance was chosen because the Lake Gaston pipeline from Pea Hill Creek in Mecklenburg County to Norfolk's water treatment plant is about 76 miles. Supply analysis at the downstream point of a 75-mile measured distance, from upstream to downstream, implies that a regional water withdrawal system could be built at the downstream point and distributed to users 75 miles upstream. Theoretically, based on the distance of the Lake Gaston transfer, such a feat could be accomplished in Virginia, but the economic restrictions are considerable. However, in order to define the boundaries of the planning area, this was the applied assumption and it limits the analysis because the implementation may not be feasible.

Generally, planning area boundaries were drawn downstream from USGS gage locations with records kept over the entire period of record. In some cases, the period of record was truncated to account for flow regulation induced by upstream impoundment and reservoir developments. In most cases, upstream flow conditions were translated to the downstream outlet of the drainage area. However, in a few instances, gage data from downstream was translated to upstream locations, particularly in those streams which flow south into North Carolina and Tennessee.

Because the 75 mile measured distance and gage location were given priority in the decision making process, planning area boundaries did differ from USGS cataloging unit boundaries. Upon occurrence, the 1995 demand estimates needed to be adjusted to account for the change in the cataloging unit boundary and were distributed according to the land area of the cataloging unit contained within the affected planning areas. Although the specific procedure applied to demand estimates in planning area that truncated cataloging unit boundaries will be discussed in *4.4.3*, the change in the planning area boundaries was the impetus for the distribution of the demand estimates. The result is an analysis that does not account for the heterogeneities associated with demand and population centers.

4.7.2 Limitations of the Supply Estimates and Projections

The control of water supply estimate procedure is that streamflow availability represents the total available supply in a planning area. By assuming streamflow conditions indicate supply availability, groundwater mining, groundwater recharge, and water stored in single or multiple use reservoirs are eliminated from supply availability. The result of the streamflow condition as the sole indicator of water supply availability may be an underestimate of supply conditions and, as a result, an overestimate of the potential water supply deficit.

Also associated with the streamflow availability estimate is that supply conditions are estimated by the streamflows under average conditions. Because the streamflow conditions have been estimated from a specified period of record, fluctuation of the streamflow from mean values is not accounted for. For example, in a "dry" year streamflow availability may be well below the value developed from the period of record and in a "wet" year the availability may be significantly increased. The streamflow conditions presented are statistically derived expressions from continuously recorded streamflow measures. They do not represent the actual values instream at any given moment, but instead an amount that can be expected to be instream under each theoretical condition in the average year. The average conditions over an extended period also do not account the effect of withdrawals made from the stream that may have increased or decreased supply availability instantaneously. Withdrawals upstream from the gage will reduce the amount of water measured at the gage and immediate changes in the streamflow conditions will not be significantly reflected in long term average expressions.

The period of measured flows can also significantly affect the streamflow availability estimate and has not been taken into consideration in the preliminary assessment procedure. Although the periods of record at for each flow condition at each gage location have been identified, the length of the record period has not been considered in the analysis. Short periods of record may introduce error that is not present in longer record periods because of an inability to reflect stream conditions that have not occurred while the stream gage has been active. Longer periods of data measurement may represent flow conditions more accurately because years of more extreme high and low precipitation may be included in the estimate of average flow conditions.

Flow conditions also do not account for the different period of record used in developing the particular flow statistic. Flow conditions for $7Q_{10}$ were derived from Nelms, et al. and the VSWCB from records that were measured through 1984 and 1977, respectively (specific gages were also truncated at other times depending upon flow regulation by development projects and record availability). Flow conditions for $1Q_{30}$, also from VSWCB estimates, were also developed from records ending in 1977. Flow conditions for Q_{AM}, Q_{50}, Q_{90} and Q_{10} were taken from USGS records through 1998 (in most cases). The result is an array of flow conditions developed from varying periods of record; because the period of record is not uniform, and in some cases not current, streamflow availability estimates do not include all data available at all the gages through the present.

Another limitation of the supply availability estimate is that streamflows were estimated for an entire planning area despite portions of the planning area being ungaged. The average cfs/mi^2 yield at the gage was developed and applied to the ungaged portion of the planning area in order to estimate the streamflow availability in the entire planning area. The total streamflow availability is limited by the fact that the average land area streamflow yield may not apply to the ungaged land area due to changes in geohydrologic characteristics downstream. In many cases, the ungaged area was limited to less than 25% of the gaged area as recommended by Hayes (1991) (see *2.3.1.1*). However, in 12 planning areas, the ungaged land area exceeded 25% because of the lack of stream gages further downstream in the planning area. Those planning areas with estimates of streamflow where ungaged land area exceeds 25% have been identified and are subject to error in the streamflow estimates that may not be associated with the flow adjustment procedure for those planning areas with less than 25% ungaged land area.

For those planning areas where upstream consumption was not a consideration, streamflow availability was assumed to be average conditions measured over the period of record for each flow characteristic. As mentioned in the preceding paragraph, the average condition developed over the period of record does not account for fluctuations in precipitation from year to year. In planning areas where upstream consumption was accounted for, streamflow availability was assumed to be average conditions less the anticipated consumption projected to take place in upstream planning areas. The average condition assumption is again in effect, but the error contained within the estimate is compounded by the projection of the expected consumption. As will be discussed in more detail in the following section, consumption was projected as a function of the projected population and demand within each planning area. Therefore, the streamflow availability projections that account for consumption also include error introduced by the consumption projections.

Another limitation in the application of the preliminary water supply availability analysis is the assumption that groundwater discharges to the surface water bodies in each planning area. Although groundwater in mountainous and riverine terrain, such as the Valley and Ridge, Blue Ridge, and Piedmont Physiographic Provinces can generally be assumed to discharge to surface water, groundwater in coastal terrain, such as the Coastal Plain Physiographic Province, cannot generally be assumed to discharge to groundwater (see *2.3*). However, the assessment of water supply availability in Virginia has assumed that groundwater discharges to the stream in all Physiographic Provinces. The result is that 11 of the 14 planning areas that have indicated a deficit under at least one flow condition in 2025 have at least a portion of the planning area in the Coastal Plain. The Coastal Plain planing areas also represent 3 of the 5 planning areas that satisfied over 50% of the 1995 total offstream demand with self-supplied groundwater. By assuming supply estimates include long-term groundwater discharge in all planning areas and by not including separate estimates of short-term groundwater supply, projected deficits in the Coastal Plain planning areas may have been exaggerated.

4.7.3 Limitations of the Demand Estimates and Projections

The demand estimate was developed based on the assumption that the 1995 demand estimates in cataloging units 02070005, 03010103 and 0505001 were distributed evenly. A portion of these three cataloging units is included in the Upper Shenandoah/Laurel and the Lower Shenandoah planning areas, the Martinsville/Ararat and the Danville planning areas and the Upper New and Lower New planning areas, respectively. The applied procedure in each of these planning areas is: (1) to assume the segregated demand estimates were evenly over the cataloging unit land area, (2) to identify the amount of land from the cataloging unit that was included in the planning area, (3) to develop a land area ratio of the portion of the cataloging unit in the planning area to the entire cataloging unit, and (4) to multiply the segregated demand estimates by the land area ratio. This methodology was not applied to the hydrologic or thermoelectric demands if the location of these facilities could be identified. The immediate implication of such a methodology is that the reported demand value in the 6 affected planning areas includes a degree of error because it is not likely to be distributed evenly across the cataloging unit land area; it does not account for heterogeneities in demand distribution. The result of the equal distribution assumption is that demand estimates in planning areas with portions of cataloging units maybe over- or under-estimated if the cataloging unit contains densely populated demand centers, which are not accounted for in the homogeneous demand assumption. The 1995 total daily offstream consumptive demand estimate in each planning area was then divided by the 1995 population estimate to develop a per capita usage. Thus, all errors associated with the population estimate are included in the total daily per capita index. The per capita index was then used to project demand as a function of projected population.

The consumption projections were developed as a function of the total demand and consumption estimates reported by the USGS in 1995. The consumption estimates for the six aforementioned planning areas containing partial cataloging units were developed as a function of contributing land area and are subject to the same error as the land area contribution procedure of the demand estimate. The estimate of the amount of water consumed was divided by the total daily offstream demand to determine the percentage of the demand that was consumed in 1995. Projections of consumption were then developed assuming that the percentage of the total daily offstream demand consumed would remain the same in each future year (i.e., that the total per capita consumption will remain constant). Therefore, the consumption estimate is subject to the assumption that the rate of consumption will not fluctuate in the future and that demand growth will grow proportional to population.

The demand projections were developed solely as a function of projected population. Projected demand includes those uses that are offstream and (total daily offstream demand). It includes water for domestic, commercial, industrial, mining, livestock and irrigation withdrawals within each planning area. Although domestic is the only demand sector directly linked to the number of persons within a planning area, demand projections assumed that demand in each of sector would increase with population. This assumption eliminated the need to project industrial and commercial growth by economic indices, mineral availability indices, and irrigation and livestock agricultural indices. However, the elimination of the projection of demand within the segregated categories may over estimate the demand projection. As discussed in section *3.3.2.1.1* and shown in Figure 2.9, per capita use has declined despite population growth in the United States since 1980. If this decline continues in Virginia in the future, the demand projections may be an overestimate of future demand.

4.7.3.1 Limitations of the Population Estimates and Projections

Population estimates were developed based on the assumption that population was distributed evenly in counties, cities and cataloging units within the Commonwealth. The 1995 population estimates were developed from the 1995 demand reports produced by the USGS. In 21 of the 27 planning areas, the 1995 population estimate was taken directly form the 1995 report because the planning area boundaries were coincidental to the cataloging unit(s) contained within the planning area. However, in those 6 planning areas that had boundaries that dissected the cataloging units, the 1995 population estimate was distributed according to the amount of land area of the cataloging unit contained with the planning area. The 1998 population estimates were developed by accounting for the amount of land area within each hydrologic unit that was contributed by each municipal jurisdiction. The 1998 Census Bureau estimates for the counties and cities within

Virginia were divided by the total jurisdiction land area to develop a population density on a per square mile basis. Land area of each municipal jurisdiction contained within each planning area was then multiplied by the appropriate population density and summed to estimate the total planning area population in 1998. For both the 1995 and 1998 population estimates, the inhomogeneities associated with population centers were dismissed from the analysis. By ignoring population heterogeneity in the 6 planning areas that contain partial cataloging units, the population in each planning area varies considerably between 1995 and 1998 largely due to uneven population distribution between the portions of the truncated demand cataloging units.

The population projections for 2000, 2005, 2015 and 2025 are developed assuming projected growth in the planning area will occur proportional to projected population growth in the Commonwealth. Projected population growth statistics were not available for counties or cities, and population projections were developed for each planning area as a function of the state population. The percentage of the total state population estimated within each planning area in 1998 was multiplied by the total population projection for the Commonwealth in each future year. This projection methodology assumes that growth within the planning areas will be proportional to growth with the Commonwealth and that immigration and emigration will be negligible between planning areas. Neither condition is likely to actually occur, however, both were necessary in order to anticipate the population in each planning area in the future years.

4.7.4 Limitations of Preliminary Assessment of Water Supply Availability

The errors associated with all the assumptions included in the development of the procedure for preliminary assessment of water supply availability culminate in the expression of the water balance conditions. Assuming that water supply availability estimates are underestimated because it does not include groundwater and artificial storage facilities for surface water and that demand projections are overestimated because not all sectors of demand will increase with population and because per capita use has declined in recent years, the water balance projections may be considered a conservative estimate. All limitations in the procedures used to develop the parts of the analysis are compounded by developing the water balance projections as a sum of those parts.

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5. Conclusions

5.1 Summary of Findings

The procedure for preliminary assessment of water supply availability provides a methodology to quantify future water supply availability at the broad regional or state scale. Because of the preliminary nature of its findings, the application of the technique does not provide detailed information about water supply availability at the local scale within the planning area. However, the procedure does provide an overview of water supply availability in the present and in the future and can be used to indicate the extent of current development in the planning area.

The application of the preliminary assessment technique to the Commonwealth of Virginia indicated that adjustments might have to be made to the general procedure based upon data availability and geographic considerations in a specific region or state. By applying the preliminary assessment procedure to the data available for Virginia, it was concluded that thirteen of twenty-seven planning areas do not indicate offstream water supply problems before 2025 under any flow condition. However, fourteen of those planning areas indicated that offstream water supply availability in the future may be in deficit under at least one flow condition.

The application of the general procedure to the Commonwealth of Virginia highlighted the limitations of the analysis. By restricting the water supply estimate to the surface and ground water captured by USGS stream gages, the groundwater that was available for mining (i.e., available for withdrawal in the short-term) was excluded from the water supply estimate. This particularly affected the water supply availability in the

Coastal Plain of the Commonwealth where groundwater cannot generally be assumed to be included in surface water flows. Water supply availability in the Coastal Plain was also limited by gage data availability in the Coastal Plain. The tidal influence on waters in this region make gage data unreliable in the Coastal Plain; by excluding short-term groundwater availability, the deficits in the Coastal Plain may be exaggerated.

The analysis was further limited by focusing only on water quantity and not water quality, the water supply assessment did not account for difficulties in water supply treatment in local areas. This may have particularly affected the Eastern Shore analysis where groundwater was estimated to be able to satisfy the demand estimates, but quality concerns that may be associated with water supplies on the Eastern Shore were not considered in the analysis.

And finally, the general procedure does not account for existing storage in the planning areas. By eliminating reservoir storage from the analysis, shortages were indicated in planning areas with considerable amounts of stored water because that water is not measured by streamflow parameters. This particularly affected several planning areas in the Commonwealth, especially the Big Sandy planning area where the John Flannagan Reservoir on the Pound River stores over 47 billion gallons of water of which about 119 million gallons is available for water supply use.

Despite the limitations that result from the assumptions made in the development and application of the procedure for preliminary assessment of water supply availability, the technique does provide an overview of basic water supply conditions of a specified region in the future. However, the regional analysis indicates only basic conditions and conclusions about water supply availability at the local level can only be made through additional research. The case studies of the Shenandoah River basin and the municipalities in the Roanoke City area indicate the types of studies that can further understanding of water supply at the regional, local and municipal level.

5.2 Future Research

The procedure for preliminary assessment of water supply availability focuses on estimating and projecting water supply conditions at the state and regional level. Within each regional planning area, storage, treatment, and distribution conditions exist that are not included in the analysis. Therefore, future research should focus on the water supply systems within each of the regional planning areas in order to catalog, evaluate, and fully conceptualize water supply availability within each system and community. For instance, within the analysis of preliminary water supply availability within Virginia, each planning area can be evaluated concerning the storage, treatment, and distribution capacity of each local supply system.

The procedure for preliminary assessment of water supply availability can also be further refined to include a means of quantifying "mined" groundwater potential in coastal geologic environments. The general procedure developed for the Eastern Shore planning area in Virginia is indicative of the type of analysis that can be included for coastal environments, but the level of detail of this type of analysis requires detailed studies that may not be able to be pursued within each planning area. Existing research in Virginia includes VSWCB reports of groundwater potentials by county; however, the specifics of the safe yield estimating procedure are vague and coincide with political jurisdictions rather than natural hydrologic boundaries.

Further research may also include establishing more readily available data within the state or region under investigation. A large limitation to the application of the procedure to Virginia was the availability of streamflow and groundwater data. Establishing surface water gages at the outlet of demand cataloging units and groundwater analyses within coastal regions will aid in the water supply availability assessment.

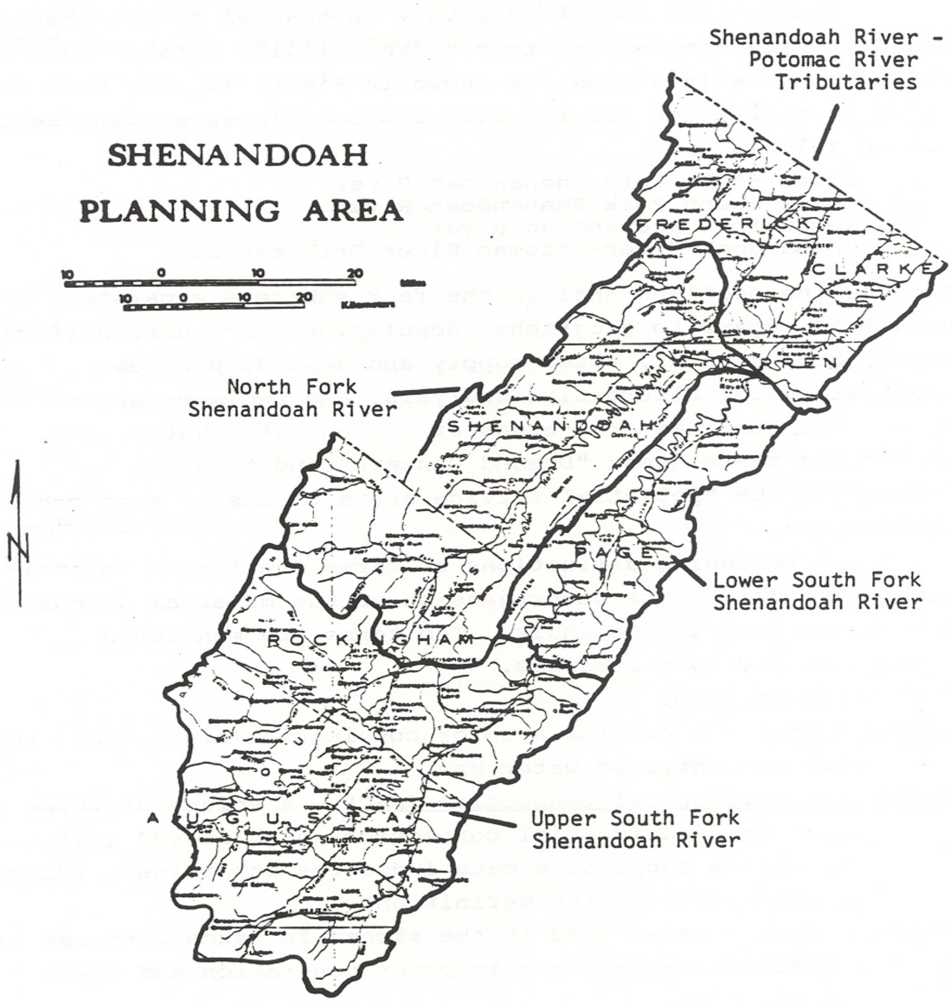
Finally, future research can take place to evaluate the accuracy of the projection methodology. Understanding whether the projection methodology can stand the test of time requires further research in projected time periods. Assessing the accuracy of the projections can only be done as future conditions become present conditions.

APPENDIX 1: The Shenandoah Valley:

Instream Flow Concerns

FIGURE 1

SUBAREAS OF THE SHENANDOAH PLANNING AREA



Source: Virginia State Water Control Board

Figure A-1.1: The Shenandoah River Basin.[277]

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[277] See note 174, supra, p. 3.

A-1.1 Introduction

The Shenandoah Valley plays a vital role in the history of the Commonwealth. Over 300 million years ago, the collision of the African and North American continents gave rise to the Valley and Ridge province of the eastern United States of which the Shenandoah Valley is part.[278] The land that lies between the Blue Ridge and Allegheny Mountains provides a rich beauty recognized by the first settlers in the 17th century. The Valley was a central strategic position in the Civil War and was a major industrial center in the 19th century; the Valley's scenic beauty seems priceless even today.[279] The historical significance, scenic beauty and recreational value of the Valley and the River system have prompted municipalities within the river basin to begin to define instream flow requirements. The following chapter will describe the Shenandoah River system, the water supply systems in the Valley, the population in the Shenandoah Valley and the actions that are being taken by municipalities within the Valley to define minimum instream flow standards.

A-1.2 The Shenandoah River System

The Shenandoah River basin is one of the eight major river basins in the Commonwealth. The Potomac River accepts the collected waters of the Shenandoah system in Harper's Ferry at the convergence of Virginia, Maryland and West Virginia. The South Fork of the Shenandoah basin collects its headwaters in the southern portion of Augusta County before converging in the South Fork mainstream. The headwaters of the

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[278] "Exploring the Valley, the River, and the State of Mind; Shenandoah." James Conaway. The Washington Post Magazine, October 21, 1990, p. w25.
[279] Id.

North Fork form in the northwestern portion of Rockingham County north of the City of Harrisonburg. These two main tributaries run relatively parallel, the North Fork through Shenandoah County and the South Fork through Page County, before their confluence in Warren County near Front Royal. The mainstem of the Shenandoah runs the remainder of Warren County before entering Clarke County and crossing the border of the Commonwealth into West Virginia just west of the Loudoun County line.[280] The precipitation that has fallen over the Shenandoah Valley has interacted with the limestone beneath the land surface and, over time, has caused Karst terrain to develop. The development of Karst terrain within the Shenandoah Valley has created some unique characteristics of the interaction of surface and ground water within the Shenandoah Valley.

A-1.2.1 The Shenandoah Surface Water - Groundwater Interface

The hydrogeologic cycle, Figure 2.1, shows various interactions that can occur between surface and ground water. Precipitation that falls on the land surface that is not concentrated as runoff into surface water bodies or evaporated into the atmosphere infiltrates the top layers of the local soil system to be taken up by the flora. The water lost to plant root systems is then returned to the atmosphere via transpiration processes. However, precipitation may also infiltrate deeper into the soil system to become part of the local or regional aquifer system. The interaction between precipitation, plant use and groundwater storage is defined by the geologic characteristics of the area under study. Just as surface water records indicate a nearly immediate change in streamflow quantities

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[280] Comments derived from the Virginia Department of Conservation and Recreation "Hydrologic Unit Map: Commonwealth of Virginia", June 1995.

after precipitation, the unique geologic characteristics of the Shenandoah Valley enable precipitation that falls on the land surface to quickly become part of the groundwater system.

The immediate influence of precipitation events on the groundwater of the Shenandoah Valley indicates the singularity of the groundwater and surface water resource. The Shenandoah Valley is underlain mostly by carbonate rocks that are particularly susceptible to solution by surface water action.[281] The formation of the Karst landscape is dependent upon the chemical reaction of water to the underlying geologic formations.

> "Limestones are composed almost entirely of calcium carbonate, $CaC0_3$, and are rarely soluble in pure water, but when carbon dioxide gas, $C0_2$, ...is dissolved in it there is formed a water solution of carbonic acid, H_2CO_3. This attacks the limestone and converts it into calcium bicarbonate, $H_2Ca(CO3)_2$."[282]

The beauty of the underground caverns of the Shenandoah has inspired the wide study of the Karst characteristics and geology within the Shenandoah Valley region. The Virginia Division of Mineral Resources of the Commonwealth catalogued and mapped the geology of the Shenandoah as well as other parts of the Commonwealth during the 1960's and 1970's. Specific geologic studies included that of the Little North Mountain,[283] the Stonehenge Limestone[284] and the Conococheague Formation[285] within the Shenandoah region. Hubbard's (1984) study of the distribution of sinkholes within the Valley's carbonate rocks has lead him to conclude that the interaction of surface water

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[281] Reeds, C.A. "The Endless Caverns of the Shenandoah Valley." American Museum of Natural History, 1925, figure, p. 41.
[282] Id., p. 31.
[283] Sherwood, Campbell, Kearns, Rader and Perry. "Geology of Little North Mountain and the Central Shenandoah Valley, Virginia. 9th Annual Virginia Geology Field Conference, 1977.
[284] Wood, R.S. "Stratigraphy of the Stonehenge Limestone in the Northwestern Part of the Shenandoah Valley, Virginia." University of Virginia, 1960.

events with the meandering Shenandoah River system and its tributaries and with the subsurface geology has directly created the underground watercourse and cavern systems.[286]

A-1.3 Water Resources Development in the Shenandoah Valley

The land that lies within the nearly 3600 square mile area is divided among numerous political entities. The basin covers parts of Highland and Augusta Counties and all of Frederick, Clark, Shenandoah, Warren, Page and Rockingham Counties. The cities of Waynesboro, Staunton, Harrisonburg and Winchester are within the basin, along with the Towns of Berryville, Boyce, Bridgewater, Broadway, Craigsville, Dayton, Edinburg, Elkton, Front Royal, Grottoes, Luray, Middletown, Mount Crawford, Mount Jackson, New Market, Shenandoah, Stanley, Stephens City, Strasburg, Timberville, Toms Brook, and Woodstock. Each of these jurisdictions has a water supply system that withdraws water for supply purposes from a surface or ground water source. In order to insure that future demands do not exceed available supply waters, it is important to identify and discuss the needs of each system in the Shenandoah Valley.

The continued development of water resources within the Shenandoah Basin requires the identification of the current water demands within the river basin. The State Water Control Board (SWCB) developed an analysis of each water system within the Shenandoah Basin in 1988. The report evaluated water use in 1980 and projected demand through 2030 so that deficiencies could be anticipated and solutions could be

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[285] Nicholas, R.L. " Stratigraphy and Sedimentation of the Conococheague Formation (Cambrian) in the Shenandoah Valley, Virginia." University of Kansas, 1954.
[286] "Hubbard, D.A., Jr. "Sinkhole distribution in the central and northern Valley and Ridge Province." In "Sinkholes: Their Geology, Engineering and Environmental Impact." Ed. B.F. Beck. University of Central Florida, 1984, p. 76.

developed and recommended. The Water Control Board developed demands as estimated functions of the growth of population and commercial and industrial development within each demand center, but it ignored the demands of instream uses.[287] The SWCB broke the Shenandoah Basin into four subareas: the upper South Fork, lower South Fork, North Fork and Shenandoah River-Potomac River tributaries subareas.

A-1.3.1 The Upper South Fork Shenandoah River Subarea

The Upper South Fork subarea was divided into three main demand centers: the Augusta, Central Rockingham and Western Rockingham demand centers (see Figure A-1.2).

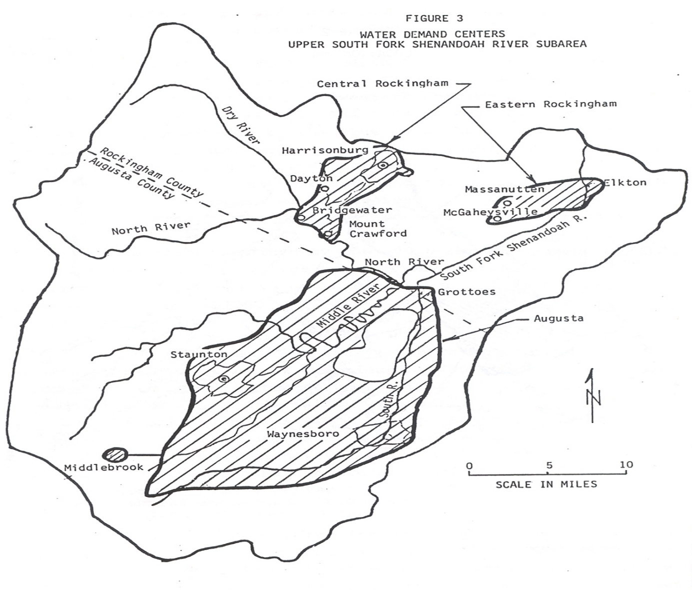

Figure A-1.2: Upper South Fork Demand Centers.[288]

The demand centers then included analysis of all centrally supplied systems within the borders in detailed fashion. Of the thirteen systems analyzed, seven rely strictly on

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[287] See note 174, supra, p. xxviii.
[288] Id., p. 10.

groundwater withdrawals, two draw only from surface waters and four use groundwater and surface water in combination. The carbonate rock aquifers underlying the whole subarea are particularly susceptible to contamination from precipitation that infiltrate after contact with surface contaminants;[289] nitrate[290] and fecal coliforms[291] have been detected in wells within the subarea. The North River is utilized by the City of Harrisonburg, the Town of Bridgewater and the City of Staunton; Harrisonburg is supplemented by the Dry River and Silver Lake Spring, and Staunton can also depend on the Middle River and Gardner Spring. The SWCB evaluated the competition for water along the North River and concluded that all uses, excluding those considered to be instream, would be satisfied except for irrigation in times of drought. Development along the North River is also hampered by the runoff of agricultural applications which can degrade the taste, odor and treatability of North River water - especially during periods of low-flow.[292]

A-1.3.2 The Lower South Fork Shenandoah River Subarea

The lower South Fork subarea was divided into four demand centers: the Shenandoah, Stanley, Luray and Front Royal demand centers (see Figure A-1.3).

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[289] Id., p. II-61, II-83, II-103.
[290] Id., p. II-83.
[291] Id., p. II-103.
[292] Id., p. II-83

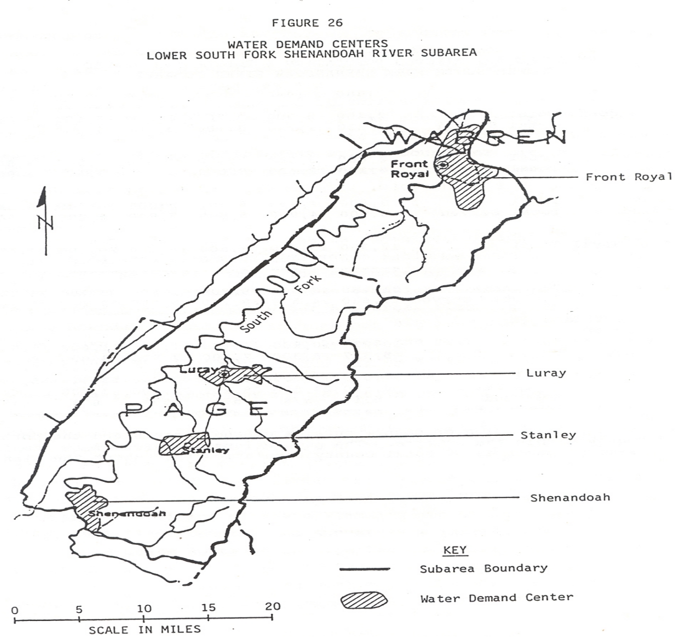

Figure A-1.3: Lower South Fork Demand Centers.[293]

The Towns of Shenandoah and Stanley depend on wells, the Town of Luray collects groundwater from two springs and the Town of Front Royal draws surface water from tributaries of the Shenandoah River, Happy Creek and Sloan Creek. The SWCB suggested that the current well sources in Shenandoah and Stanley might not be sufficient for the demands expected by 2030. Each of the Towns have added wells since the 1988 report; Stanley now has six wells instead of four,[294] and Shenandoah now has three wells rather than two.[295] The South Fork was analyzed to recognize any demand development conflicts among competing uses, including assimilative capacity, and none were found to exist under drought flow conditions.[296]

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[293] Id, p. II-113.
[294] Written correspondence with Stanley Town Superintendent Terry A. Petit dated June 3, 1999 indicated the addition of two wells, the latest placed in 1994 can produce 600 gpm.
[295] Written correspondence with Shenandoah Town Manager Larry E. Dovel dated May 25, 1999 indicated that three wells now supply Shenandoah's distribution system.
[296] See note 174, supra, p. II-130.

A-1.3.3 The North Fork Shenandoah River Subarea

The North Fork subarea was divided into the following six demand centers: Basye, Broadway/Timberville/New Market (BTNM), Central Shenandoah, Edinburg, Mount Jackson and Strasburg (see Figure A-1.4).

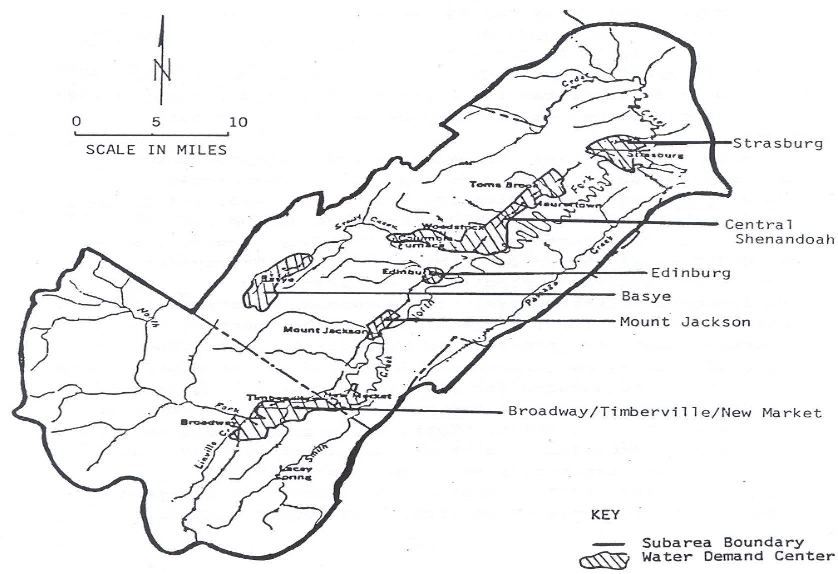

Figure A-1.4: North Fork Demand Centers. [297]

Within the Basye demand center the Stoney Creek Sanitary District depends on eight wells, Shrine Mont draws from seven springs and Bryce Resort withdraws from Stony Creek and a private well. The Town of Broadway owns an intake on the North Fork just above the confluence of Linville Creek; the Town of Timberville uses two wells and one spring; and, the Town of New Market draws from three wells and Smith Creek. Within the Central Shenandoah demand center, the Town of Woodstock takes water from the North Fork, while the Toms Brook-Maurertown Service Authority pumps water from two

[297] Id., p. II-163.

wells. The Towns of Edinburg, Mount Jackson and Strasburg each represent a separate demand center. Edinburg pumps from two wells, Mount Jackson depends on three wells and two springs and Strasburg owns an intake on the North Fork.

The high number of systems within the North Fork subarea may be indicative of the potential for source failures because of over development. The North Fork supplies three of the ten systems analyzed and Broadway is expected to develop source deficits by 2000.[298] The VSWCB specifies the potential for demand conflicts within BTNM between water supply, industrial processing, irrigation and aquatic life and assimilative capacity protection in the North Fork subarea.[299] Two of the groundwater systems, Stoney Creek Sanitary District and Toms Brook-Maurertown Service Authority, are anticipated to develop source problems[300] also, but the SWCB recommends in each case that more wells be added to the existing system.[301]

A-1.3.4 The Shenandoah River-Potomac River Tributaries Subarea

The Shenandoah River-Potomac River Tributaries subarea is represented by four major demand centers: Berryville, Boyce/Millwood/White Post, Lake Holiday Estates and Winchester-Frederick County (see Figure A-1.5).

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[298] SWCB deficit projection based on the North Fork as a single source, note 232, p. II-196. Personal correspondence with Broadway Manager Chalres L. Lohr dated June 8, 1999 indicated that Linville Creek also serves the Broadway system.
[299] See note 174, supra, p. II-208.
[300] Id., p. II-182.
[301] Id., p. II-195 and II-222, respectively.

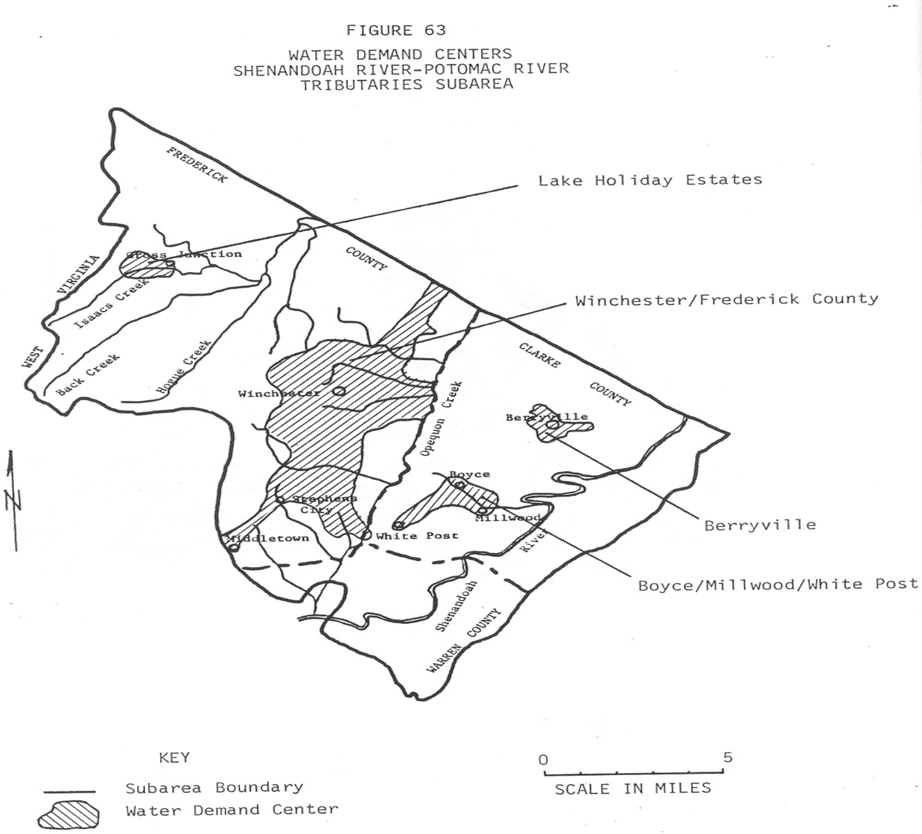

Figure A-1.5: Potomac Tributaries Demand Centers. [302]

The Town of Berryville draws water from the mainstem of the Shenandoah River that has a safe yield of 148 MGD at the stream intake[303]; thus, no problems are anticipated. The Boyce/Millwood/White Post demand center represents the service area of the Clarke County Service Authority that is served by a single spring. Lake Holiday Estates' system is served by three wells in Frederick County. Nearly 80% of the water drawn from these wells is unaccounted for, and these losses are the main reason for the projected source deficit around 2000.[304] The Winchester-Frederick County demand center includes the City of Winchester, Frederick County Sanitation Authority and the Towns of Middletown

[302] Id., p. 246.
[303] See note 37, supra, p. 82. Safe yield is equivalent to the $1Q_{30}$ on the Shenandoah at the intake location.
[304] See note 174, supra, p. II-279.

and Stephens City. Winchester sells water to each of the other entities within the demand center after withdrawing and treating water from the North Fork. The safe yield of the North Fork at the Winchester intake is 36.7 MGD,[305] but the effect of upstream uses on the availability of water at Winchester is not considered in the estimate. Another notable characteristic of the Winchester system is the potential for an interbasin transfer conflict; the water withdrawn from the North Fork is returned to the waters of other Potomac River tributaries.[306] The sole dependence of each system upon Winchester's water treatment plant[307] requires the continued availability of North Fork waters in the future.[308]

A-1.4 Population in the Shenandoah Valley

The development of the Shenandoah Valley at a higher rate than expected[309] has put an unpredicted stress on the water systems within the area. The higher rate of growth in the Valley's urban centers and increased transient tourist population within the Lord Fairfax and Central Shenandoah Planning Districts[310] indicates that steps should be taken to guard the Shenandoah Valley's water resources against unsustainable development.

The population plays an important factor in determining the amount of water needed to satisfy the demands of local and regional communities. The SWCB developed domestic/commercial/industrial demand projections in the 1988 report series exclusively as a function of population projections based on 1980 per capita consumption rates within

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[305] See note 37, supra, p. 80.
[306] Telephone correspondence with LFPDC Director Tom Christoffel on July 1, 1999.
[307] Written correspondence with FCSA Director Wellington Jones dated June 2, 1999 indicated that Frederick County has developed a 4 MGD water treatment facility at the Stephens City Quarries.
[308] Written correspondence with Winchester Public Utilities Operations Superintendent John Merriner indicated that the Winchester system is currently updating withdrawal capabilities to 14 MGD.
[309] Lord Fairfax Planning Commission MIF Committee. "North Fork Shenandoah River MIF Action Plan." April 9, 1999. E-mail from LFPDC Director Tom Christoffel, July 1, 1999.

the local system.[311] The population of the planning area according to the 1980 census was 296,770;[312] 1996 estimates indicate that the population within the SWCB planning area has reached approximately 364,000.[313] The Department of Planning and Budget's projections assumed slow growth across the entire planning area and applied county growth rates to the Towns that lie within them.[314]

The graphs of actual and projected population also show unanticipated growth around the planning area's four independent cities: Winchester, Harrisonburg, Staunton and Waynesboro. Winchester's population (Fig. A-1.6) in 1996 was estimated to be 23,000, some 1,600 more people than anticipated in the DPB year 2000 projections. The same statement can be made for Harrisonburg (Fig. A-1.7), Staunton (Fig. A-1.8) and Waynesboro (Fig. A-1.9); each of the three later independent cities exceeding projected populations for the year 2000 in 1996 by over 9000, 3000 and 4000 people, respectively.

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[310] Tourism increase noted in the annual series "Virginia's Local Economies", 1998 edition, no.6 and no.7. Published by the Weldon-Cooper Center for Public Service.
[311] See note 174, supra, p. I-6.
[312] Id, p. I-18.
[313] Julia H. Martin. "1996 Virginia Population Estimates." Spotlight on Virginia, vol. 1, no. 1, Weldon Cooper Center for Public Service, February 1997. The article provided estimates by city and county. Augusta County's population was weighted at 80% based on the land area contributing to the Shenandoah Basin.
[314] Id., Appendix A, p. 4-5.

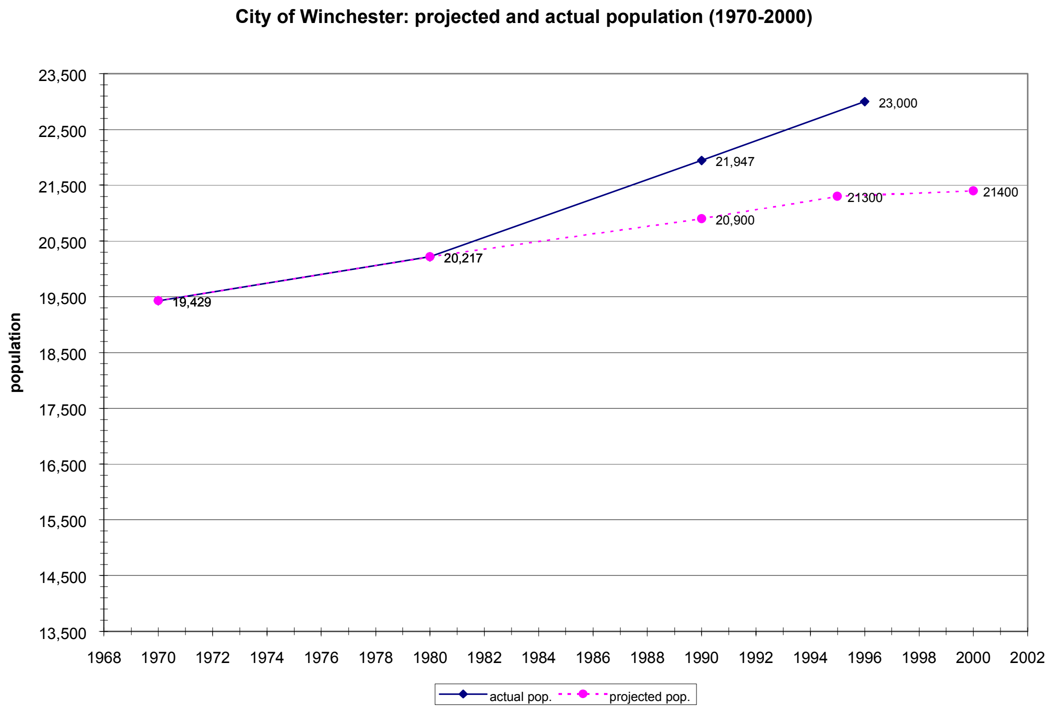

Figure A-1.6: Winchester projected and actual population.

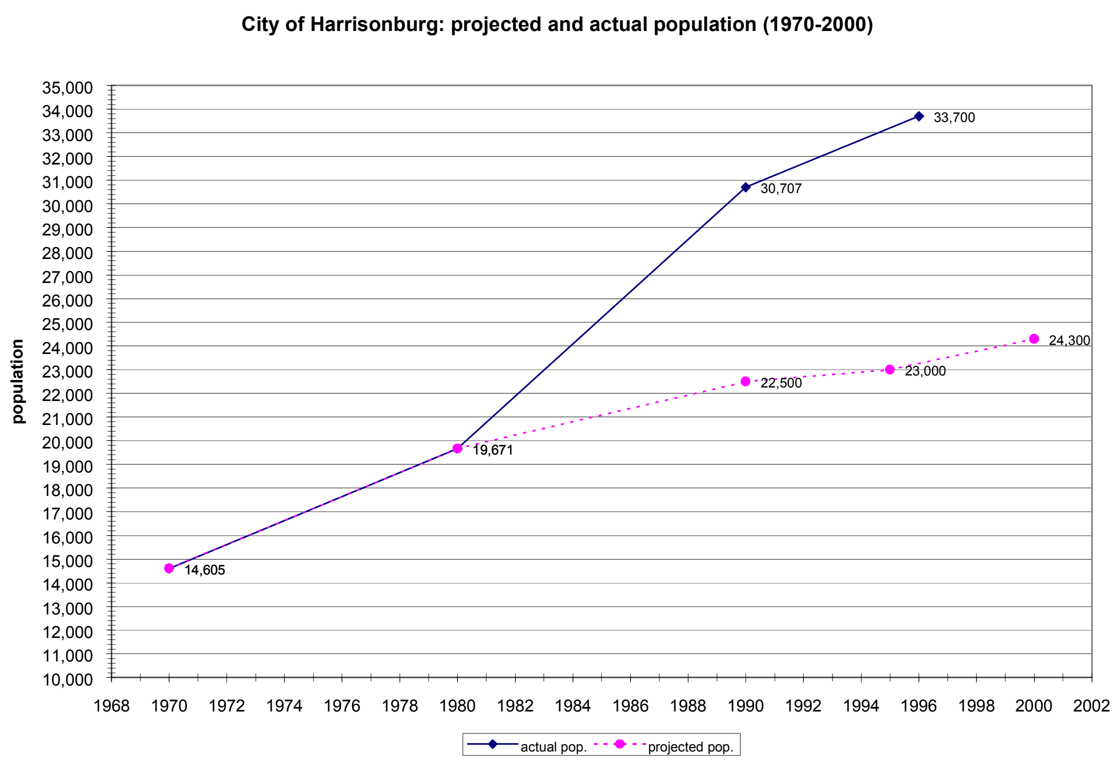

Figure A-1.7: Harrisonburg projected and actual population.

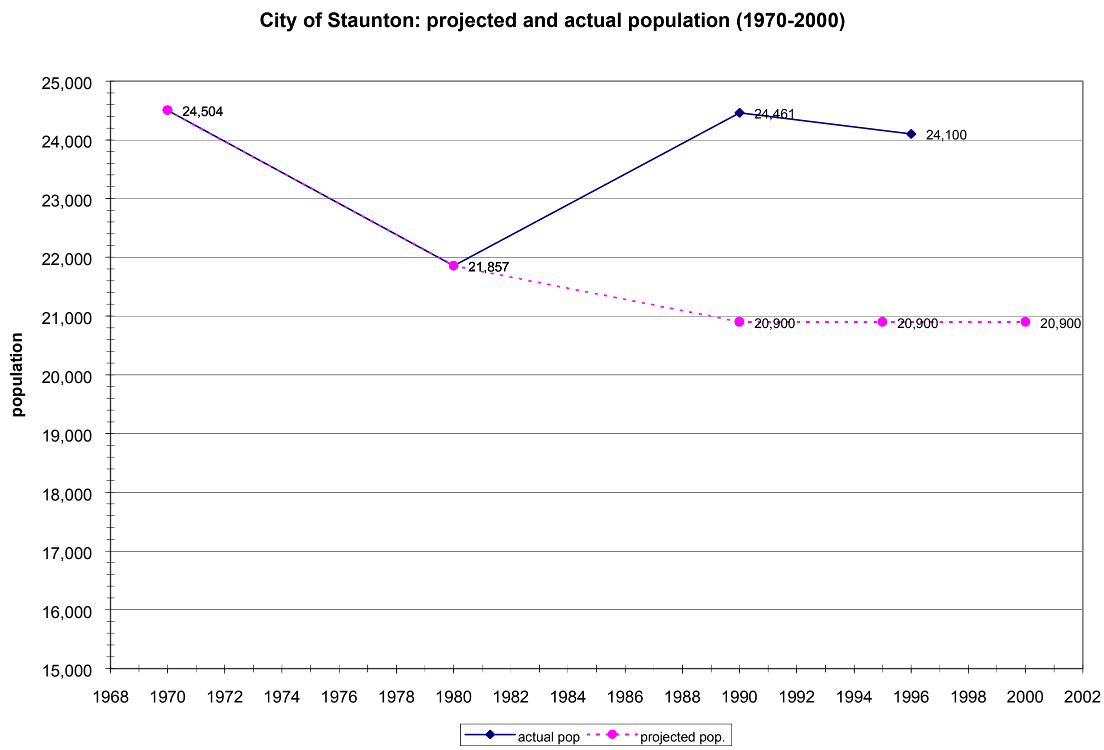

Figure A-1.8: Staunton projected and actual population.

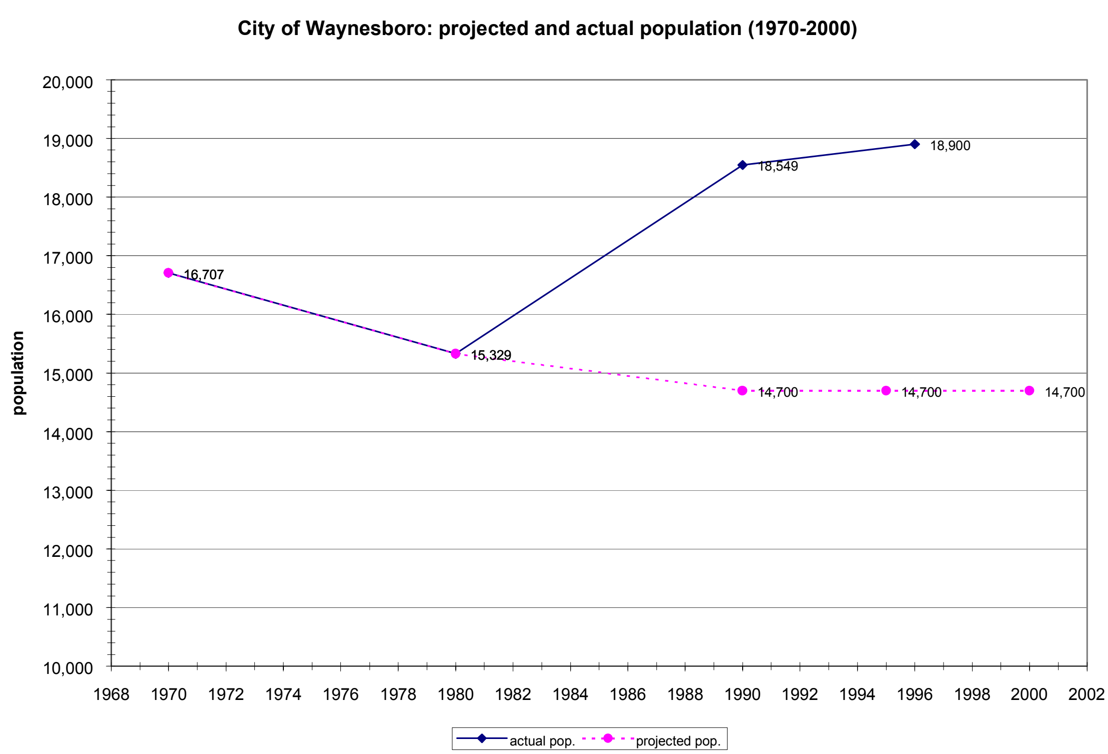

Figure A-1.9: Waynesboro projected and actual population.

The unanticipated growth means that SWCB demand estimates and projections made in 1988 were low. Low population estimates lead to an underestimation of water demands by the SWCB based on the following demand projection formula used for domestic and commercial sectors:[315]

$$DCWD = GPCD \times PYP$$

where DCWD = domestic/commercial water demand
GPCD = gallons per capita per day for system
PYP = projected year population.

The underestimates indicate that the SWCB likely labeled inadequate systems as adequate. The projected demands indicated that of the 36 central waterworks within the 17 demand centers, 20 should not experience water systems problems; the remaining 16 were identified as facing some kind of deficiency - source, treatment or delivery.[316] The unforeseen population growth and higher domestic demands have increased the amount of water withdrawn for offstream uses. As withdrawals have increased, the amount of water left instream for nonconsumptive ecological and environmental uses may have been diminished. Therefore, there has been a growing sentiment in the Shenandoah Valley to define minimum instream flow standards.

A-1.5 The Shenandoah Valley's Instream Flow Concerns

Recognizing the need to sustain the flows of the Shenandoah River for instream uses, the Lord Fairfax Planning District Commission (LFPDC) coordinated a multijurisdictional study of minimum instream flows (MIF) in the Shenandoah Basin. Clarke, Page and Warren Counties, the City of Harrisonburg and the Town of

[315] See note 174, supra, p. I-5

Bridgewater have petitioned the Department of Environmental Quality's Water Control Board (SWCB) for the designation of North River as a Surface Water Management Area under the Surface Water Management Act.[317,318] The petitions have been made in order to explicitly define the instream flow requirements for "recreational needs, wildlife habitat," and waste assimilation,[319] and to provide an enforceable means of instream flow protection. The requests have not been granted by SWCB due to the concerns of municipal public utilities that SWMA designations would be arbitrary without an accurate data baseline of instream flow needs.[320]

The first phase of the Shenandoah MIF process helped identify the need for a study to quantify necessary instream flow. The Shenandoah is vital to local municipalities in assimilating waste and supplying a viable drinking water source. The City of Winchester and the Towns of Front Royal, Woodstock, Strasburg and Berryville, all of whom draw drinking water from the Shenandoah within LFPDC boundaries, expressed an interest in the establishment of MIF standards low flow conditions.[321] Instantaneous low flows in WY 1992 on the North Fork, South Fork and Mainstem fell to 10%, 24% and 14.5% of mean annual flow (MAF)[322], respectively.

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[316] Id., p. xxx.
[317] Lord Fairfax Planning District Commission. "Minimum Instream Flow - Designing a Plan of Action for the North Fork, South Fork and Mainstem of the Shenandoah River within the Lord Fairfax Planning District - Phase I." January 1994, p. 1.
[318] Written correspondence with Bridgewater Superintendent Bob Holton dated July 28, 1999.
[319] See note 317, supra.
[320] Id.
[321] Id., p. 2.

According to the Virginia Commission of Game and Inland Fisheries (VCG&IF), similar low flow conditions in 1988 were "low enough to provide documented evidence of chronic fish kills."[323] The local fish stock provides recreation to "thousands of local and regional citizens each year." [324] The flow levels were below the US Fish and Wildlife (USFWS) and VCG&IF recommended voluntary conservation trigger of 30 percent of (MAF)[325] to protect instream fish populations. The average monthly flows of 3 months on the North Fork, 2 months on the South Fork and 2 months on the Mainstem were below the 30% MAF standard. [326] The 30% MAF standard is not enforceable in Virginia, but voluntary enforcement of the 30% standard would have required severe voluntary conservation efforts in each of the localities affected. Frequent conservation measures are traditionally unacceptable "to the municipalities that rely on the Shenandoah River for their domestic water supplies."[327]

In order to promote collaboration of the many groups of users within the Shenandoah Basin, the LFPDC study commission offered its support to encourage communication between stakeholders. The Shenandoah River Advisory Group and municipal administrators and utility directors began dialogue to address the numerous aspects of the requests for SWMA declarations. The ensuing discussion forced the LFPDC to ask which flow condition instream indicated a need to protect the needs of all

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322 Prugh, Herman and Belval. "Water Resources Data Virginia Water Year 1992." USGS Water-Data Report VA-92-1, p. 74, 64, 82, respectively. As shown in "Minimum Instream Flow - Designing a Plan of Action for the North Fork, South Fork and Mainstem of the Shenandoah River within the Lord Fairfax Planning District - Phase I." Lord Fairfax Planning District Commission. January 1994, Attachment A.
323 See note 317, supra, p. 2.
324 Id., p.1.
325 Id, p. 3.
326 The LFPDC did not report the specific 1988 low flow conditions, but review of the 1988 USGS surface water records indicated flows of about 10%, 30% and 25% MAF in August and September on the North Fork, South Fork and Mainstem, respectively.
327 See note 317, p.3.

stream users. The 30% MAF and $7Q_{10}$ methodologies were immediately identified as potential measures of indications of flow conditions that established a need for conservation efforts.[328] The LFPDC then set out to obtain the funding and expertise to establish a means of identifying the appropriate instream flow protection strategy for the waters of the Shenandoah Valley.

A-1.5.1 The Mainstem Shenandoah Demonstration Project

After reviewing other MIF studies done within the Commonwealth, the LFPDC began the Mainstem Shenandoah Demonstration Project that sought to demonstrate the optimum amount of water that should remain instream to satisfy offstream and instream uses. The project would establish MIF decision-making criteria and put complex engineering methodologies in terms that the committee and public at large could understand.[329] With the financial support of the City of Winchester, the Towns of Berryville, Front Royal, Strasburg and Woodstock, Clarke County, the Department of Environmental Quality, the Virginia Environmental Endowment, the Coalition of Area Environmental Organizations and the Coalition of Area River Recreational-Use Businesses, the LFPDC and the USGS published Water-Resources Investigations Report 98-4157 in 1998. The US Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM) was used in the demonstration project

> "to set the stage for the identification and compilation of the major instream-flow issues in the Shenandoah River Basin, to develop the required multidisciplinary technical team to conduct more detailed studies, and to develop basin specific habitat and flow requirements for fish species, species assemblages, and various water uses in the Shenandoah River Basin."[330]

[328] Id, p. 2, 4.
[329] Id.
[330] See note 93, supra, p. 1.

The IFIM was chosen to model the Shenandoah River to optimize offstream and instream water uses in the Valley. The Shenandoah study utilized mid-range flow modeling techniques that required the collection of hydrologic and biological data from the study area.[331] The River was divided into three stream segments as a function of uniform flow regimes, and the study area was selected from the middle segment because the "mesohabitat types (riffle, run and pool) occur in a somewhat repetitive pattern" and flow is not regulated by dams.[332]

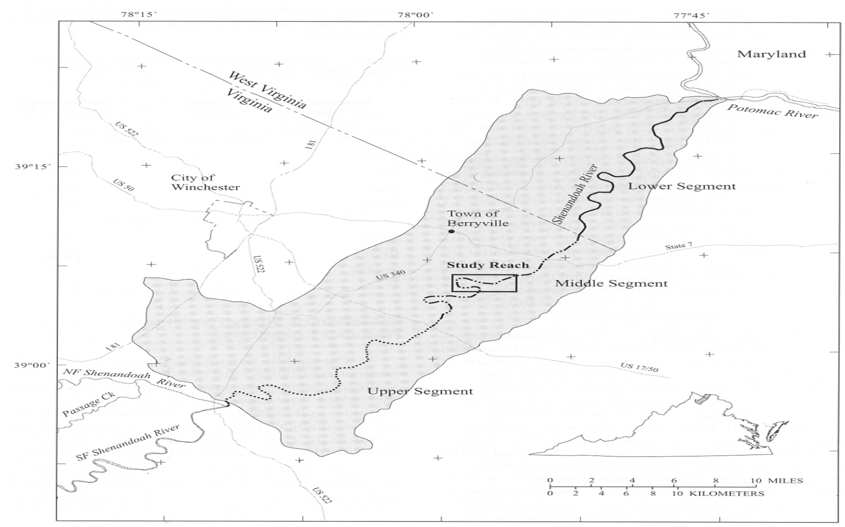

Figure A-1.2: The Mainstem Shenandoah IFIM study area (not to scale).[333]

The study reach was then divided into twenty transects of the following random habitat distribution: 4 pool, 10 run and 6 riffle.[334]

[331] Id., p. 5.
[332] Id., p. 10.
[333] Id., p. 9, figure 5.
[334] Id., p. 11.

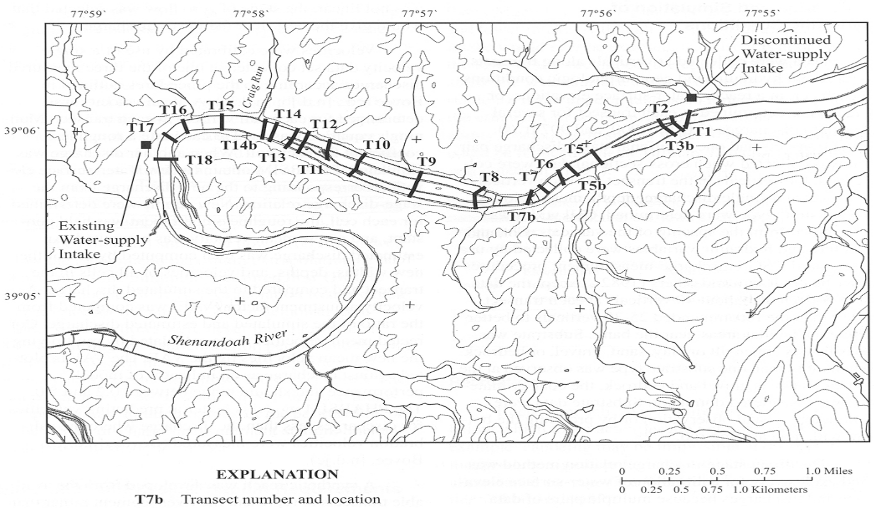

Figure A-1.3: The Mainstem Shenandoah IFIM study Transect locations (not to scale).[335]

At each transect, stage, velocity, depth and substrate data were collected; fifteen of the transects were used to calibrate a 1000 foot synthetic reach in the Physical Habitat Simulation System (PHABSIM) model. The model was then run over a variation of 60 to 3000 cfs of flow in order to calculate depth, mean velocities and develop habitat suitability indices (SIs) as a measure of the effect of discharge on habitat availability.[336] Discharge in the stream was adjusted in order to predict the effects of discharge upon water supply withdrawal, recreational and aquatic biota needs as functions of depth, velocity and substrate diameter.

The effects of the simulated flows were reported for each characteristic instream use. The water supply analysis indicated that full intake capacity would be available to the Town of Berryville at flows greater than 700 cfs (85% of the time); intake capacity would be limited at flows less than 100 cfs (less than 1% of the time).[337] Flows for

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[335] Id., p. 11, figure 6.
[336] Id., p. 12-13. 60 cfs was chosen as a low value because it is the minimum instantaneous low flow on record at Millville, WV.
[337] Id., p. 19.

recreation along the mainstem of the Shenandoah would be sufficient for canoeing at flows greater than or equal to 1200 cfs, available 63 percent of the time.[338] Habitat conditions for blacknose dace (the minnow control species)[339] are optimum only between about 300 and 600 cfs, but decrease only slightly above 600 cfs; thus, flows below 300 cfs will limit sustainability of the population only about 2 percent of the time.[340] White sucker fish (the bottom dweller control species)[341] require 500 cfs of flow to exist in an optimum habitat, an occurrence that has a 94 percent probability.[342] Muskellunge (the top predator control species)[343] can tolerate a "wide range of depths but tolerate a relatively narrow range of velocities and substrate types;" thus, only a few of the simulated conditions indicated a suitable habitat for muskellunge.[344]

The study provided indications of the types of conditions to be avoided in the management of the Shenandoah River as a multiple use resource. The authors contend that the simulated results provide an understanding of the potential impacts of variable flow conditions upon the multiple uses in the stream in order to stimulate discussion among the stakeholders. They repeatedly point out, however, that the results of the demonstration project are general in nature and not known to be directly applicable to the Shenandoah because the information is derived from a theoretical modeling attempt rather than a representative reach.[345] The representative reach would require a smaller study area and more transects for an accurate depiction of the actual conditions within the

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[338] Id.
[339] Id., p. 14.
[340] Id., p. 20, figure 12.
[341] Id., p. 14.
[342] Id., p. 21, figure 13.
[343] Id., p. 14.
[344] Id., p. 22, figure 14.
[345] Id., p. 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23.

Shenandoah;[346] time and financial resources limited the scope of data collection. Despite the limitations of the results of the study, the stakeholders in the Mainstem Shenandoah MIF debate now have a platform from which to launch studies that are more specifically focused on the effects of "incremental changes in streamflow" on aquatic habitat viability and recreational use.[347]

A-1.5.2 The North Fork Action Plan

The North Fork of the Shenandoah is the next part of the Shenandoah River Basin for which an MIF study is planned. In April 1999, the LFPDC MIF committee designed an action plan for an IFIM study of the North Fork of the River. The Action Plan identifies the need for this next part of the MIF process by emphasizing that 63 percent of the population growth in the Valley is taking place along the North Fork of the Shenandoah which contributes only 20 percent to the Mainstem at its confluence with the South Fork.[348] The scattered low precipitation conditions of 1998 and 1999 have significantly increased the awareness of low flow conditions across the state and the need for the North Fork planning effort. The Action Plan identified an expected study completion period of four years with a budget of $278,000 subsidized by the Virginia Environmental Endowment, the General Assembly, local governments, LFPDC, USGS and DEQ.[349]

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[346] Id., p. 12.
[347] Id., p. 23.
[348] See 309, supra, p. 2.
[349] Id., p. 6.

The North Fork MIF study will mirror the Mainstem IFIM study. The results of the study are intended to be used as a tool in the MIF decision process and as a means of gaining public acceptance of scientific knowledge. Between July 1, 1999 and July 1, 2002, the USGS plans to install the data collection instrumentation at designated transect locations within the study reach, while the LFPDC intends to begin discussion with local stakeholders about the model and the use of its output in the study.[350] The Action Plan will continue as a collaborative multidisciplinary standard and involve the following parties: USGS, Virginia Tech, VDG&IF, DEQ, Virginia Department of Conservation and Recreation, USFWS, US Army Corps of Engineers, Virginia Department of Health, LFPDC, the Counties of Clarke, Shenandoah and Warren, the City of Winchester, the Towns of Berryville, Front Royal, Strasburg and Woodstock and representatives of agricultural, environmental, recreational and business users. The final analysis and report are expected at the beginning of July in 2003.

A-1.6 Conclusions

The unique hydrogeologic, historic, recreational and aesthetic characteristics of the growing Shenandoah Valley have resulted in a unique water resource planning approach within Virginia to address the instream demand concerns of water users in the region. Rapid recharge of groundwater, numerous separate supply systems, increased population and a desire to protect instream water uses all have the potential to create conflict between the various users of the Shenandoah River. The collaboration of municipalities, local business and environmental and recreational user groups and the

[350] Id., p. 3.

scientific community to cooperatively manage the River's resources is a difficult task within the separated governmental structure of the Commonwealth. The complexity is compounded because MIF policy has yet to be legally defined by the General Assembly. The lack of formal guidance lengthens and complicates the process because the defenders of the study must first establish the authority and need for MIF definitions. The LFPDC has established the public forum for discussion and identification of the need for MIF definition; attracted the necessary local, regional and national funding and scientific interest; and achieved the planning goals of the first phases of the process. The proactive rather than reactive approach to MIF concerns within the Shenandoah Valley will serve the Shenandoah Valley well in the future if MIF policies are made mandatory rather than voluntary. The actions of the Lord Fairfax Planning District Commission set a high standard for other regions within the Commonwealth that may anticipate instream use conflicts.

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A-1.8 ACKNOWLEDGEMENTS: Appendix 1

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Wellington Jones, Director, Frederick County Sanitation Authority
Charles Lohr, Manager, Town of Broadway
John Merriner, Utilities Superintendent, City of Winchester
Terry A. Petit, Utilities Director, Town of Stanley

APPENDIX 2: The Roanoke Valley Water Supply System: Crisis in a Time of Drought

A-2.1 Introduction

The Roanoke valley was first explored by colonial settlers that began to move west from the original Jamestown settlement in Virginia. Colonel Abraham Wood commissioned the first documented exploration on September 1, 1671 by sending forth Thomas Batts, Thomas Wood, Robert Fallam and the Appomattox Indian Chief Percute from Fort Henry on the James River.[351] They came to the Totera Indian village on September 8th that same year and became the first white men in the Roanoke Valley.[352] The first settler is known to be Mark Evans, in the Roanoke Valley prior to 1744, who traveled south through the Shenandoah Valley from Pennsylvania to a 1910-acre grant that included land along Crystal Spring.[353] The Anglo-Indian agreement in 1744 that initiated the construction of a road through the Shenandoah Valley[354] encouraged the migration of many Pennsylvanian families to the Roanoke Area including the Evans, Tosh ,Acres, Monahan and Kinder families in and around Roanoke, and the Browns, Masons and Burks near Salem.[355] The availability of land and good water supplies, provided by the springs, creeks, and rivers in the region , coupled with the new roadway, enabled the settlement of 35 families by 1753.[356] In 1771, Israel Christian purchased the "Stone House" in Roanoke and established a general store that by 1773 became a well-

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[351] Prillaman, H.R. "A Place Apart: A Brief History of the Early Williamson Road and North Roanoke Valley Residents and Places." H.R. Prillaman, March 1982, p. 4.
[352] Id.
[353] Id.
[354] White, C. "Roanoke 1740-1982." Roanoke Valley Historical Society, 1982, p. 8.
[355] Id., p. 4.

renowned trading post for the surveyors and migratory traffic that "went west through the Roanoke Valley."[357]

The Roanoke Valley continues to serve as an important trading and industrial center in southwestern Virginia. With short travel times to Interstates 81 and 64 and Routes 460 and 11 and access to nearly two-thirds of the nation's population within a 500 mile radius of the area,[358] Roanoke is a hub in the system that transports goods between northern industrial centers and southern distribution centers. Because of the importance of the Valley to transportation and industry, to local commerce, and to the permanent citizens, it is important that the region be able to sustain the present and the future water supply demands of the transient and local populations.

A-2.2 Existing Supply Facilities in the Roanoke Valley

Roanoke City, Salem City, the Town of Vinton and Roanoke County are the four municipal water supply systems that supply water to residents in the Roanoke Valley. The four Valley utilities collectively produce about 55 MGD, and current collective demand is 29.3 MGD.[359]

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[356] See note 351, supra.
[357] Id., p. 15-16.
[358] "About the City of Roanoke." Roanoke City. http://www.ci.roanoke.va.us/about/index.html
[359] "Drain on water supply forecast in generation." Todd Jackson and C.S. Murphy. Roanoke Times and World News, August 22, 1999, p. A1.

A-2.2.1 Roanoke City

Roanoke City's water supply is derived from four separate sources (see Figure A-2.4). The Carvins Cove Reservoir is the City's main water supply reservoir and supplies 80 percent of the current 17 million gallons per day (MGD) demand.[360] The treatment plant at the Cove can treat up to 28 MGD,[361] and the reservoir holds water that runs off of the surrounding 17.9 square mile (13, 000 acre) watershed and water diverted from Tinker and Catawba Creeks in the immediate area (see Tables A-2.1 and A-2.2).[362] Diversions from Tinker and Catawba Creeks are restricted by flowby requirements imposed on the City.[363] The City is required to allow 4 cubic feet per second (cfs) and 6 cfs to pass the diversion weirs on Tinker and Catawba Creeks, respectively. If the Cove is not full on January 1 of each year, the flowby requirement is reduced by 50 percent on each stream.[364] The safe yield of the Carvins Cove Reservoir is 17.4 MGD based on the 579 day critical drought period of 1980-1982.[365] Another portion of the demand is supplied by the 510 million gallon Falling Creek and Beaverdam Creek Reservoir system that can treat and distribute up to 2 MGD of water.[366] The safe yield of this small reservoir system is estimated to be 1.45 MGD over the same 579 day critical drought period.[367] The remainder of the demand is supplied by Crystal Spring which "has an

[360] "Carvins Cove level 21' low." Todd Jackson. Roanoke Times and World News, March 16, 1999, p. B1.
[361] "Water Department: History." Roanoke City. http://www.ci.roanoke.va.us/depts/water/history.html
[362] See note 37, supra, p. 105.
[363] Id., p. 106.
[364] Id., p. 107.
[365] Id., If the Cove is intentionally lowered before Jan. 1 of each year, the safe yield increases to 18 MGD.
[366] "Falling Creek offers another water supply to City of Roanoke." Joel Turner. Roanoke Tiems and World News, July 27, 1998, p. A5.
[367] See note 37, supra, p. 106.

estimated drought safe yield of 3.5 MGD."[368] Combining all the safe yield estimates, the entire system should be able to supply about 23 MGD over the critical drought period.

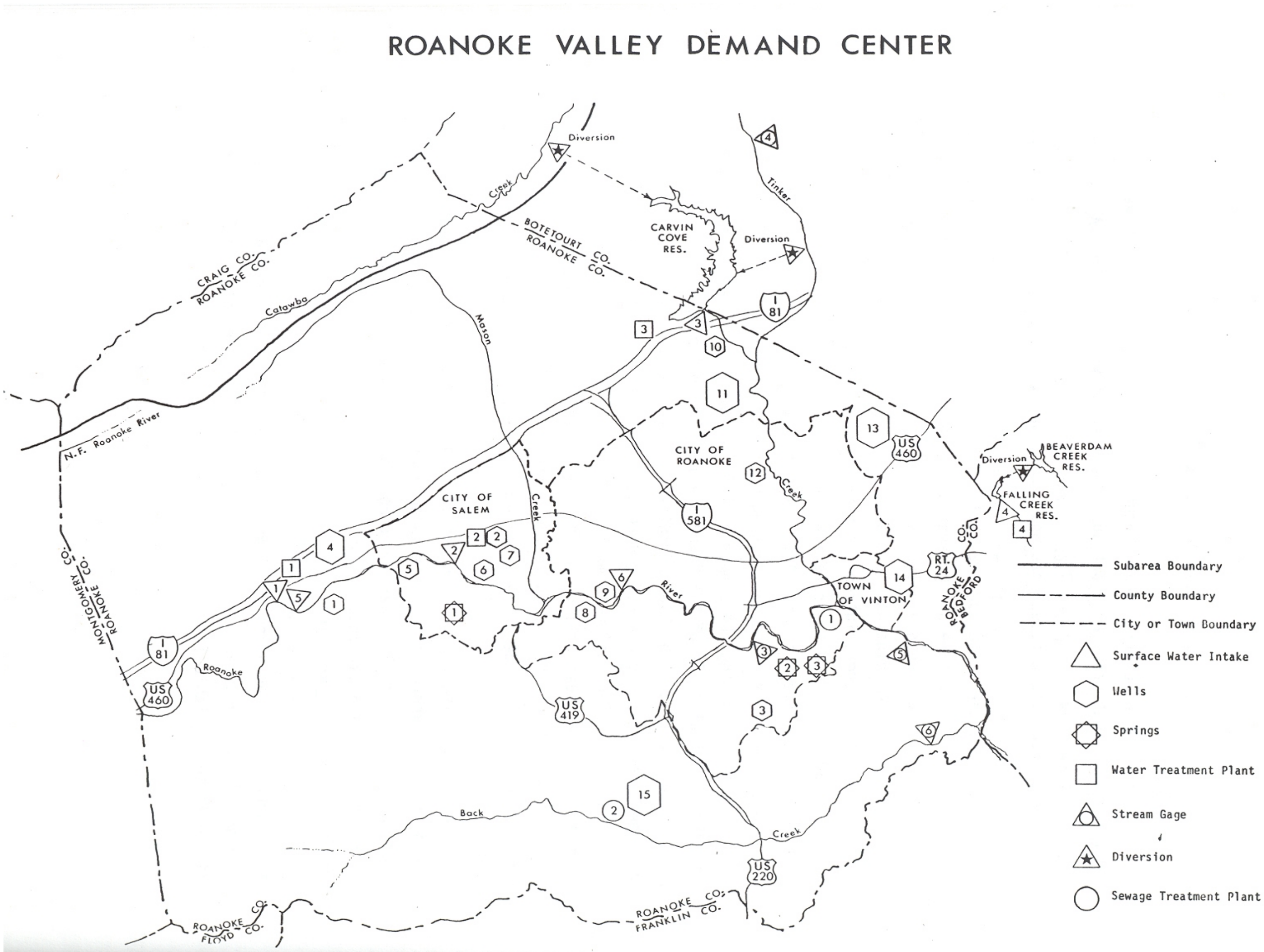

Figure A-2.1: The Roanoke Valley Demand Center.[369] (see *A-2.7*)

Table A-2.1: Tinker Creek flows; unadjusted - weir and gage are located coincidentally.[370]

Tinker Creek USGS Station 02055100	
period of record	1956-1998
Drainage area	11.7 mi^2
mean annual flow (MAF)	12.4 cfs
10% exceedance	24 cfs
50% exceedance	7 cfs
90% exceedance	2.6 cfs

368 See note 82, supra, p. II-40.
369 Id, p. II-38.
370 See note 28, supra, p. 368.

Table A-2.2: Catawba Creek flows at weir, adjusted proportional to drainage area.[371]

Catawba Creek USGS Station 02018500		
	at gage	at weir
Period of record	1953-1998	1953-1998
Drainage area	34.3 mi^2	23.5 mi^2
Mean annual flow (MAF)	35.7 cfs	24.5 cfs
10% exceedance	73 cfs	50 cfs
50% exceedance	14 cfs	9.6 cfs
90% exceedance	4.3 cfs	2.9 cfs

A-2.2.2 City of Salem

The City of Salem withdraws water from the Roanoke River. The City owns and operates two intake structures on the River: an older 5 MGD intake and treatment plant and a newer 3 MGD intake and treatment facility upstream near Glenvar that can be upgraded to 15 MGD.[372] Because the source is a direct stream withdrawal rather than an impounded reservoir, the SWCB estimated the safe yield as the one-day average low-flow occurring once every thirty years ($1Q_{30}$) and reported the value as 18.1 cubic feet per

second (11.9 MGD).[373] The flow values at the Glenvar intake were calculated based on the values at the Lafayette Roanoke gage and adjusted according to drainage area as has been done in the following table (an addition of almost 11% of the gaged land area):

[371] Id., p. 274.
[372] See note 82, supra, p. II-40.
[373] See note 37, supra, p. 104.

Table A-2.3: Roanoke River flows at Lafayette, adjusted proportional to drainage area.[374]

Roanoke River at Lafayette USGS Station 02054500	at gage	at weir
Period of record	1943-1998	1943-1998
Drainage area	257 mi^2	285 mi^2
mean annual flow (MAF)	159 MGD	176 MGD
10% exceedance	323 MGD	358 MGD
50% exceedance	87.7 MGD	97.3 MGD
90% exceedance	32.9 MGD	36.5 MGD

A-2.2.3 The Town of Vinton

The Town of Vinton's water supply is drawn completely from groundwater. The Town's water supply network was part of Roanoke County's previous groundwater supply system,[375] but is now independent. Vinton owned three wells that could pump and distribute 1.73 MGD as part of the County's system;[376] since becoming independent, the system has been upgraded to 14 active wells that are permitted to provide 3.7 MGD by the Virginia Department of Health.[377] Vinton's population currently demands 1.5 MGD; the Town sells 1 MGD to the City of Roanoke and a small portion to the County.[378,379]

A-2.2.4 Roanoke County

In 1996 Roanoke County began operating the Spring Hollow Reservoir in western Roanoke County just upstream from the Glenvar gage on the Roanoke River (USGS Station 02054530). The Spring Hollow Reservoir is dammed by the 243 foot high Clifford D. Craig Memorial Dam that impounds 3.2 billion gallons of water and forms a

[374] See note 28, supra, p. 360.
[375] See note 82, supra, p. II-40.
[376] Id.
[377] "Vinton officials ask residents to voluntarily conserve water." C.S. Murphy. Roanoke Times and World News, August 26, 1999, p. B6.
[378] Id.
[379] The county purchases water from the Vinton system as a result of distribution infrastructure limitations. Gary Robertson, Roanoke County Utilities Director. Lecture given at Virginia Tech, September 22, 1999.

158-acre lake.[380] The Spring Hollow Reservoir collects runoff from the surrounding 540-acre watershed and stores water pumped from the Roanoke River.[381] The water is pumped via an 80 MGD capacity intake structure to the upstream end of the reservoir so that the reservoir may act as the 15 MGD water treatment plant's sedimentation basin.[382] The county currently only uses about 2.5 MGD, but upon expansion the reservoir can supply up to 23 MGD.[383] The reservoir was originally intended to yield 30 MGD,[384] but the Corps of Engineers permit requirements reduced estimated safe yield to 23 MGD.[385]

Withdrawals from the Roanoke River that supply the offstream reservoir are limited by the US Army Corps of Engineers permit granted for the construction in 1988. The permit grants Roanoke County the right to pump water from the River as long as specific minimum instream flows are maintained at the Glenvar gage (See Table A-2.4). The permit requires at least 40 percent of mean annual flow (MAF) to remain instream in April and May of each year.[386] If the reservoir has at least 100 days of water supply, 30 percent MAF is required to flow past the gage for the rest of the year,[387] but with 100 days or less of water supply, only 20 percent MAF must pass.[388]

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380 "Spring Hollow Reservoir Tour." Roanoke County Utility Department. http://www.co.roanoke.us/utility/shr-tour.html.
381 Id.
382 Id.
383 "As city conserves, it sells water to county." C.S. Murphy. Roanoke Times and World News, April 10, 1999, p. A1.
384 See note 82, supra, p. II-48.
385 "Fill'er up time at Spring Hollow Reservoir." Jan Vertefeuille. Roanoke Times and World News, July 11, 1994, p. C1.
386 Department of the Army Permit Number 84-0404-06. Special Condition 13.
387 Id., Special Condition 14.
388 Id., Special Condition 15.

Table A-2.4: Roanoke River flows at Glenvar just downstream from Spring Hollow intake.[389]

Roanoke River at Glenvar USGS Station 02054530	
Period of record	1992-1998
MAF	213 MGD
20% MAF	42.6 MGD
30% MAF	63.9 MGD
40% MAF	85.2 MGD
10% exceedance	417 MGD
50% exceedance	108 MGD
90% exceedance	43.2 MGD

A-2.3 Is There a Water Shortage in the Roanoke Valley?

In the past, the Roanoke Valley local governments have experienced difficulty in cooperating in the planning and development of water resources. The political jurisdictions and traditional divisions create a need to compete for tax income and budget revenues, often placing an emphasized need on separation and independence.[390] The revenue pressures and political climate in the Roanoke Valley traditionally have prevented the cooperation of local governments to pool water resources and supply water through a regional water authority. Low precipitation, high heat and mandatory water conservation measures in 1999 have promoted a change in the governments' isolated independence.

A-2.3.1 Roanoke's Carvins Cove

Beginning in late May 1998, the Carvins Cove pool level dipped below its normal elevation of 1170 feet above mean sea level.[391] Following the El Nino event of late

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[389] See note 28, supra, p. 364.
[390] "Divided we stand in pursuit of prosperity." Dwayne Yancey. Roanoke Times and World News, June 21, 1993, p. A-1.
[391] All cove levels from p. A2 of the Roanoke Times under "Lake levels."

winter and early spring of 1998, Carvins Cove was at its full storage capacity of six billion gallons.[392] The dry conditions of the summer of 1998 caused cove levels to fall through the end of water year 1998. An unusually dry fall and winter in 1998 and into 1999 failed to replenish the Cove.

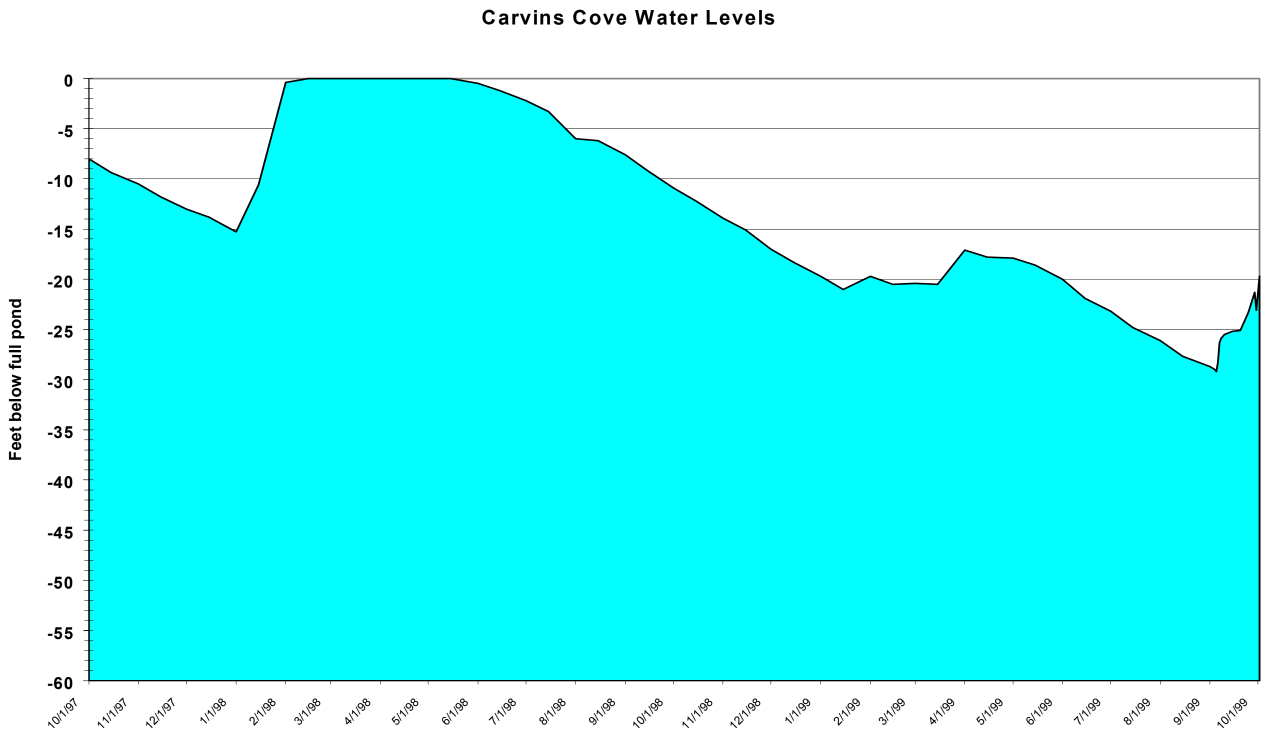

Figure A-2.2: Carvins Cove pool elevation, Jan 1, 1997 through October 1, 1999.

The declining water levels continued through the new year. Moderate rains helped to sustain water levels around the 20 feet below full pool level until May of 1999. In May the levels began to decrease at about one foot every ten days.[393] The high demands of summer caused by filling swimming pools, watering lawns and washing cars drained the Cove to 24 feet below full pool in early July. The twenty-four feet below level was the trigger point for the enactment of mandatory water restrictions for the "first

[392] "Efforts to save water begin." Todd Jackson. Roanoke Times and World News, July 8, 1999, p. A1.

time in City history."[394] The restrictions prohibited serving water without request at local restaurants, watering lawns, washing cars, filling pools and operating ornamental fountains.[395] At 24 feet below full pool, the reservoir's storage capacity is reduced to 50 percent of capacity (3 billion gallons) and can sustain 180 days of water use at current demand levels.[396]

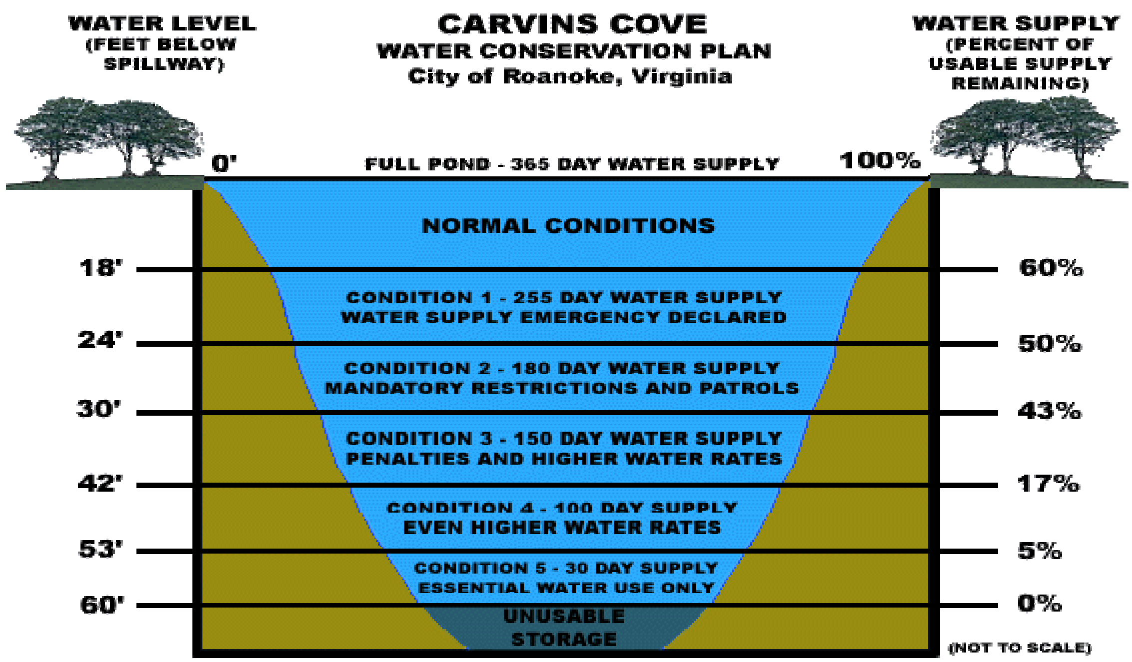

Figure A-2.3: Carvins Cove water levels and available water supply.[397]

The Cove reached its record level of 29.2 feet below full pool on September 5th, 1999. The weekend of September 5th brought nearly five inches of rain to some areas of southwest Virginia[398] and brought the cove level up almost three feet in two days.[399]

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393 "Carvins Cove: Roanoke's Shrinking Water Source." The Roanoke Times, 1999. http://www.roanoke.com/roatimes/Cove.
394 See note 393, supra.
395 Id.
396 "Water Conservation Plan." City of Roanoke, VA, August 11, 1999. http://www.ci.roanoke.va.us/depts/water/wave/plan.html
397 Id.
398 "Dennis storms deliver relief." Tad Dickens and Todd Jackson. Roanoke Times and World News, September 8, 1999, p. A1.
399 "Lake Levels" on p. A2 of the Roanoke Times September 5, 6, and 7, 1999.

Hurricane Dennis significantly contributed to the Tinker Creek and Catawba Creek watersheds; the increased flow conditions permitted the diversion weirs to collect much needed water for the Cove.[400]

A-2.3.2 Compromise in a Time of Need

The question of need arises not from the lack of water within the Roanoke Valley, current collective daily demand is only 50% of current collective daily capacity, but from the lack of past regional cooperation. Although rainfall has been below normal, especially from June 1998 to May 1999, is Mother Nature to blame? Public sentiment in the Valley would answer that the problem lies in the "balkanized local governments'" inability to "view the Valley as a whole."[401] The "Cove crisis" seems to be the result of the City's past reluctance to raise water rates and aid the County in connecting the two systems - "there's no water problem. It's a distribution problem."[402]

The low water levels at Carvins Cove initiated a shift in the attitudes of Roanoke City officials. The City was originally partnered with Roanoke County and the City of Salem to help share the costs and benefits of the Spring Hollow Reservoir. Roanoke and Salem backed out of the project in 1989 when environmental considerations forced reservoir research and construction costs up and reservoir yields down.[403] As the costs continued to increase, Roanoke officials could not justify raising City water rates, "some

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[400] "Watershed's flow into Carvins Cove continues." Todd Jackson. Roanoke Times and World News, September 9, 1999, p. B1.
[401] "More than weather created a water shortage." EDITORIAL. Roanoke Times and World News, April 7, 1999, p. A12. See also Editorials on 4/13/99, 6/9/99, 6/29/99, 7/7/99, 8/2/99, 8/5/99 and Letters to the Editor on 7/13/99, 7/14/99, 8/11/99, 8/12/99, 8/13/99, 8/14/99, 8/16/99, 8/19/99.
[402] "Drought sparks flood of ideas." Todd Jackson and C.S. Murphy. Roanoke Times and World News, June 20, 1999, p. B1.
[403] Gary Robertson, Roanoke County Utilities Director. Lecture given at Virginia Tech, September 22, 1999.

of the state's lowest,"[404] for water that had no immediate need. The continuously declining cove levels through 1999 have made the need more immediate.

The low water levels at Carvins Cove have also prompted an increased desire for regional cooperation. Roanoke Mayor David Bowers in his 1999 "State of the City" address called for regional cooperation that would allow "thinking outside the box."[405] Roanoke County Chairman Bob Johnson expressed the County's desire to "negotiate a solution that is fair to the City."[406] The two governments signed a water-sharing deal on August 11th, 1999 after a summer of negotiations. The deal cancels the County's obligation to buy 2.25 MGD from the City[407] that the County "just as soon not buy" because of a surplus of water at Spring Hollow.[408] The county gained, "at no cost," access to city water lines in the northern portion of the County to distribute Spring Hollow water to county residents.[409] The County is expected to pay for two new connections that will enable the transfer of 3.9 MGD from Spring Hollow to Carvins Cove in times of emergency.[410] The City will lose the five thousand dollars a day it made from the County's purchase of 2.25 MGD that will be replaced by increased customer water rates.[411] The county will save $23 million from the cancelled water purchase contract and the negation of the need to duplicate distribution lines.[412] The County is expected to sell $3 million worth of Spring Hollow water to Roanoke City that will flow

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[404] See note 403, supra.
[405] "Mayor hopes to dampen next water crisis." Todd Jackson. Roanoke Times and World News, July 7, 1999, p. A1.
[406] "A county view of the city's water shortage." Bob Johnson. Roanoke Times and World News, August 3, 1999, p. A9.
[407] "Roanoke strikes a water deal." Todd Jackson and C.S. Murphy. Raonoke Times and World News, August 12, 1999.
[408] "Roanoke's city-county water story gets even more absurd." EDITORIAL. Roanoke Times and World News, April 7, 1999, p. A12.
[409] See note 408, supra.
[410] Id.
[411] Id.
[412] Id.

to Carvins Cove through the duration of the immediate water supply emergency, which will help compensate for the $1.6 million already paid to the City for Carvins Cove water for the remainder of 1999.[413]

A-2.4 Conclusions: Increased Cooperation Between Roanoke Valley Governments?

Although the water deal did not completely interconnect the two systems or create a regional water authority, it exemplifies a growing trend of inter-governmental cooperation in the Roanoke area. In addition to the cooperation necessary to collaborate on the development of the Roanoke Regional Airport, several other projects have shown the Roanoke Valley governments that regional development can be successful. The five Roanoke Valley governments signed a sewage treatment agreement in 1994 that helped share the costs of the $41.5 million expansion of the regional sewage treatment plant.[414] The Roanoke Valley Greenway Commission was established in 1996 through the Fifth District Planning District Commission office and united the Roanoke Valley governments in an effort to protect "open space managed for conservation, recreation and nonmotorized transportation" in the Roanoke area.[415] Roanoke, Roanoke County and Vinton have also developed the Roanoke Valley Resource Authority which owns and operates trash hauling and landfilling services within the Roanoke Valley.[416] Roanoke and Roanoke County have also held discussions "about money-saving ways to (a) cooperate in the delivery of services, (b) standardize regulatory procedures, (c) exploit

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[413] Id.
[414] "Sewer signing nears; treatment plant finishes legal maze." Dan Casey. Roanoke Times and World News, October 3, 1994, p. C1.
[415] Belcher, E.H. "Greenways: The Greening of Roanoke." *The Virginia Review*, Jan/Feb 1998, p. 26.
[416] "Roanoke flip-flops on garbage hauling issue." Dan Casey. Roanoke Times and World News, October 8, 1996, p. C1.

economies of scale,"[417] (d) purchase jointly "employee health insurance" and (e) to unify "police and fire communications."[418] The 1999 water agreement seems to be yet another step in the evolving process of the regionalization of services provided by the governments of the Roanoke Valley.

The "drought" of water year 1999 has helped to initiate new efforts to regionalize the water supply services of the Roanoke Valley. The lack of cooperation in the development of the Spring Hollow Reservoir in previous years has begun to come full circle as Roanoke City was forced to accept its benefits and costs in the summer of 1999. The dependence of Roanoke City on the small catchment areas and flow contributions of Catawba and Tinker Creeks to fill Carvins Cove seems to perpetuate low reservoir levels at the end of the summer of each year. The signing of the new water agreement and the difficulty of developing new sources may provide the elements for a regional water supply system in the future that utilizes the more consistent flow patterns of the Roanoke River and the high but underutilized yields of Spring Hollow. However apparent future water needs may become, a regional water authority cannot be developed without a major shift in the current paradigm of local government separation and independence.

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[417] "Regionalism on a roll." EDITORIAL. Roanoke Times and World News, March 10, 1996, p. F2.
[418] "Roanoke County, City discuss joint insurance." Dan Casey. Roanoke Times and World News, March 5, 1996, p. C1.

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A-2.6: LEGEND FOR FIGURE A-2.1 AND MEASURED RAINFALL AMOUNTS IN THE ROANOKE VALLEY IN WATER YEARS 1998 AND 1999

Municipal

Location	Owner/Description
	Intake
△1	Salem City - Roanoke R. Intake
△2	Salem City - Roanoke R. Intake
△3	Roanoke City - Carvin Cove Res.
△4	Roanoke City - Falling Ck. Res.
⬡2	Salem City - 1 well
⬡3	Roanoke City - 2 wells
⬡4	Roanoke Co. - 2 wells (West Service)
⬡11	Roanoke Co. - 17 wells (North Service)
⬡13	Roanoke Co. - 5 wells (East Service)
⬡14	Vinton Town - 6 wells
⬡15	Roanoke Co. - 47 wells (South Service)
✡1	Salem City - Mowles Spring
✡2	Roanoke City - Crystal Springs
✡3	Roanoke City - Muse Spring
	Water Treatment Plants
□1	Salem City - Glenvar WTP
□2	Salem City - Salem WTP
□3	Roanoke City - Carvins Cove WTP
	Sewage Treatment Plants
○1	Roanoke City - Roanoke Regional STP
○2	Roanoke County - Starkey STP

Industrial

Location	Owner/Description
	Intake
△5	Koppers Inc-Roanoke R. Intake and Discharge
△6	Norfolk & Western Railway - Roanoke R. Intake and Discharge to Lick Run
⬡1	Kroger Co.- 1 well
⬡5	Roanoke Electric Steel- 1 well (Salem)
⬡6	Graham-White Mfg - 2 wells
⬡7	Valleydale Packers - 1 well
⬡8	Virginia Plastics - 3 wells
⬡9	Roanoke Electric Steel - 2 wells and discharge to Peters Creek
⬡10	ITT - 1 well
⬡12	Eli Lilly CO. - 2 wells
	Stream Gages
△3	USGS - Roanoke City - Walnut Street
△4	USGS - near Danville
△5	USGS - below Niagara Dam on Blue Ridge Parkway
△6	USGS - near Dundee
	Diversions
☆	Catawba Ck. to Carvins Cove Reservoir
☆	Tinker Creek to Carvins Cove Reservoir
☆	Beaverdam Reservoir to Falling Creek Reservoir

Figure A-2.4: Legend for Figure A-2.1.[419]

[419] See note 82, supra, p. II-39.

Month	avg rain[1]	WY 98[2]	WY 99[2]
October	3.85"	1.39"	1.47"
November	3.19"	2.65"	0.86"
December	2.97"	2.37"	2.32"
January	2.62"	7.97"	3.70"
February	3.04"	8.00"	2.14"
March	3.48"	5.20"	2.77"
April	3.25"	4.58"	2.71"
May	3.98"	4.47"	2.27"
June	3.19"	2.03"	0.86"
July	3.91"	0.86"	5.96"
August	4.10"	6.17"	2.63"
September	3.50"	1.10"	7.38"
Annual	41.09	46.79	35.07

			departure
1997	october	1.39	-2.46
	november	2.65	-0.54
	december	2.37	-0.6
1998	january	7.97	5.35
	february	8.00	4.96
	march	5.20	1.72
	april	4.58	1.33
	may	4.47	0.49
	SUBTOTAL	**36.63**	**10.25**
	june	2.03	-1.16
	july	0.86	-3.05
	august	6.17	2.07
	september	1.10	-2.40
	october	1.47	-2.38
	november	0.86	-2.33
	december	2.32	-0.65
1999	january	3.70	1.08
	february	2.14	-0.90
	march	2.77	-0.71
	april	2.71	-0.54
	may	2.27	-1.71
	SUBTOTAL	**28.40**	**-12.68**
	june	0.86	-2.33
	july	5.96	2.05
	august	2.63	-1.47
	SUBTOTAL	**9.45**	**-1.75**
	september	7.38	3.88
	SUBTOTAL	**7.38**	**3.88**
	TOTAL	**72.41**	**-0.3**

-14.43

1. The average rainfall data from the Roanoke Airport gage, 1961-1990, http://water.dnr.state.sc.us/climate/sercc/products/normals/447285_30yr_norm.html
2. The monthly rainfall totals from p. A2 of the Roanoke Times on the 2nd of each following month.

VITA

Troy Brandon Wallace, son of William Oliver Wallace, Jr. and Holly Francis Christmas Wallace, was born on April 30th, 1976 in Chicago, Illinois. After graduating from Frederick High School in 1994, Troy went to Virginia Polytechnic Institute and State University to pursue Civil and Environmental Engineering. With a Bachelor's Degree in 1998, Troy was invited to join the Hydrosystems Division Master's Degree program, and completed the degree requirements in March, 2001. Upon graduation, Troy joined the Faculty of the Charles E. Via, Jr. Department of Civil and Environmental Engineering for a short-term project that was an extension of his graduate work. Troy is a member of the American Water Resources Association, the American Society of Civil Engineers, and Chi Epsilon Honors Society.

APPENDICES:

Preliminary Assessment of Water Supply Availability in the Commonwealth of Virginia

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APPENDIX A: PLANNING AREAS DEVELOPED FROM

VIRGINIA HYDROLOGIC UNITS

#	BASIN NAME	STATE UNITS	CONTRIBUTING RIVERS	USGS UNITS INCLUDED	DRAINAGE (mi^2)
1	Upper Potomac	A01-A25	Potomac, Occoquan, Goose Cr.	02070008, 10	1625.60
2	Lower Potomac	A26-A34	Potomac, Chopawamsic Cr., Quantico Cr.	02070011	691.08
3	Up Shen/Laurel	B01-B03,B10-B34	S.F. Shenan., South, Christ. Cr., Middle	02070001, 05(p'tl)	1233.23
4	L Shen/Opequon	B04-B09,B35-B58	N.F. Shenan., S.F. Shenan.	02070004, 05(p'tl), 06, 07	2151.87
5	Upper Rappahannock	E01-E18	Rappahannock, Rapidan	02080103	1566.90
6	Lower Rappahannock	E19-E26	Rappahannock	02080104	1157.13
7	Pamunkey	F01-F14	N. Anna, S. Anna, Pamunkey	02080106	1472.76
8	Mattaponi	F15-F25	Matta, Po, Ni, Mattaponi	02080105	911.40
9	Upper James/Maury	I01-I37	James, Cowpasture, Jackson, Maury	2080201, 02	2976.03
10	U Mid James/Rivanna	H01-H32	James, Slate, Hardware, Rockfish, Rivanna	02080203, 04	2790.46
11	Lower Middle James	H33-H39	James, Willis	02080205	945.49
12	Appomattox	J01-J17	Appomattox, Swift Cr.	02080207	1598.35
13	Lower James	G01-G15	Chickahominy, James	02080206	1925.85
14	Mainland Bay/York	C01-C08, D07,F26-F27	Piankatank, G. Wicomico, Ware Cr., York	02080102, 07, 08	1114.26
15	Eastern Shore	C09-C16,D01-D06		02080109, 10	1105.30
16	Meherrin	K01-K13	Meherrin, Great Cr., Fountaine Cr.	3010204	1115.53
17	Nottoway	K14-30	Nottoway, Stony Cr., Assamoosick Swamp	3010201	1722.63
18	Blackwater/SE Coast	K31-K42	Blackwater, Seacock Cr., NW River	03010202, 03, 05	1413.37
19	Upper Roanoke	L01-L29	Roanoke, Pigg, Big Otter, Goose Cr.	03010101	2191.30
20	Lower Roanoke	L30-L41, L75-L82	Roanoke	03010102, 06	1811.01
21	Martinsville/Ararat	L42-L56,M01-M03	Smith, Dan, Mayo, Ararat	03010103(p'tl), 03040101	1028.37
22	Danville	L57-L74	Banister, Dan. Hyco	03010103 (p'tl), 05, 04	1361.23
23	Upper New	N01-N15	New	5050001 (p'tl)	1455.80
24	Lower New	N16-N37	New, Little, Little Walker Cr., Claytor Lake	5050001 (p'tl), 02	1609.54
25	Holston	O01-O14	S.F. Holston, M.F. Holston, N.F. Holston	06010102,01	1322.04
26	Clinch/Powell	P01-P24	Clinch, Powell	06010205, 06	1810.81
27	Big Sandy	Q01-Q13	Levisa F., Russel F.	05070201, 02	998.81

VIRGINIA area by summing planning areas		**41106**
Chesapeake Bay		1223
	Excluding BAY	<u>**including BAY**</u>
Virginia Area by summing County and City areas within Hydrologic Units	41082	**42304**
Virginia Area by summing County and City Jurisdictional Areas	41081	**42304**
Virignia area by summing planning areas*	41106	**42329**
Virginia area by summing hydrologic unit areas*	41098	**42321**
difference in area by summing h.u. basin areas	17	0.04%
difference in area by summing planning areas	25	0.06%

*Discrepancy in land area totals is assumed to be negligible and the result of the fact that planning and hydrologic unit areas were based on areas projected in Arcview GIS rather than the hydrologic unit areas reported in the Hydrologic Unit Atlas.

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.^{2})	% Basin
Upper Potomac					
	A01	23,801	Potomac River--Piney Run--Dutchman Creek	37.19	2.29%
	A02	59,209	Catoctin Creek	92.51	5.69%
	A03	27,357	Potomac River--Limestone Branch	42.75	2.63%
	A04	50,855	Upper Goose Creek--Gap Run	79.46	4.89%
	A05	57,022	Middle Goose Creek--Panther Skin Creek	89.10	5.48%
	A06	28,483	North Fork Goose Creek	44.50	2.74%
	A07	34,175	Beaverdam Creek	53.40	3.28%
	A08	76,601	Lower Goose Creek--Little Run	119.69	7.36%
	A09	54,975	Potomac River--Broad Run	85.90	5.28%
	A10	14,488	Sugarload Run	22.64	1.39%
	A11	56,759	Potomac River--Difficult Run	88.69	5.46%
	A12	27,495	Potomac River--Fourmile Run--Pimmit Run	42.96	2.64%
	A13	28,518	Cameron Run	44.56	2.74%
	A14	22,046	Potomac River--Dogue Creek--Little Hunting Creek	34.45	2.12%
	A15	36,555	Accotink Creek	57.12	3.51%
	A16	23,316	Pohick Creek	36.43	2.24%
	A17	65,282	Upper Cedar Run--Licking Run	102.00	6.27%
	A18	60,137	Lower Cedar Creek--Town Run	93.96	5.78%
	A19	88,401	Broad Run--Kettle Run	138.13	8.50%
	A20	18,391	Upper Occoquan River--Lake Jackson	28.74	1.77%
	A21	59,791	Upper Bull Run--Little Bull Run	93.42	5.75%
	A22	33,813	Cub Run	52.83	3.25%
	A23	30,899	Lower Bull Run--Popes Head Creek	48.28	2.97%
	A24	22,465	Occoquan River Reservoir	35.10	2.16%
	A25	39,547	Potomac River--Lower Occoquan River--Neabsco Creek	61.79	3.80%
TOTAL		1,040,383		1,625.60	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.^{2})	% Basin
Lower Potomac					
	A26	66,737	Potomac River--Quantico Creek--Chopawamsic Creek	104.28	15.09%
	A27	35,674	Upper Aquia Creek--Beaverdam Run	55.74	8.07%
	A28	20,942	Lower Aquia Creek	32.72	4.73%
	A29	73,743	Potomac River--Potomac Creek	115.22	16.67%
	A30	38,978	Potomac River--Upper Machodoc Creek	60.90	8.81%
	A31	52,444	Potomac River--Mattox Creek--Popes Creek--Rosier Creek	81.94	11.86%
	A32	58,823	Potomac River--Nominin Creek--Lower Machodoc Creek	91.91	13.30%
	A33	42,398	Potomac River--Yeomico River	66.25	9.59%
	A34	52,553	Potomac River--Coan River--Lower Wicomico River	82.11	11.88%
TOTAL		442,291		691.08	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.^{2})	% Basin
Upper Shenandoah					
	B10	39,777	Upper Middle River	62.15	5.04%
	B11	41,864	Middle River--Jennings Branch	65.41	5.30%
	B12	48,991	Middle River--Lewis Creek	76.55	6.21%
	B13	17,148	Moffett Creek	26.79	2.17%
	B14	68,792	Christians Creek	107.49	8.72%
	B15	22,686	Lower Middle River	35.45	2.87%
	B16	41,550	Upper Middle River	64.92	5.26%
	B17	28,350	Middle North River	44.30	3.59%
	B18	31,677	Briery Branch	49.50	4.01%
	B19	10,078	Mossy Creek	15.75	1.28%
	B20	46,721	Upper Dry River	73.00	5.92%
	B21	10,059	Lower Dry River	15.72	1.27%
	B22	20,047	Muddy Creek	31.32	2.54%
	B23	26,868	Lower North River	41.98	3.40%
	B24	11,871	Long Glade Creek	18.55	1.50%
	B25	15,918	Cooks Creek	24.87	2.02%
	B26	12,254	Blacks Run	19.15	1.55%
	B27	5,309	Pleasant Run	8.30	0.67%
	B28	14,675	Naked Creek	22.93	1.86%
	B29	9,636	Mill Creek	15.06	1.22%
	B30	26,847	Upper South River	41.95	3.40%
	B31	52,260	Middle South River	81.66	6.62%
	B32	71,044	Lower South River	111.01	9.00%
	B33	28,604	Middle South Fork Shenandoah River	44.69	3.62%
	B34	17,162	Cub Run	26.81	2.17%
Laurel	B01	24,059	Upper North Fork South Branch Potomac River--Laurel Fork	37.59	3.05%
	B02	37,898	Upper South Branch Potomac River	59.22	4.80%
	B03	7,126	Upper South Fork South Branch Potomac River	11.13	0.90%
TOTAL		720,186		1,233.23	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.^{2})	% Basin
Lower Shenandoah					
	B35	68,672	South Fork Shenandoah River--Elk Run--Boone Run	107.30	4.99%
	B36	28,149	Naked Creek	43.98	2.04%
	B37	46,799	South Fork Shenandoah River--Cub Run	73.12	3.40%
	B38	35,644	South Fork Shenandoah River--Mill Creek	55.69	2.59%
	B39	56,791	Hawksbill Creek	88.74	4.12%
	B40	81,352	South Fork Shenandoah River--Gooney	127.11	5.91%
	B41	32,473	Lower South Fork Shenandoah River	50.74	2.36%
	B42	42,456	Upper North Fork Shenandoah River--German River	66.34	3.08%
	B43	36,291	North Fork Shenandoah River--Little Dry River	56.71	2.64%
	B44	43,737	North Fork Shenandoah River--Shoemaker River	68.34	3.18%
	B45	64,536	North Fork Shenandoah River--Holmans Creek	100.84	4.69%
	B46	29,764	Linville Creek	46.51	2.16%
	B47	67,276	Smith Creek	105.12	4.89%
	B48	47,202	North Fork Shenandoah River--Mill Creek	73.75	3.43%
	B49	72,622	Stony Creek	113.47	5.27%
	B50	55,220	North Fork Shenandoah River--Narrow Passage Creek	86.28	4.01%
	B51	35,049	Lower North Fork Shenandoah River--Tumbling Run	54.76	2.54%
	B52	55,904	Upper Cedar Creek	87.35	4.06%
	B53	44,716	Lower Cedar Creek	69.87	3.25%
	B54	56,186	Passage Creek	87.79	4.08%
	B55	45,603	Upper Shenandoah River	71.25	3.31%
	B56	30,303	Crooked Run	47.35	2.20%
	B57	46,339	Shenandoah River--Spout Run	72.41	3.36%
	B58	36,898	Lower Shenandoah River	57.65	2.68%
Opequon	B04	12,974	Sleepy Creek	20.27	0.94%
	B05	45,743	Upper Back Creek--Isaacs Creek	71.47	3.32%
	B06	26,673	Hogue Creek	41.68	1.94%
	B07	34,943	Lower Back Creek--Brush Creek--Babbs Run	54.60	2.54%
	B08	37,341	Upper Opequon Creek	58.35	2.71%
	B09	59,543	Lower Opequon Creek	93.04	4.32%
TOTAL		1,159,982		2,151.88	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Upper Rappahannock					
	E01	79,209	Upper Rappahannock River--Thumb Run--Jordan River	123.76	7.95%
	E02	84,770	Rappahannock River--Carter Run--Great Run	132.45	8.51%
	E03	30,646	Hughes River	47.88	3.08%
	E04	49,337	Upper Hazel River	77.09	4.95%
	E05	59,642	Upper Thornton River	93.19	5.99%
	E06	40,656	Lower Thornton River	63.52	4.08%
	E07	43,977	Lower Hazel River--Muddy Run--Indian Run	68.71	4.41%
	E08	54,863	Rappahannock River--Marsh Run	85.72	5.51%
	E09	58,111	Mountain Run	90.80	5.83%
	E10	50,298	Rappahannock River--Deep Run--Rock Run	78.59	5.05%
	E11	45,416	Upper Rapidan River--Conway River	70.96	4.56%
	E12	35,416	Rapidan River--South River	55.34	3.55%
	E13	76,439	Rapidan River--Blue Run--Beautiful Run	119.44	7.67%
	E14	55,383	Upper Robinson River--White Oak Run	86.54	5.56%
	E15	68,950	Lower Robinson River--Crooked Run--Deep Run	107.73	6.92%
	E16	38,170	Rapidan River--Cedar Run	59.64	3.83%
	E17	74,611	Rapidan River--Mine Run--Mountain Run	116.58	7.49%
	E18	50,524	Lower Rapidan River	78.94	5.07%
TOTAL		996,418		1556.90	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Lower Rappahannock					
	E19	29,009	Rappahannock River--Motts Run	45.33	3.92%
	E20	59,907	Rappahannock River--Massaponax Creek	93.60	8.09%
	E21	127,974	Rappahannock River--Mill Creek--Goldenvale Creek	199.96	17.28%
	E22	98,986	Rappahannock River--Occupacia Creek--Peedee Creek	154.67	13.37%
	E23	143,771	Rappahannock River--Catpoint Creek--Piscataway Creek	224.64	19.41%
	E24	63,588	Rappahannock River--Totuskey Creek	99.36	8.59%
	E25	108,261	Rappahannock River--Lagrange Creek--Lancaster Creek	169.16	14.62%
	E26	109,071	Lower Rappahannock River--Corrotman River	170.42	14.73%
TOTAL		740,565		1157.13	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Pamunkey					
	F01	50,410	Upper South Anna River	78.77	5.35%
	F02	61,732	South Anna River--Roundabout Creek	96.46	6.55%
	F03	120,974	South Anna River--Taylors Creek	189.02	12.83%
	F04	38,923	Lower South Anna River	60.82	4.13%
	F05	26,248	Newfound River	41.01	2.78%
	F06	84,941	Upper North Anna River	132.72	9.01%
	F07	119,773	Lake Anna--Pamunkey Creek	187.15	12.71%
	F08	13,932	Contrary Creek	21.77	1.48%
	F09	86,307	Lower North Anna River--Northeast Creek	134.86	9.16%
	F10	30,432	Upper Little River	47.55	3.23%
	F11	45,262	Lower Little River	70.72	4.80%
	F12	56,156	Upper Pamunkey River--Mechumps Creek	87.74	5.96%
	F13	137,487	Middle Pamunkey River--Black Creek--Totopotomoy Creek	214.82	14.59%
	F14	69,986	Lower Pamunkey River	109.35	7.43%
TOTAL		942,565		1472.76	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Mattaponi	F15	33,148	Ni River	51.79	5.68%
	F16	59,416	Po River	92.84	10.19%
	F17	46,475	Upper Mattaponi River--Poni River	72.62	7.97%
	F18	41,896	Matta River	65.46	7.18%
	F19	40,018	South River	62.53	6.86%
	F20	31,512	Polecat Creek	49.24	5.40%
	F21	111,059	Mattaponi River--Herring Creek--Chapel Creek	173.53	19.04%
	F22	87,720	Maracossic Creek--Beverly Run	137.06	15.04%
	F23	61,253	Mattaponi River--Garnetts Creek	95.71	10.50%
	F24	42,116	Mattaponi River--Courthouse Creek	65.81	7.22%
	F25	28,679	Lower Mattaponi River	44.81	4.92%
TOTAL		583,294		911.40	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.^{2})	% Basin
Upper James					
	I01	101,135	Upper Jackson River	158.02	5.31%
	I02	90,299	Back Creek	141.09	4.74%
	I03	28,977	Lake Moomaw--Hughes Draft	45.28	1.52%
	I04	40,215	Jackson River--Falling Spring Creek	62.84	2.11%
	I05	22,979	Cedar Creek	35.91	1.21%
	I06	7,834	Cove Creek--Sweet Springs Creek	12.24	0.41%
	I07	55,495	Dunlap Creek	86.71	2.91%
	I08	25,189	Ogle Creek	39.36	1.32%
	I09	75,421	Lower Jackson River--Wilson Creek--Karnes Creek	117.85	3.96%
	I10	38,496	Upper Potts Creek	60.15	2.02%
	I11	44,345	Lower Potts Creek	69.29	2.33%
	I12	48,545	Upper Cowpasture River	75.85	2.55%
	I13	70,441	Bullpasture River	110.06	3.70%
	I14	60,793	Cowpasture River--Thompson Creek--Dry Run	94.99	3.19%
	I15	31,694	Stuart Run	49.52	1.66%
	I16	36,854	Cowpasture River--Mill Creek	57.58	1.93%
	I17	48,498	Lower Cowpasture River--Simpson Creek--Pads Creek	75.78	2.55%
	I18	55,056	Upper James River--Sinking Creek--Mill Creek	86.02	2.89%
	I19	62,838	Upper Craig Creek	98.18	3.30%
	I20	8,779	Meadow Creek	13.72	0.46%
	I21	66,987	Johns Creek	104.67	3.52%
	I22	79,463	Lower Craig Creek--Patterson Creek---Lower Barbours Creek	124.16	4.17%
	I23	19,988	Upper Barbours Creek	31.23	1.05%
	I24	41,954	James River--Lapsley Run	65.55	2.20%
	I25	73,830	Catawba Creek	115.36	3.88%
	I26	39,974	Looney Creek--Mill Creek	62.46	2.10%
	I27	54,547	James River--Jennings Creek	85.23	2.86%
	I28	37,731	James River--Elk Creek--Cedar Creek	58.95	1.98%
Maury	I29	47,055	Upper Calfpasture River	73.52	2.47%
	I30	85,413	Lower Calfpasture River--Mill Creek	133.46	4.48%
	I31	18,448	Brattons Run	28.82	0.97%
	I32	53,440	Little Calfpasture River	83.50	2.81%
	I33	52,091	Upper Maury River--Kerrs Creek	81.39	2.73%
	I34	51,412	Hays Creek	80.33	2.70%
	I35	29,771	Middle Maury River--Mill Creek	46.52	1.56%
	I36	75,916	South River	118.62	3.99%
	I37	43,615	Lower Maury River--Poague River	68.15	2.29%
	I38	79,141	Buffalo Creek	123.66	4.16%
TOTAL		1,904,657		2976.03	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Upper Middle James					
	H01	62,461	James River--Reed Creek	97.59	3.50%
	H02	68,380	Pedlar River	106.84	3.83%
	H03	77,386	James River--Blackwater Creek--Ivy Creek	120.92	4.33%
	H04	30,808	Harris Creek	48.14	1.73%
	H05	105,983	James River--Beaver Creek--Beck Creek	165.60	5.93%
	H06	37,510	Wreck Island Creek	58.61	2.10%
	H07	19,933	Bent Creek	31.15	1.12%
	H08	44,517	James River--David Creek	69.56	2.49%
	H09	81,748	Upper Tye River	127.73	4.58%
	H10	45,344	Piney River	70.85	2.54%
	H11	60,662	Upper Buffalo River	94.78	3.40%
	H12	37,504	Lower Buffalo River	58.60	2.10%
	H13	42,234	Lower Tye River--Rucker Run	65.99	2.36%
	H14	45,836	James River--Sycamore Creek	71.62	2.57%
	H15	57,084	North Fork Rockfish River--South Fork Rockfish River	89.19	3.20%
	H16	101,387	Lower Rockfish River	158.42	5.68%
	H17	74,499	James River--Totier Creek--Rock Island Creek	116.40	4.17%
	H18	49,110	North Fork Hardware River--South Fork Hardware River	76.73	2.75%
	H19	39,061	Hardware River	61.03	2.19%
	H20	56,080	James River--Bear Garden Creek--South Creek	87.62	3.14%
	H21	98,972	Upper Slate River	154.64	5.54%
	H22	58,004	Lower Slate River	90.63	3.25%
Rivanna	H23	63,478	Mechums River	99.18	3.55%
	H24	49,376	Moormans River	77.15	2.76%
	H25	23,096	Buck Mountain Creek	36.09	1.29%
	H26	35,181	South Fork Rivanna River--Ivy Creek	54.97	1.97%
	H27	113,229	North Fork Rivanna River--Swift Run--Preddy Creek	176.92	6.34%
	H28	37,662	Upper Rivanna River--Moores Creek	58.85	2.11%
	H29	45,668	Middle Rivanna River--Buck Island Creek	71.36	2.56%
	H30	40,153	Mechunk Creek	62.74	2.25%
	H31	60,383	Lower Rivanna River--Ballinger Creek	94.35	3.38%
	H32	23,202	Cunningham Creek	36.25	1.30%
TOTAL		1,294,502		2790.51	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Lower Middle James					
	H33	114,220	James River--Deep Creek--Muddy Creek	178.47	18.88%
	H34	72,146	Byrd Creek	112.73	11.92%
	H35	67,796	Upper Willis River	105.93	11.20%
	H36	110,334	Lower Willis River	172.40	18.23%
	H37	45,430	Big Lickinghole Creek	70.98	7.51%
	H38	65,378	James River--Beaverdam Creek--Fine Creek	102.15	10.80%
	H39	129,811	James River--Tuckahoe Creek--Norwood Creek	202.83	21.45%
TOTAL		605,115		945.49	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Appomattox					
	J01	125,568	Upper Appomattox River	196.20	12.28%
	J02	74,177	Buffalo Creek--Spring Creek	115.90	7.25%
	J03	28,056	Sandy River	43.84	2.74%
	J04	43,968	Bush River	68.70	4.30%
	J05	27,248	Briery Creek	42.58	2.66%
	J06	101,711	Appomattox River--Big Guinea Creek--Saylers Creek	158.92	9.94%
	J07	76,170	Appomattox River--Skinquarter Creek--Rocky Ford Creek	119.02	7.45%
	J08	73,873	Flat Creek	115.43	7.22%
	J09	16,449	Nibbs Creek	25.70	1.61%
	J10	36,018	Appomattox River--Smacks Creek--Sappony Creek	56.28	3.52%
	J11	131,601	Deep Creek	205.63	12.86%
	J12	53,730	Lake Chesdin--Whipponock Creek	83.95	5.25%
	J13	40,392	Namozine Creek	63.11	3.95%
	J14	25,012	Lake Chesdin--Winterpock Creek--Winticomack Creek	39.08	2.45%
	J15	52,571	Lower Appomattox River--Ashton Creek	82.14	5.14%
	J16	41,161	Upper Swift Creek--Swift Creek Reservoir	64.31	4.02%
	J17	75,241	Lower Swift Creek	117.56	7.36%
TOTAL		1,022,945		1598.35	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Lower James					
	G01	102,442	James River--Falling Creek--Proctors Creek	160.07	8.31%
	G02	56,404	James River--Turkey Island Creek--Fourmile Creek	88.13	4.58%
	G03	94,226	James River--Powell Creek--West Run--Bailey Creek	147.23	7.64%
	G04	85,935	James River--Wards Creek--Upper Chippokes Creek	134.27	6.97%
	G05	67,999	Upper Chickahominy River--Upham Brook--Stony Run	106.25	5.52%
	G06	80,287	Chickahominy River--White Oak Swamp--Beaverdam Creek	125.45	6.51%
	G07	46,014	Chickahominy River--Rumley River	71.90	3.73%
	G08	78,001	Lower Chickahominy River--Morris Creek--Lower Diascund Creek	121.88	6.33%
	G09	27,992	Upper Diascund Creek--Diascund Creek Reservoir	43.74	2.27%
	G10	91,164	James River--Powhatan Creek--Grays Creek	142.44	7.40%
	G11	198,662	James River--Pagen River--Warwick River--Chuckatuck Creek	310.41	16.12%
	G12	41,123	Speights Run--Lake Cohoon-Lake Meade--Lake Kilby	64.25	3.34%
	G13	55,378	Nansemond River--Bennett Creek	86.53	4.49%
	G14	41,825	Western Branch Resrvoir	65.35	3.39%
	G15	165,092	Hamptons River--Elizabeth River	257.96	13.39%
TOTAL		1,232,544		1925.85	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Mainland Chesapeake Bay					
	C01	83,107	Chesapeake Bay--Great Wicomico River	129.85	11.65%
	C02	89,789	Dragon Swamp	140.30	12.59%
	C03	52,275	Piankatank River	81.68	7.33%
	C04	86,121	Chesapeake Bay--East River--North River	134.56	12.08%
	C05	47,917	Ware River	74.87	6.72%
	C06	31,652	Chespeake Bay--Severn River	49.46	4.44%
	C07	76,151	Chesapeake Bay--Back River--Poquoson River	118.99	10.68%
	C08	60,928	Lynnhaven River--Little Creek	95.20	8.54%
	D07	2,736	Rudee Inlet	4.27	0.38%
York	F26	129,238	Upper York River--Poropotank River--Queen Creek--Ware Creek	201.93	18.12%
	F27	53,215	Lower York River--Carter Creek--King Creek	83.15	7.46%
TOTAL		713,129		1114.26	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Eastern Shore	C09	19,509	Pocomoke River--Pitts Creek	30.48	2.76%
	C10	178,607	Chesapeake Bay--Holdens Creek	279.07	25.25%
	C11	22,191	Chesapeake Bay--Onancock Creek	34.67	3.14%
	C12	16,510	Pungoteague Creek	25.80	2.33%
	C13	57,429	Nandua Creek--Occohannock Creek--Nasawadox Creek	89.73	8.12%
	C14	19,498	Chesapeake Bay--Hungars Creek	30.47	2.76%
	C15	13,845	Cherrystone Inlet--Kings Creek	21.63	1.96%
	C16	11,127	Chesapeake Bay--Old Plantation Creek	17.39	1.57%
	D01	75,529	Chincoteague Bay--Little Mosquito Creek	118.01	10.68%
	D02	10,118	Assawoman Creek	15.81	1.43%
	D03	67,882	Metomkin Bay--Burtons Bay	106.07	9.60%
	D04	106,095	Hog Island Bay--Machipongo River	165.77	15.00%
	D05	43,414	Outlet Bay--Ramshorn Bay	67.83	6.14%
	D06	65,638	Magothy Bay--Mockhorn Bay	102.56	9.28%
TOTAL		707,391		1105.30	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Meherrin					
	K01	66,937	South Meherrin River--Middle Meherrin River	104.59	9.38%
	K02	98,264	North Meherrin River	153.54	13.76%
	K03	82,311	Upper Meherrin River--Flat Rock Creek--Mason Creek	128.61	11.53%
	K04	49,276	Meherrin River--Stony Creek--Taylors Creek	76.99	6.90%
	K05	67,102	Meherrin River--Genito Creek--Allen Creek	104.85	9.40%
	K06	36,713	Great Creek	57.36	5.14%
	K07	17,592	Roses Creek	27.49	2.46%
	K08	57,150	Meherrin River--Reedy Creek	89.30	8.00%
	K09	52,688	Meherrin River--Falling Run	82.32	7.38%
	K10	47,510	Upper Fontaine Creek--Rattlesnake Creek	74.23	6.65%
	K11	44,593	Middle Fountaine Creek--Cattail Creek--Beaverpond Creek	69.68	6.25%
	K12	31,149	Lower Fountaine Creek--Mill Swamp	48.67	4.36%
	K13	62,652	Lower Meherrin River--Tarrara Creek--Flat Swamp	97.89	8.78%
TOTAL		713,937		1115.53	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Nottoway					
	K14	71,804	Upper Nottoway River--Big Hounds Creek	112.19	6.51%
	K15	48,493	Little Nottoway River	75.77	4.40%
	K16	88,846	Nottoway River--Tommeheton Creek--Crooked Creek	138.82	8.06%
	K17	56,718	Nottoway River--Waqua Creek	88.62	5.14%
	K18	33,111	Sturgeon Creek	51.74	3.00%
	K19	75,185	Nottoway River--Bicksin Creek--Harris Swamp	117.48	6.82%
	K20	60,440	Butterwood Creek--White Oak Creek	94.44	5.48%
	K21	52,154	Stony Creek--Southwest Swamp	81.49	4.73%
	K22	44,480	Sappony Creek	69.50	4.03%
	K23	152,783	Nottoway River--Rowanty Creek--Jones Hole Swamp	238.72	13.86%
	K24	54,370	Nottoway River--Hunting Quarter Swamp	84.95	4.93%
	K25	43,507	Raccoon Creek--Spring Creek	67.98	3.95%
	K26	67,382	Upper Three Creek--Otterdam Swamp	105.28	6.11%
	K27	72,292	Lower Three Creek--Angelico Creek--Poplar Swamp	112.96	6.56%
	K28	63,455	Nottoway River--Mill Swamp--Nottoway Swamp	99.15	5.76%
	K29	69,357	Assamoosick Swamp	108.37	6.29%
	K30	48,106	Lower Nottoway River--Mill Creek	75.17	4.36%
TOTAL		1,102,482		1722.63	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Blackwater					
	K31	77,130	Blackwater Swamp--Warwick Swamp	120.52	8.53%
	K32	108,139	Upper Blackwater River--Cypress Swamp	168.97	11.95%
	K33	61,153	Middle Blackwater River	95.55	6.76%
	K34	55,416	Rattlesnake Swamp--Mill Swamp	86.59	6.13%
	K35	66,014	Seacock Swamp	103.15	7.30%
	K36	104,811	Lower Blackwater River--Kingsale Swamp--Corrowaugh Swamp	163.77	11.59%
	K37	1,225	Upper Chowan River--Buckhorn Creek	1.91	0.14%
	K38	61,488	Somerton Creek	96.07	6.80%
Southeast Coastal	K39	126,087	Dismal Swamp--Cypress Swamp	197.01	13.94%
	K40	70,715	Northwest River	110.49	7.82%
	K41	105,651	North Landing River	165.08	11.68%
	K42	66,725	Back Bay	104.26	7.38%
TOTAL		904,555		1413.37	100.00%

Upper Roanoke					
	L01	88,608	South Fork Roanoke River--Bottom Creek--Elliott Creek	138.45	6.32%
	L02	74,077	North Fork Roanoke River--Bradshaw Creek	115.74	5.28%
	L03	40,545	Upper Roanoke River	63.35	2.89%
	L04	53,302	Roanoke River--Mason Creek	83.28	3.80%
	L05	71,628	Tinker Creek--Carvin Creek--Glade Creek	111.92	5.11%
	L06	37,546	Back Creek	58.67	2.68%
	L07	94,855	Roanoke River--Smith Mountain Lake--Beaverdam Creek	148.21	6.76%
	L08	75,652	Upper Blackwater River	118.21	5.39%
	L09	29,184	Maggodee Creek	45.60	2.08%
	L10	45,837	Lower Blackwater River--Smith Mountain Lake	71.62	3.27%
	L11	27,352	Gills Creek	42.74	1.95%
	L12	12,096	Lower Smith Mountain Lake	18.90	0.86%
	L13	41,783	Leesville Lake--Old Womans Creek	65.29	2.98%
	L14	69,593	Upper Pigg River	108.74	4.96%
	L15	39,222	Big Chestnutt Creek--Little Chestnutt Creek	61.28	2.80%
	L16	23,277	Middle Pigg River	36.37	1.66%
	L17	66,059	Snow Creek--Turkeycock Creek	103.22	4.71%
	L18	52,840	Lower Pigg River	82.56	3.77%
	L19	45,989	Roanoke River--Sycamore Creek	71.86	3.28%
	L20	38,992	Upper Goose Creek	60.93	2.78%
	L21	62,799	Middle Goose Creek--Bore Auger Creek--Wolf Creek	98.12	4.48%
	L22	63,017	Lower Goose Creek	98.46	4.49%
	L23	34,766	Upper Big Otter River	54.32	2.48%
	L24	32,427	North Otter Creek	50.67	2.31%
	L25	42,829	Big Otter River--Elk Creek	66.92	3.05%
	L26	44,269	Little Otter River--Machine Creek	69.17	3.16%
	L27	44,636	Big Otter River--Buffalo Creek	69.74	3.18%
	L28	27,661	Lower Big Otter River	43.22	1.97%
	L29	21,594	Flat Creek	33.74	1.54%
TOTAL		1,402,434		2191.30	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Lower Roanoke					
	L30	126,788	Roanoke River--Straightstone Creek--Childrey Creek	198.11	10.94%
	L31	35,463	Seneca River	55.41	3.06%
	L32	40,661	Upper Falling River	63.53	3.51%
	L33	30,639	South Fork Falling River	47.87	2.64%
	L34	60,783	Lower Falling River--Little Falling River	94.97	5.24%
	L35	19,155	Molleys Creek	29.93	1.65%
	L36	62,196	Roanoke River--Turnip Creek--Catawba Creek	97.18	5.37%
	L37	95,364	Cub Creek	149.01	8.23%
	L38	38,794	Roanoke River--Hunting Creek--Wallace Branch	60.62	3.35%
	L39	140,320	Roanoke Creek--Horsepen Creek--Wards Fork Creek	219.25	12.11%
	L40	41,419	Roanoke River--Sandy Creek	64.72	3.57%
	L41	45,547	Difficult Creek	71.17	3.93%
	L75	121,719	John Kerr Reservoir--Butcher Creek	190.19	10.50%
	L76	15,704	Buffalo Creek	24.54	1.35%
	L77	68,643	Bluestone Creek--Little Bluestone Creek	107.25	5.92%
	L78	81,842	Lake Gaston--Allen Creek--Cox Creek	127.88	7.06%
	L79	61,009	Lake Gaston--Miles Creek--Flat Creek--Smith Creek	95.33	5.26%
	L80	24,099	Lake Gaston--Great Creek	37.65	2.08%
	L81	34,782	Lake Gaston--Poplar Creek	54.35	3.00%
	L82	14,121	Lake Gaston--Pea Hill Creek	22.06	1.22%
TOTAL		1,159,047		1811.01	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Martinsville					
	L42	76,653	Upper Dan River--Little Dan River	119.77	11.65%
	L43	55,625	Upper South Mayo River--Russell Creek	86.91	8.45%
	L44	12,423	Spoon Creek	19.41	1.89%
	L45	12,579	Lower South Mayo River	19.65	1.91%
	L46	52,987	North Mayo River	82.79	8.05%
	L47	17,281	Horse Pasture Creek	27.00	2.63%
	L48	2,746	Mayo River	4.29	0.42%
	L49	5,708	Matrimony Creek	8.92	0.87%
	L50	43,614	Upper Smith River	68.15	6.63%
	L51	93,611	Smith River--Philpott Reservoir--Renet Bag Creek	146.27	14.22%
	L52	43,036	Smith River--Town Creek--Blackberry Creek	67.24	6.54%
	L53	62,250	Smith River--Reed Creek--Beaver Creek	97.27	9.46%
	L54	37,922	Lower Smith Creek	59.25	5.76%
	L55	19,168	Marrowbone Creek	29.95	2.91%
	L56	46,825	Leatherwood Creek	73.16	7.11%
Ararat	M01	2,038	Fisher River--Little Fisher River	3.18	0.31%
	M02	40,144	Stewarts Creek--Pauls Creek--Lovills Creek	62.72	6.10%
	M03	33,546	Upper Ararat River	52.42	5.10%
TOTAL		658,156		1028.37	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Danville					
	L57	49,769	Dan River--Cascade Creek	77.76	5.71%
	L58	77,260	Sandy River	120.72	8.87%
	L59	20,451	Sandy Creek (west)	31.95	2.35%
	L60	32,223	Dan River--Cane Creek	50.35	3.70%
	L61	23,861	Fall Creek	37.28	2.74%
	L62	71,285	Dan River--Sandy Creek (east)--Winns Creek	111.38	8.18%
	L63	40,412	Birch Creek	63.14	4.64%
	L64	76,723	Dan River--Lawsons Creek--Miry Creek	119.88	8.81%
	L65	59,574	Upper Banister River	93.08	6.84%
	L66	29,117	Cherrystone Creek	45.49	3.34%
	L67	85,101	Middle Banister River--Elkhorn Creek	132.97	9.77%
	L68	41,986	Whitehorn Creek	65.60	4.82%
	L69	21,952	Stinking River	34.30	2.52%
	L70	63,451	Sandy Creek (west)	99.14	7.28%
	L71	56,060	Lower Banister River--Polecat Creek	87.59	6.43%
	L72	24,868	Terrible Creek	38.86	2.85%
	L73	38,868	Dan River--Aarons Creek	60.73	4.46%
	L74	58,227	Hyco River--Big Bluewing Creek-Mayo Creek	90.98	6.68%
TOTAL		871,188		1361.23	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Upper New					
	N01	25,099	Helton Creek--Big Horse Creek	39.22	2.69%
	N02	40,853	Upper New River--Wilson Creek	63.83	4.38%
	N03	48,892	Fox Creek	76.39	5.25%
	N04	64,119	New River--Peach Bottom Creek--Little River	100.19	6.88%
	N05	53,769	Elk Creek	84.01	5.77%
	N06	90,307	New River--Chestnutt Creek--Brush Creek	141.10	9.69%
	N07	46,038	Crooked Creek	71.93	4.94%
	N08	70,808	New River--Shorts Creek--Pine Run	110.64	7.60%
	N09	88,814	Cripple Creek	138.77	9.53%
	N10	92,587	Upper Reed Creek	144.67	9.94%
	N11	55,841	Lower Reed Creek	87.25	5.99%
	N12	24,533	Cove Creek	38.33	2.63%
	N13	66,265	Upper Big Reed Island Creek--Laurel Fork	103.54	7.11%
	N14	110,566	Lower Big Reed Island Creek--Greasy Creek--Burks Fork	172.76	11.87%
	N15	53,220	Little Reed Island Creek	83.16	5.71%
TOTAL		931,710		1455.80	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Lower New					
	N16	53,468	New River--Claytor Lake--Macks Creek	83.54	5.19%
	N17	59,718	Peak Creek	93.31	5.80%
	N18	41,160	New River--Crab Creek	64.31	4.00%
	N19	66,099	East Fork Little River	103.28	6.42%
	N20	45,593	West Fork Little River	71.24	4.43%
	N21	113,323	Little River--Indian Creek--Brush Creek	177.07	11.00%
	N22	88,346	New River--Toms Creek--Back Creek--Stroubles Creek	138.04	8.58%
	N23	66,172	New River--Sinking Creek	103.39	6.42%
	N24	29,418	New River--Little Stony Creek	45.97	2.86%
	N25	100,562	Walker Creek	157.13	9.76%
	N26	60,824	Kimberling Creek	95.04	5.90%
	N27	38,496	Little Walker Creek	60.15	3.74%
	N28	29,766	Stony Creek	46.51	2.89%
	N29	24,791	New River--East River	38.74	2.41%
	N30	50,621	Upper Wolf Creek	79.10	4.91%
	N31	20,601	Hunting Camp Creek	32.19	2.00%
	N32	65,490	Lower Wolf Creek--Clear Fork	102.33	6.36%
	N33	15,649	Laurel Creek	24.45	1.52%
	N34	3,336	Rich Creek	5.21	0.32%
	N35	4,273	New River--Adair Run	6.68	0.41%
	N36	35,979	Upper Bluestone River	56.22	3.49%
	N37	16,420	Bluestone River--Laurel Fork	25.66	1.59%
TOTAL		1,030,104		1609.54	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Holston					
	O01	62,778	Upper South Fork Holston River	98.09	7.42%
	O02	76,711	South Fork Holston River--Whitetop Laurel Creek	119.86	9.07%
	O03	52,170	Upper Middle Fork Holston River	81.52	6.17%
	O04	50,272	Middle Fork Holston River--Hungry Mother Creek	78.55	5.94%
	O05	52,294	Lower Middle Fork Holston River	81.71	6.18%
	O06	51,972	South Holston Lake--Wolf Creek--Fifteenmile Creek	81.21	6.14%
	O07	42,152	South Fork Holston River--Beaver Creek	65.86	4.98%
	O08	9,159	Reedy Creek	14.31	1.08%
	O09	72,488	Upper North Fork Holston River	113.26	8.57%
	O10	75,272	North Fork Holston River--Laurel Creek	117.61	8.90%
	O11	103,213	North Fork Holston River--Wolf Creek--Tumbling Creek	161.27	12.20%
	O12	91,716	North Fork Holston River--Abrams Creek	143.31	10.84%
	O13	45,373	Lower North Fork Holston River--Possum Creek	70.90	5.36%
	O14	60,538	Big Moccasin Creek	94.59	7.15%
TOTAL		846,107		1322.04	100.00%

	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Clinch					
	P01	37,942	Upper Clinch River	59.29	3.27%
	P02	41,560	Clinch River--Indian Creek	64.94	3.59%
	P03	35,473	Clinch River--Middle Creek	55.43	3.06%
	P04	56,275	Clinch River--Swords Creek--Lewis Creek	87.93	4.86%
	P05	79,509	Little River	124.23	6.86%
	P06	58,035	Big Cedar Creek	90.68	5.01%
	P07	39,586	Clinch River--Thompson Creek	61.85	3.42%
	P08	20,311	Dumps Creek	31.74	1.75%
	P09	95,540	Clinch River--Little Stony Creek	149.28	8.24%
	P10	17,466	Lick Creek	27.29	1.51%
	P11	64,211	Guest River	100.33	5.54%
	P12	26,629	Stony Creek	41.61	2.30%
	P13	77,101	Clinch River--Stock Creek--Cove Creek	120.47	6.65%
	P14	85,235	Copper Creek	133.18	7.35%
Powell	P15	53,577	North Fork Clinch River	83.71	4.62%
	P16	17,253	Clinch River--Blackwater River	26.96	1.49%
	P17	72,033	Upper Powell River--Callahan Creek--Roaring Fork	112.55	6.22%
	P18	26,154	South Fork Powell River	40.86	2.26%
	P19	29,472	Powell River--Camp Creek	46.05	2.54%
	P20	56,983	North Fork Powell River	89.04	4.92%
	P21	69,748	Powell River--Hardy Creek	108.98	6.02%
	P22	29,708	Wallen Creek	46.42	2.56%
	P23	34,003	Powell River--Martin Creek	53.13	2.93%
	P24	35,118	Powell River--Indian Creek	54.87	3.03%
TOTAL		1,158,921		1810.81	100.00%

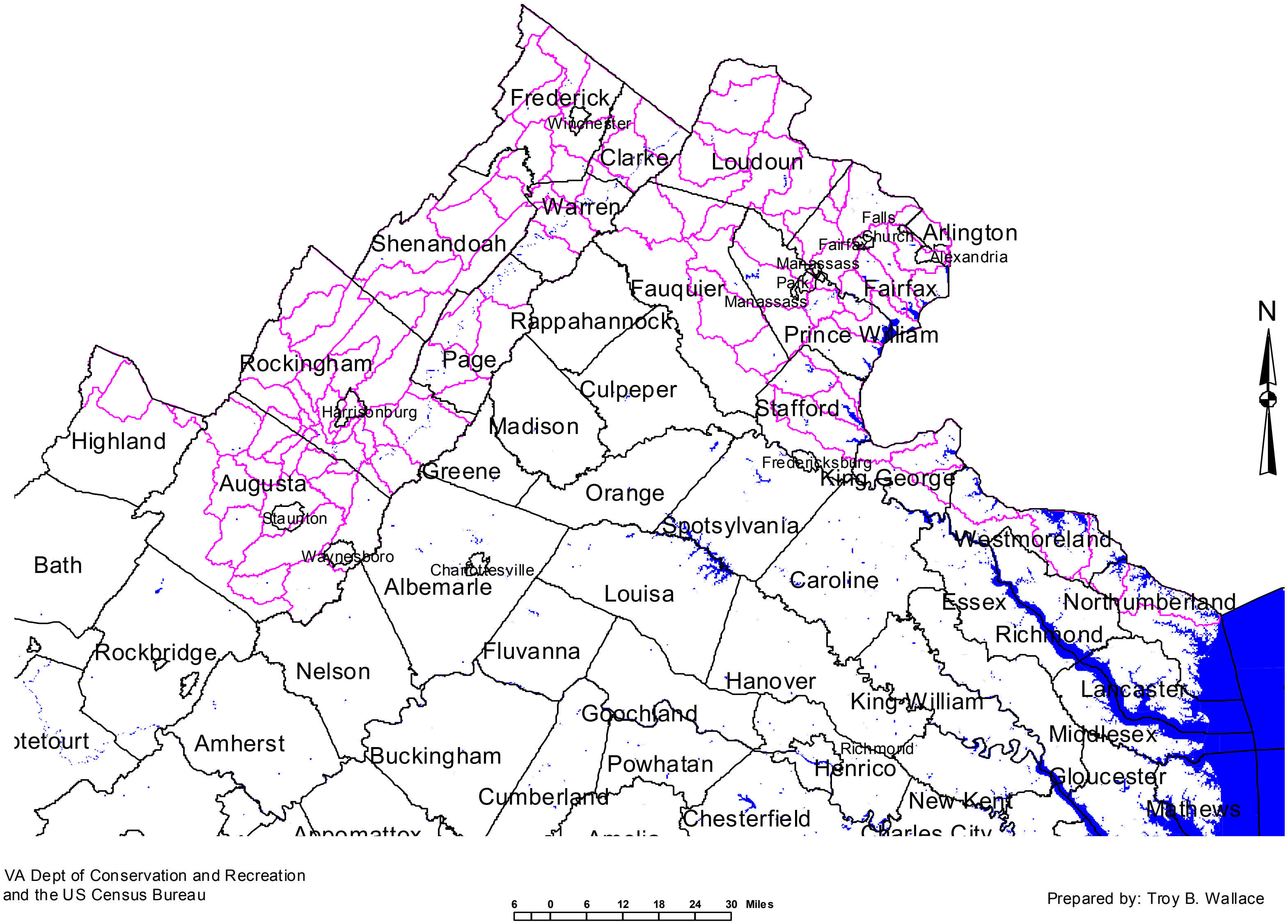
	SUBBASIN	AREA (acres)	DESCRIPTION	AREA (mi.2)	% Basin
Big Sandy					
	Q01	29,766	Dry Fork--Jacobs Fork--Horsepen Creek	46.51	4.66%
	Q02	6,146	Tug Fork	9.60	0.96%
	Q03	56,485	Knox Creek	88.26	8.84%
	Q04	40,208	Upper Levisa Fork--Garden Creek	62.82	6.29%
	Q05	58,207	Dismal Creek	90.95	9.11%
	Q06	26,628	Levisa Fork--Prater creek	41.61	4.17%
	Q07	26,193	Slate Creek	40.93	4.10%
	Q08	45,718	Levisa Fork--Home Creek--Bull Creek	71.43	7.15%
	Q09	48,315	Upper Russell Fork	75.49	7.56%
	Q10	50,049	Russell Fork--Lick Creek--Fryingpan Creek	78.20	7.83%
	Q11	68,160	McClure River--Caney Creek	106.50	10.66%
	Q12	39,366	Russell Fork--Russell Prater Creek	61.51	6.16%
	Q13	86,594	Pound River	135.30	13.55%
	Q14	57,400	Cranesnest River	89.69	8.98%
TOTAL		639,237		998.81	100.00%

APPENDIX B: PLATES DEPICTING VIRGINIA'S HYDROLOGIC AND JURISDICTIONAL BOUNDARIES

B.1: MAPS OF THE DRAINAGE BASINS, MUNICIPAL JURISDICTIONS

AND HYDROLOGIC UNITS OF VIRGNIA

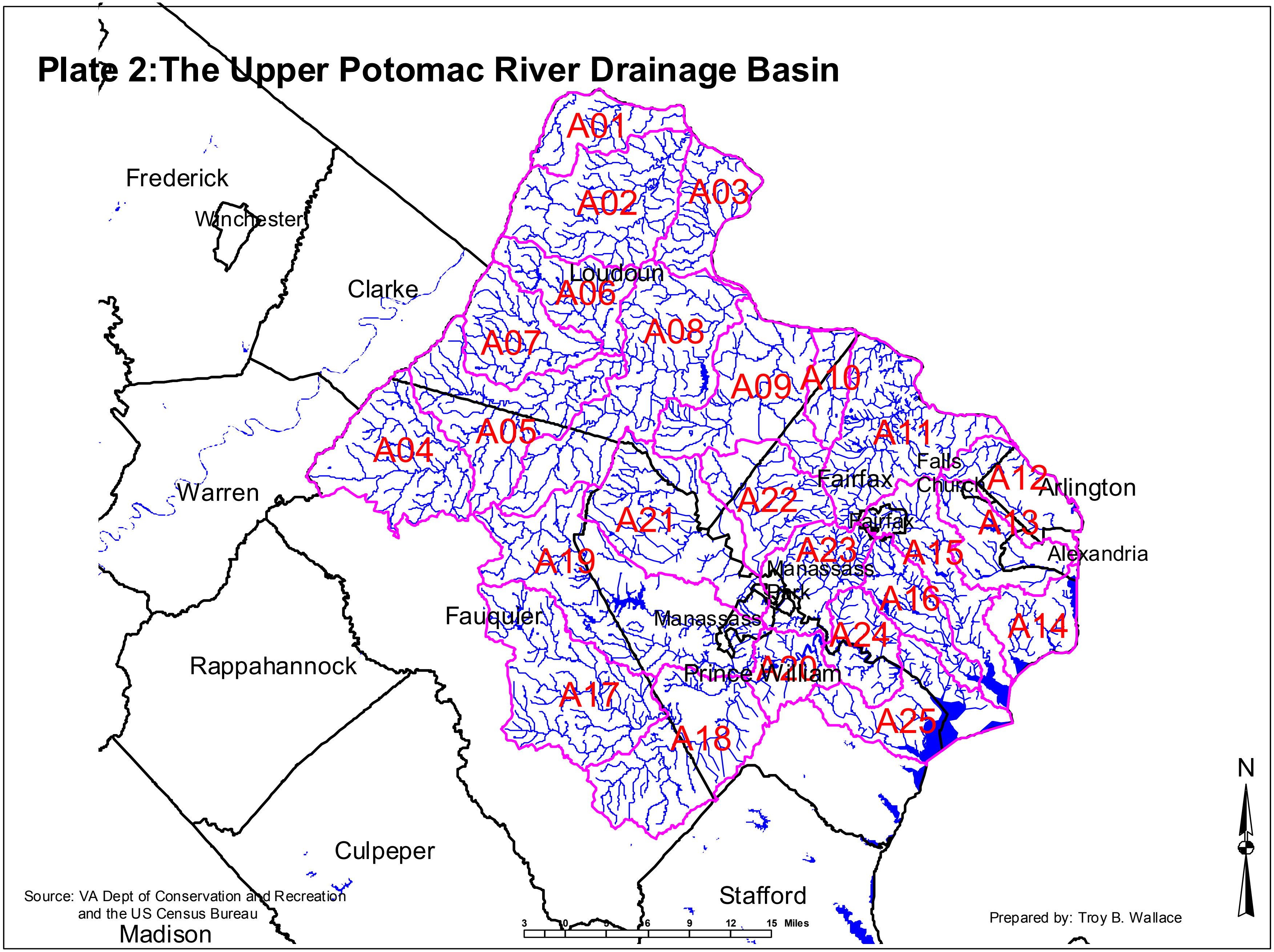
Plate 1:The Virginia Portion of the Potomac River Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 2:The Upper Potomac River Drainage Basin



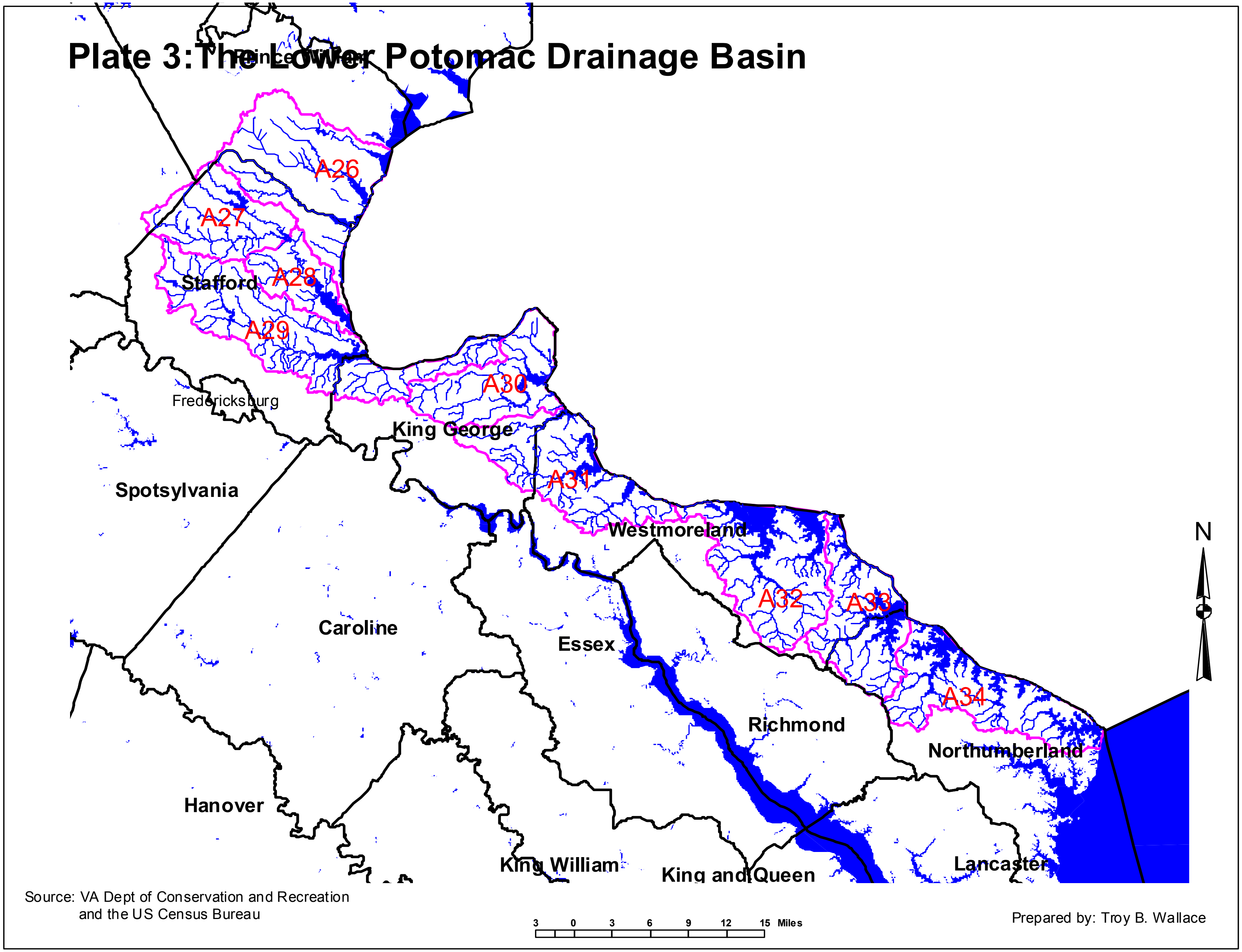
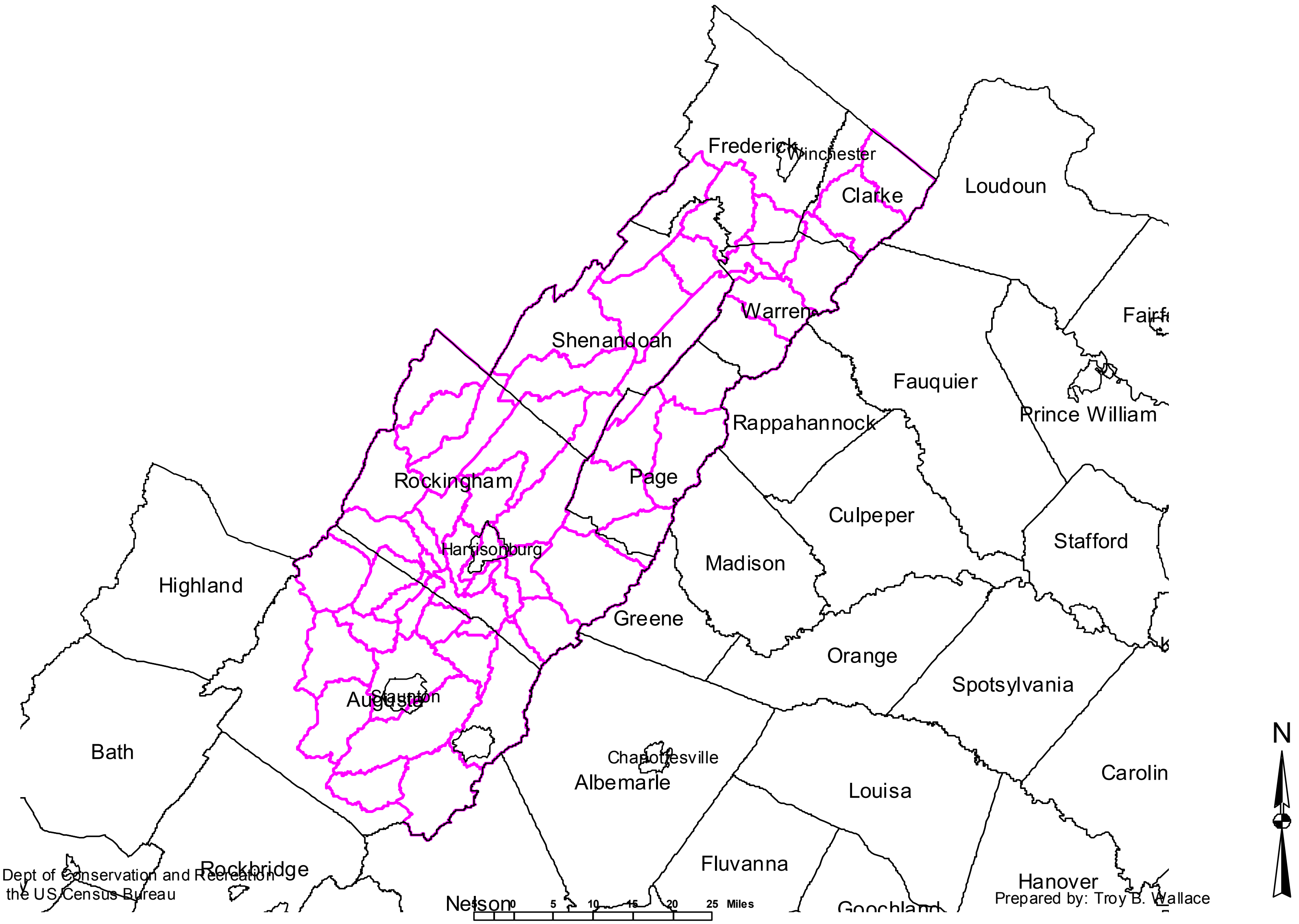


Plate 3:The Lower Potomac Drainage Basin
A26
A27
A28
A29
A30
A31
A32
A33
A34
Stafford
Fredericksburg
King George
Spotsylvania
Westmoreland
Caroline
Essex
Richmond
Northumberland
Hanover
King William
King and Queen
Lancaster
N
Source: VA Dept of Conservation and Recreation
and the US Census Bureau
3 0 3 6 9 12 15 Miles
Prepared by: Troy B. Wallace

Plate 4: The Shenandoah River Basin (Potomac)



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 5: The Upper Shenandoah Drainage Basin (Potomac)

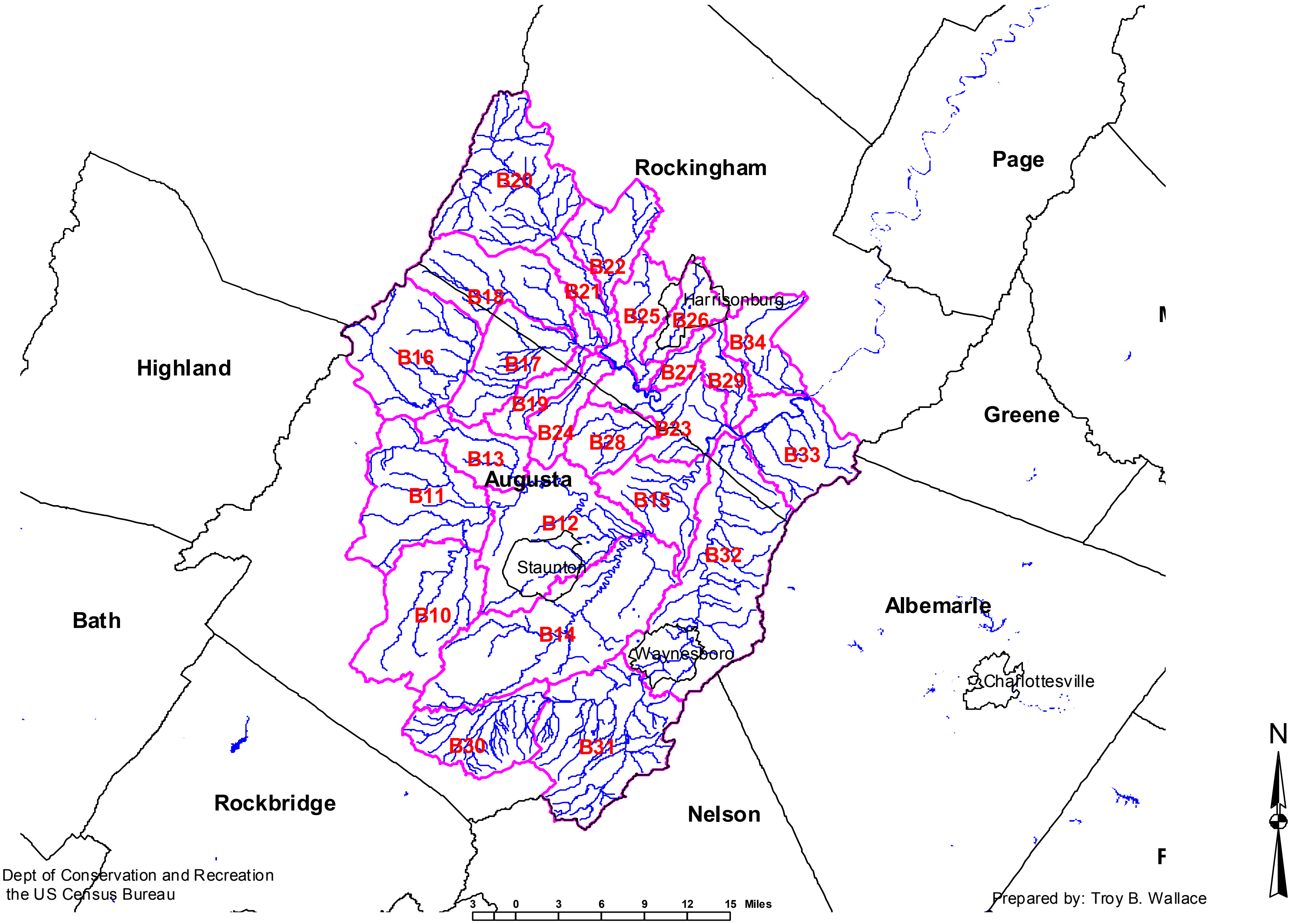


Plate 6: The Lower Shenandoah River Drainage Basin (Potomac)

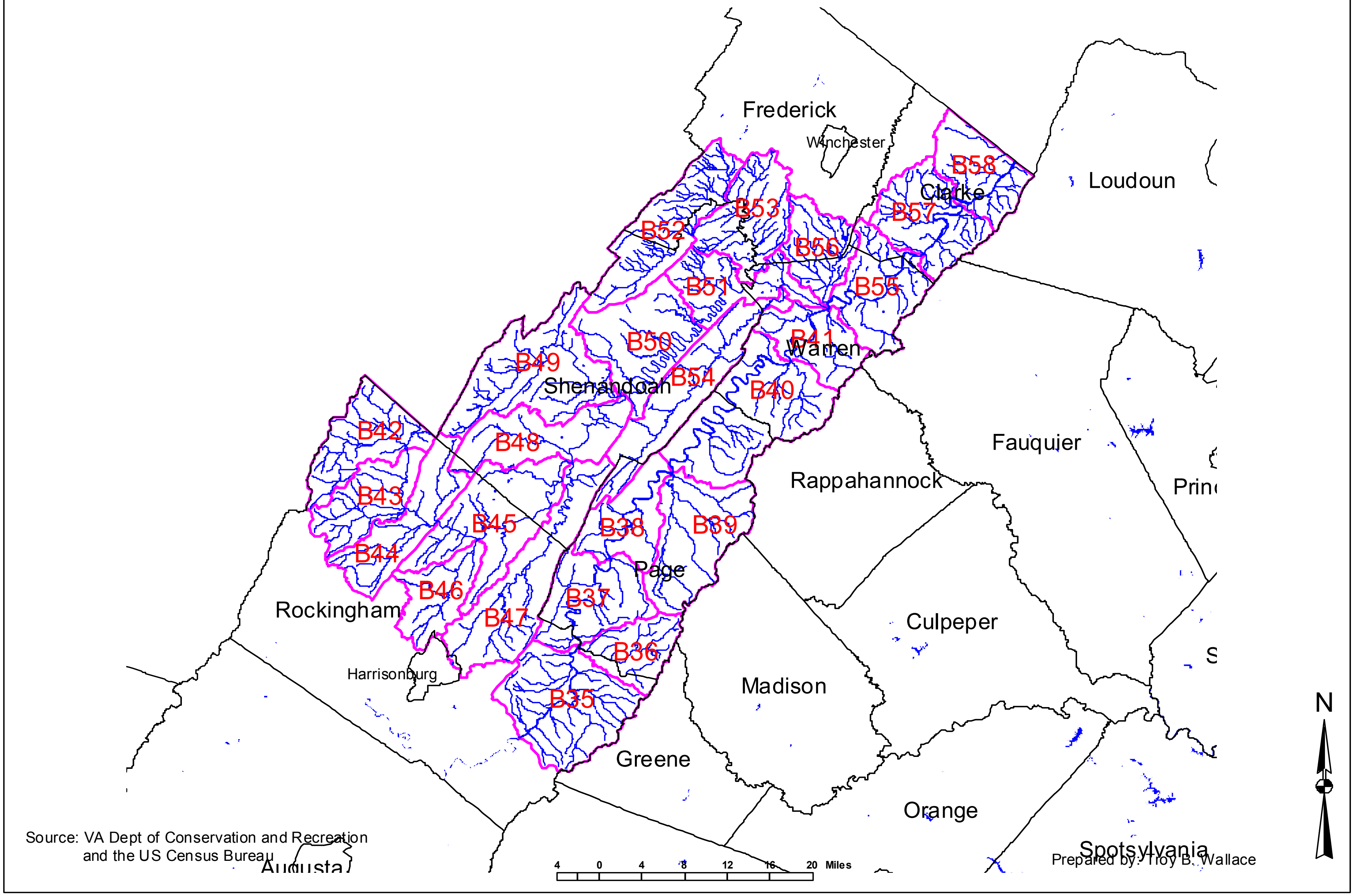
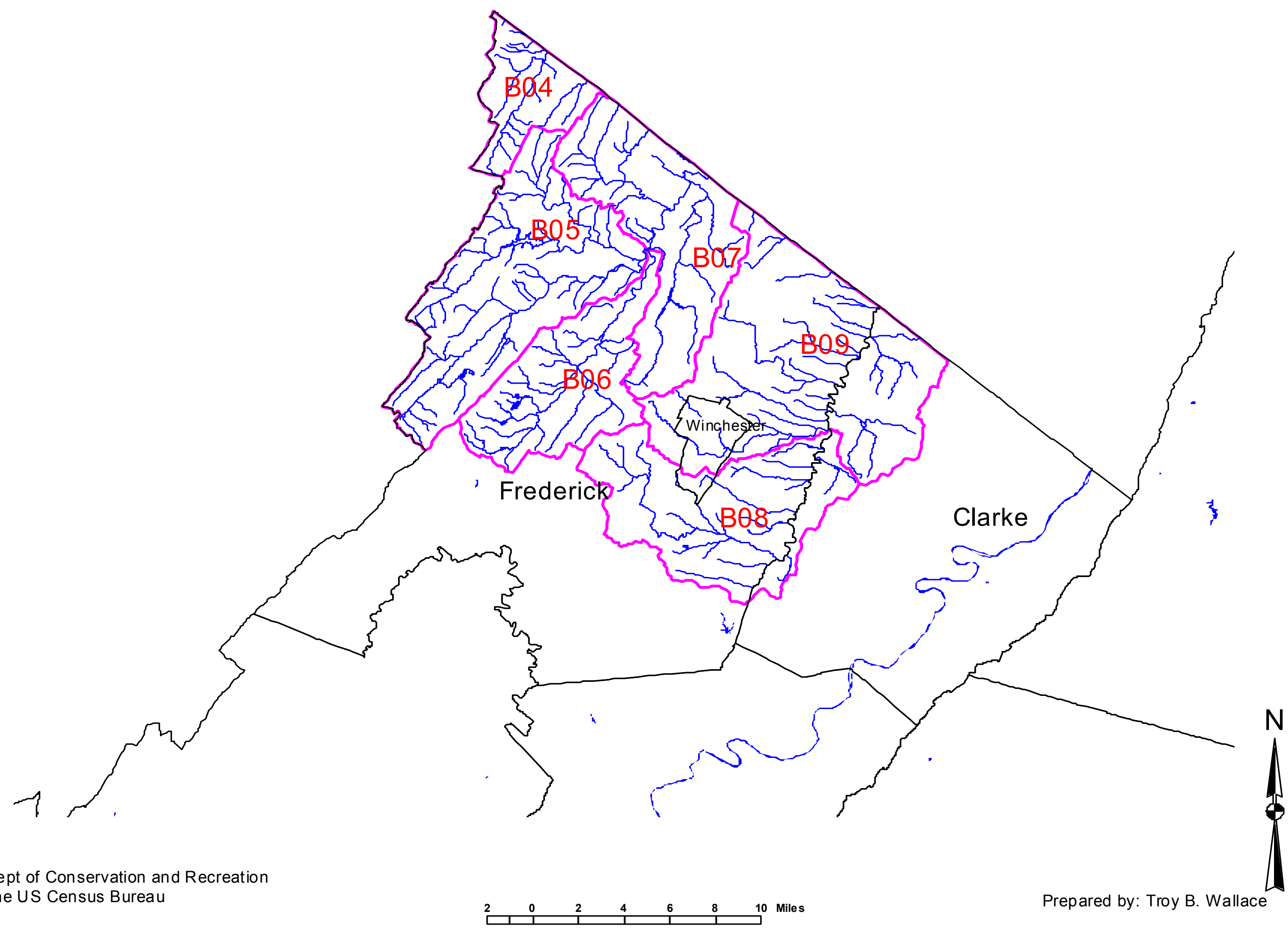


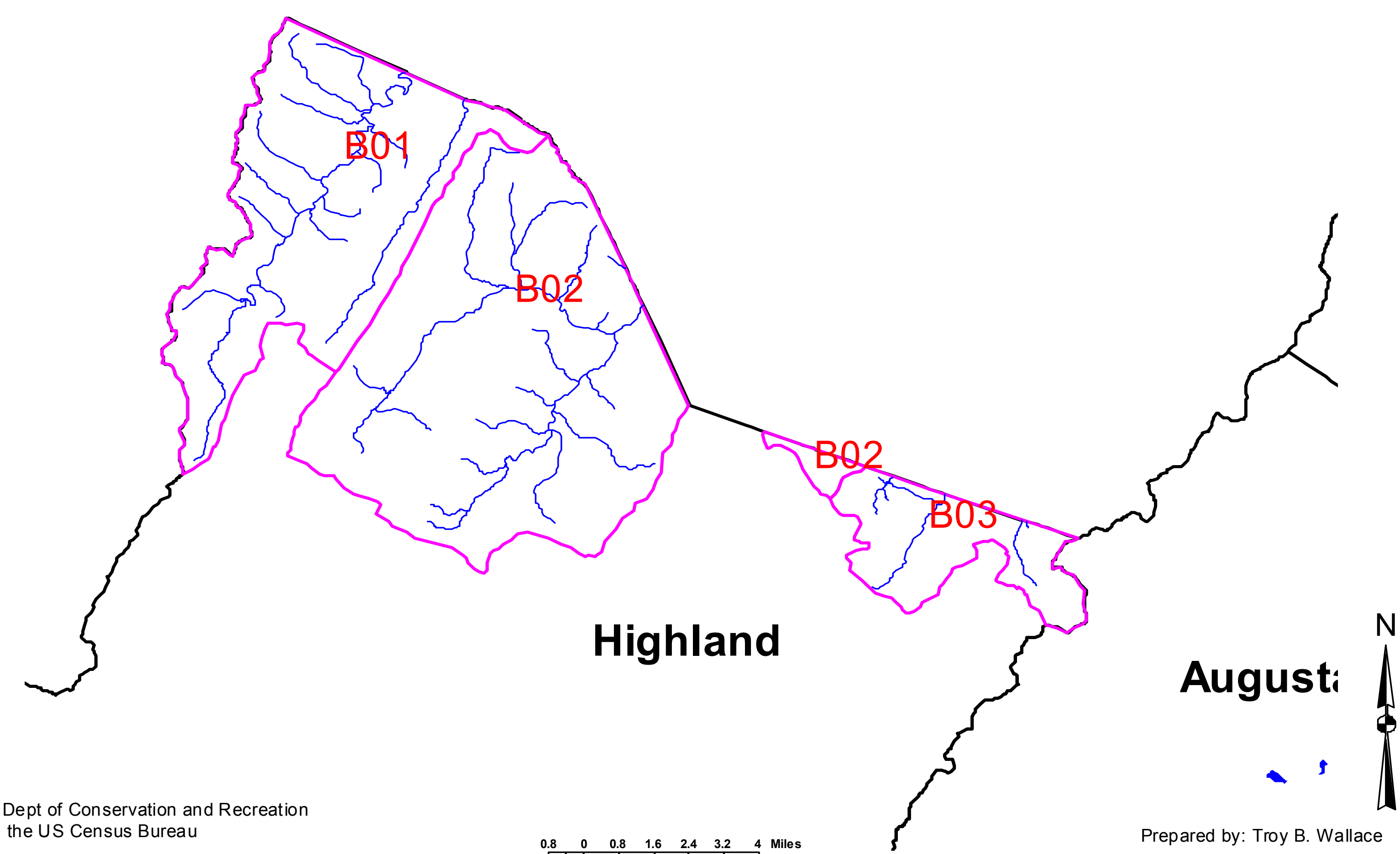
Plate 7: Opequon Portion of the Potomac River Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 8: The Laurel Portion of the Potomac River Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

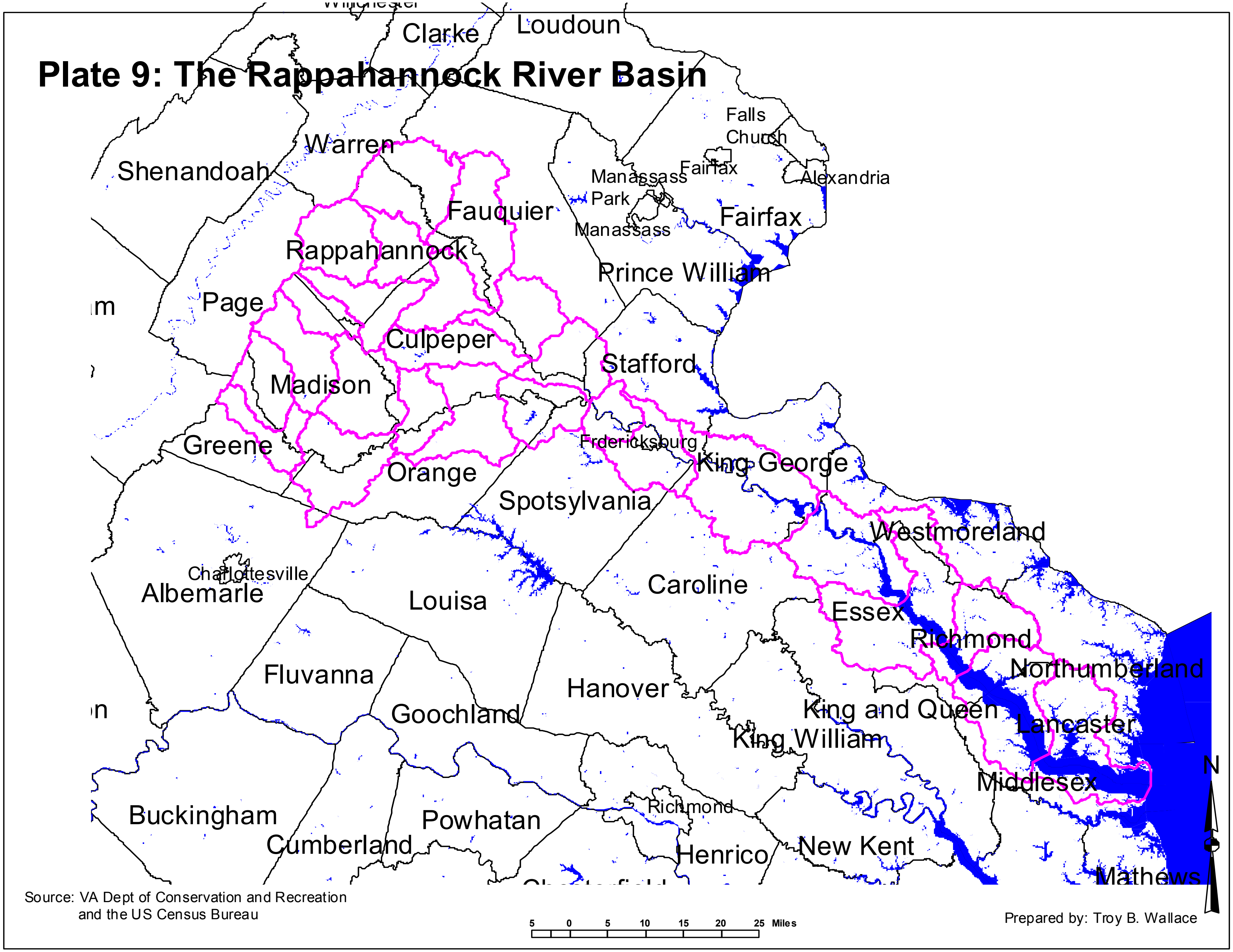
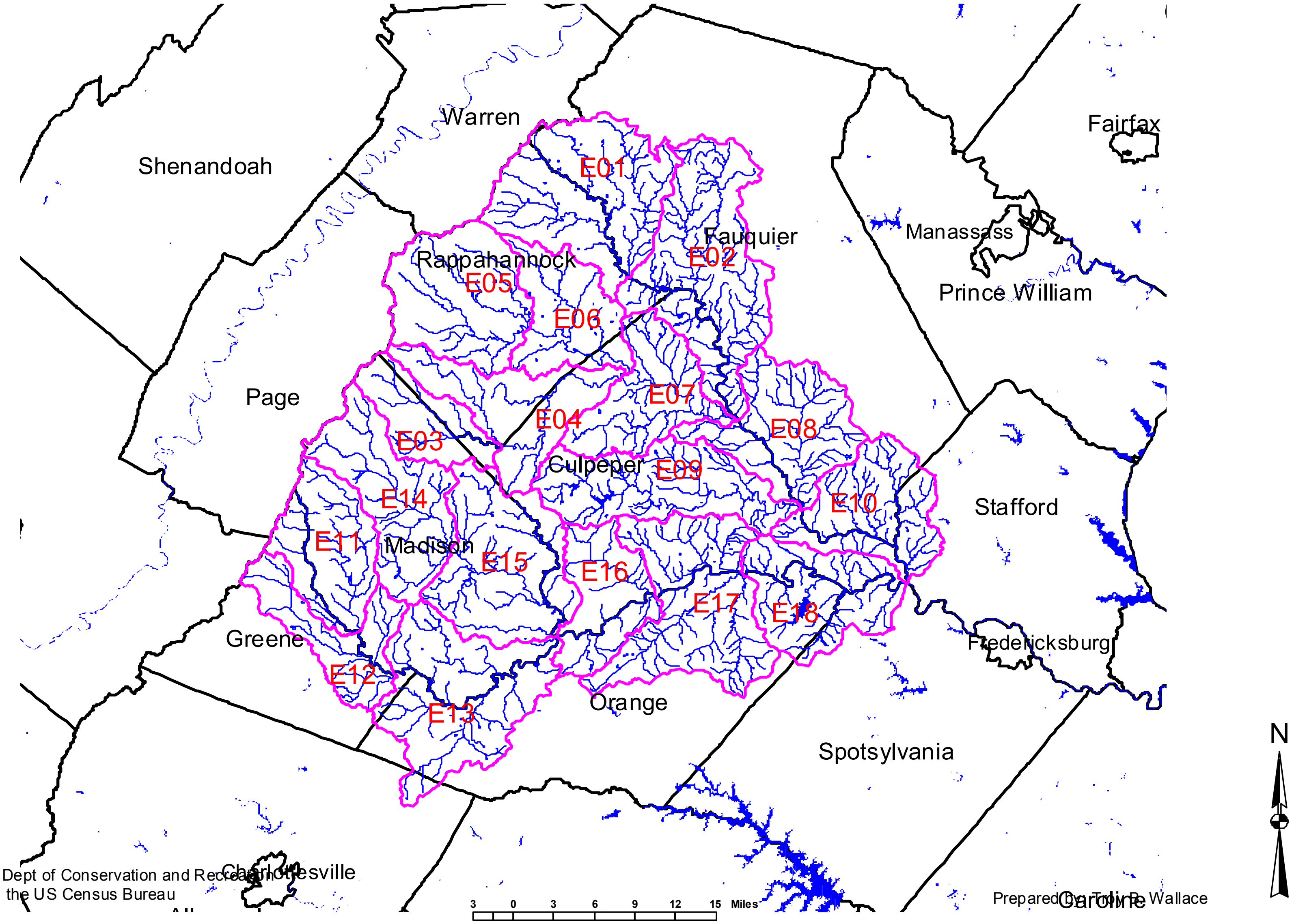


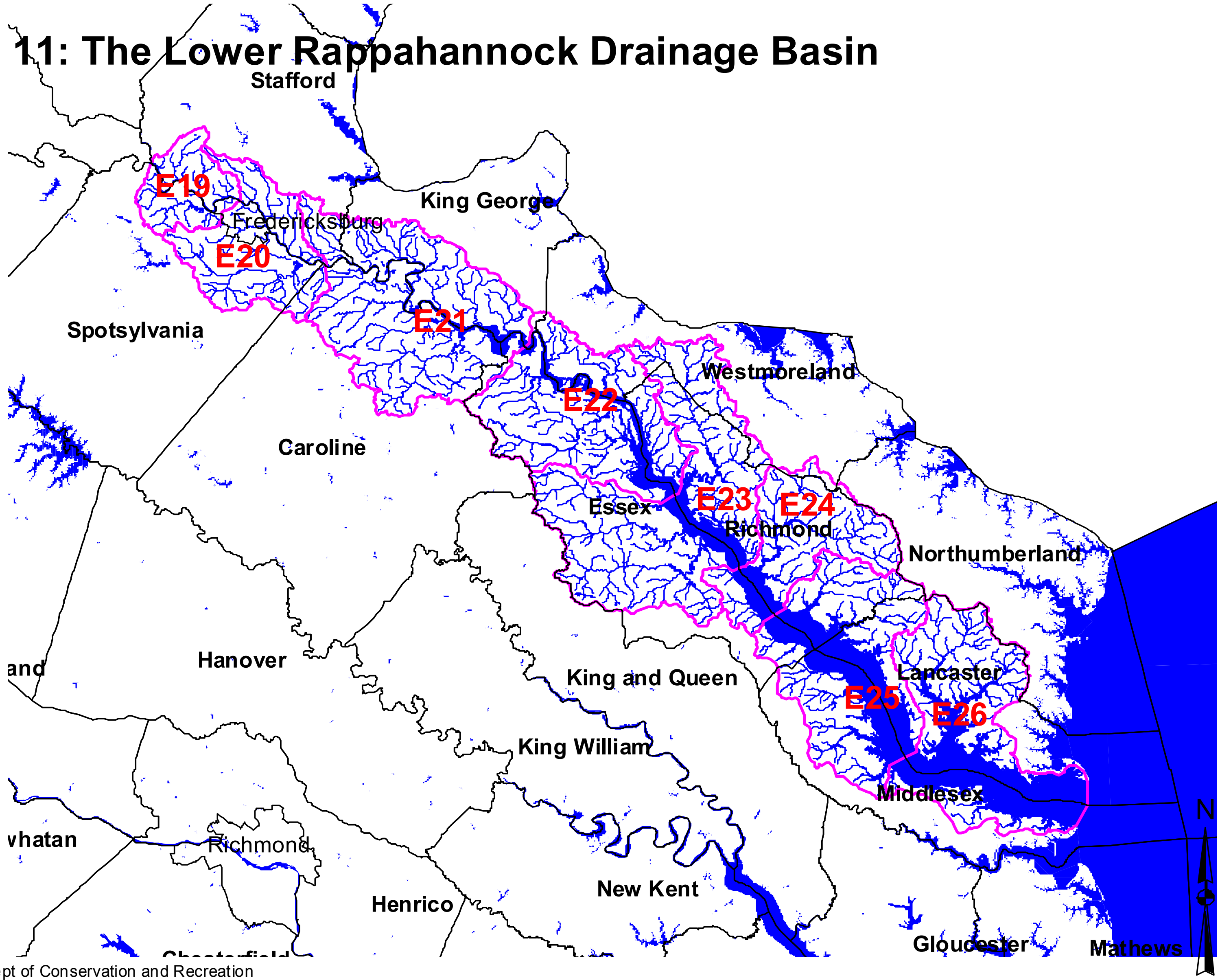
Plate 9: The Rappahannock River Basin
Clarke
Loudoun
Warren
Shenandoah
Falls Church
Manassass Park
Fairfax
Alexandria
Fauquier
Manassass
Fairfax
Rappahannock
Prince William
Page
Culpeper
Stafford
Madison
Greene
Frdericksburg
King George
Orange
Spotsylvania
Westmoreland
Charlottesville
Albemarle
Louisa
Caroline
Essex
Richmond
Northumberland
Fluvanna
Hanover
King and Queen
Goochland
Lancaster
King William
Middlesex
N
Richmond
Buckingham
Powhatan
Cumberland
Henrico
New Kent
Mathews
Source: VA Dept of Conservation and Recreation and the US Census Bureau
5 0 5 10 15 20 25 Miles
Prepared by: Troy B. Wallace

Plate 10: The Upper Rappahannock Drainage Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Plate 11: The Lower Rappahannock Drainage Basin



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

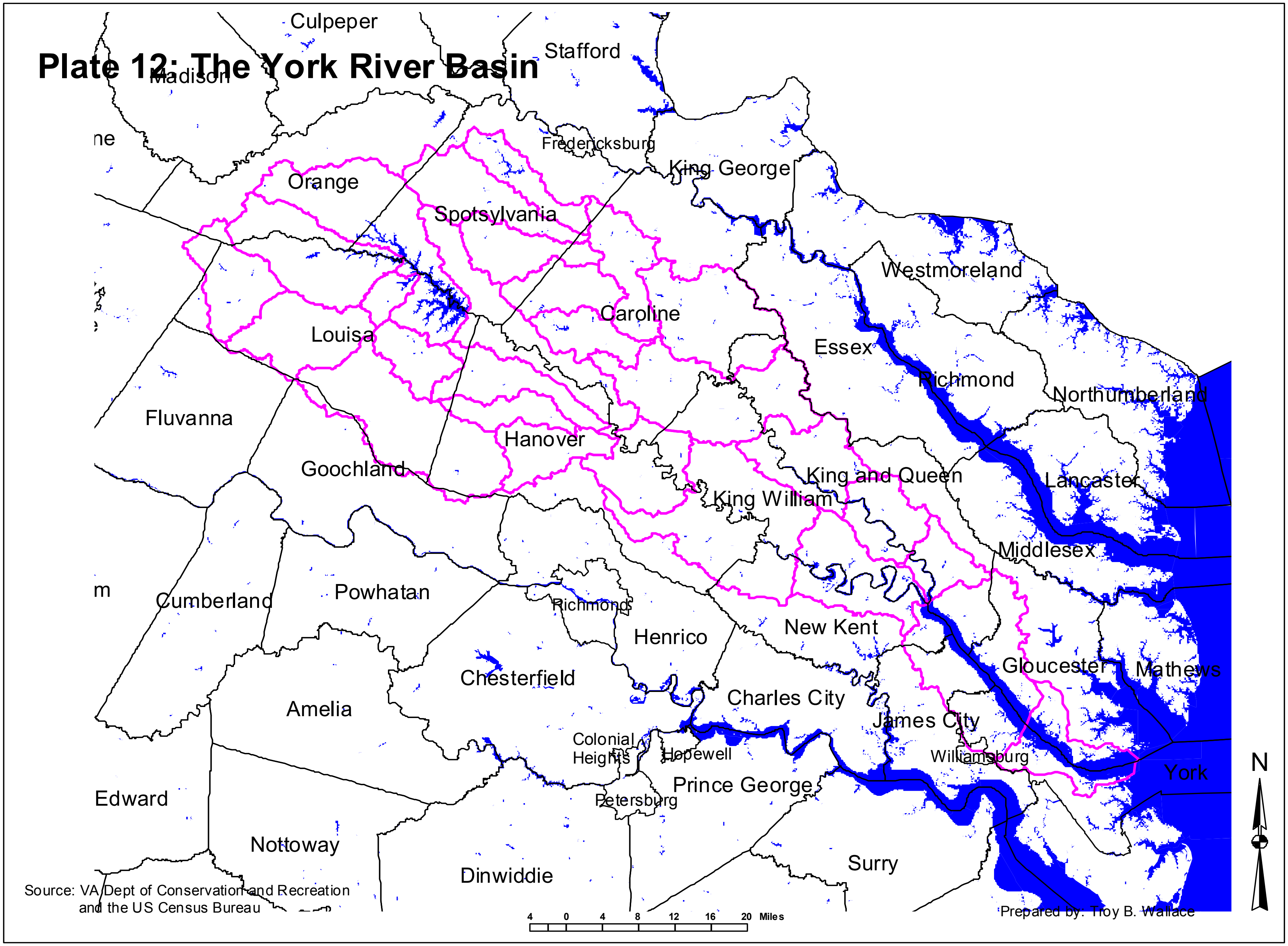


Plate 12: The York River Basin
Culpeper
Madison
Stafford
Fredericksburg
King George
Orange
Spotsylvania
Westmoreland
Caroline
Louisa
Essex
Richmond
Northumberland
Fluvanna
Hanover
Goochland
King and Queen
Lancaster
King William
Middlesex
Cumberland
Powhatan
Richmond
Henrico
New Kent
Gloucester
Mathews
Chesterfield
Charles City
Amelia
James City
Colonial Heights
Hopewell
Williamsburg
York
Edward
Prince George
Petersburg
Nottoway
Surry
Dinwiddie
N
Source: VA Dept of Conservation and Recreation and the US Census Bureau
4 0 4 8 12 16 20 Miles
Prepared by: Troy B. Wallace

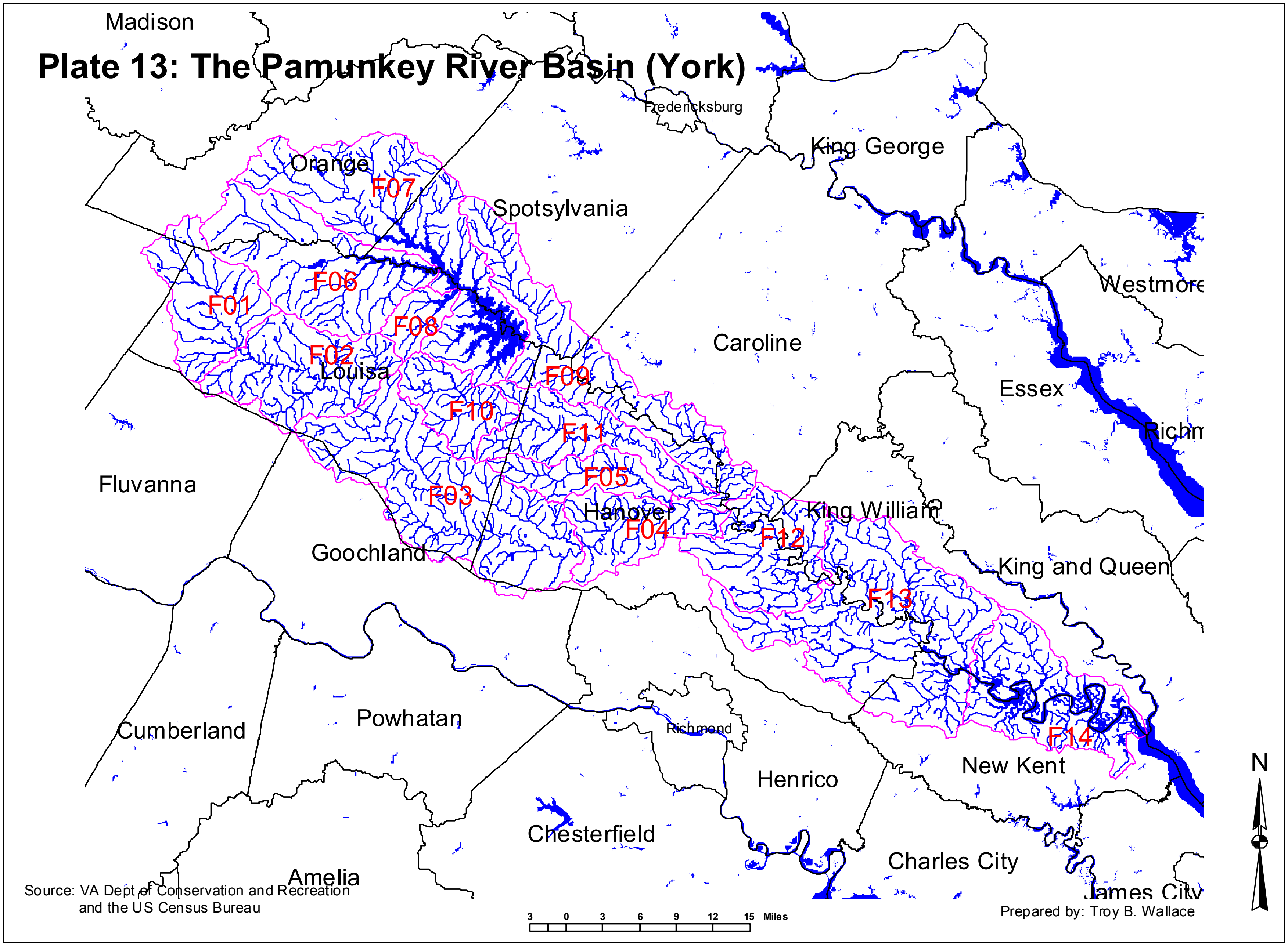
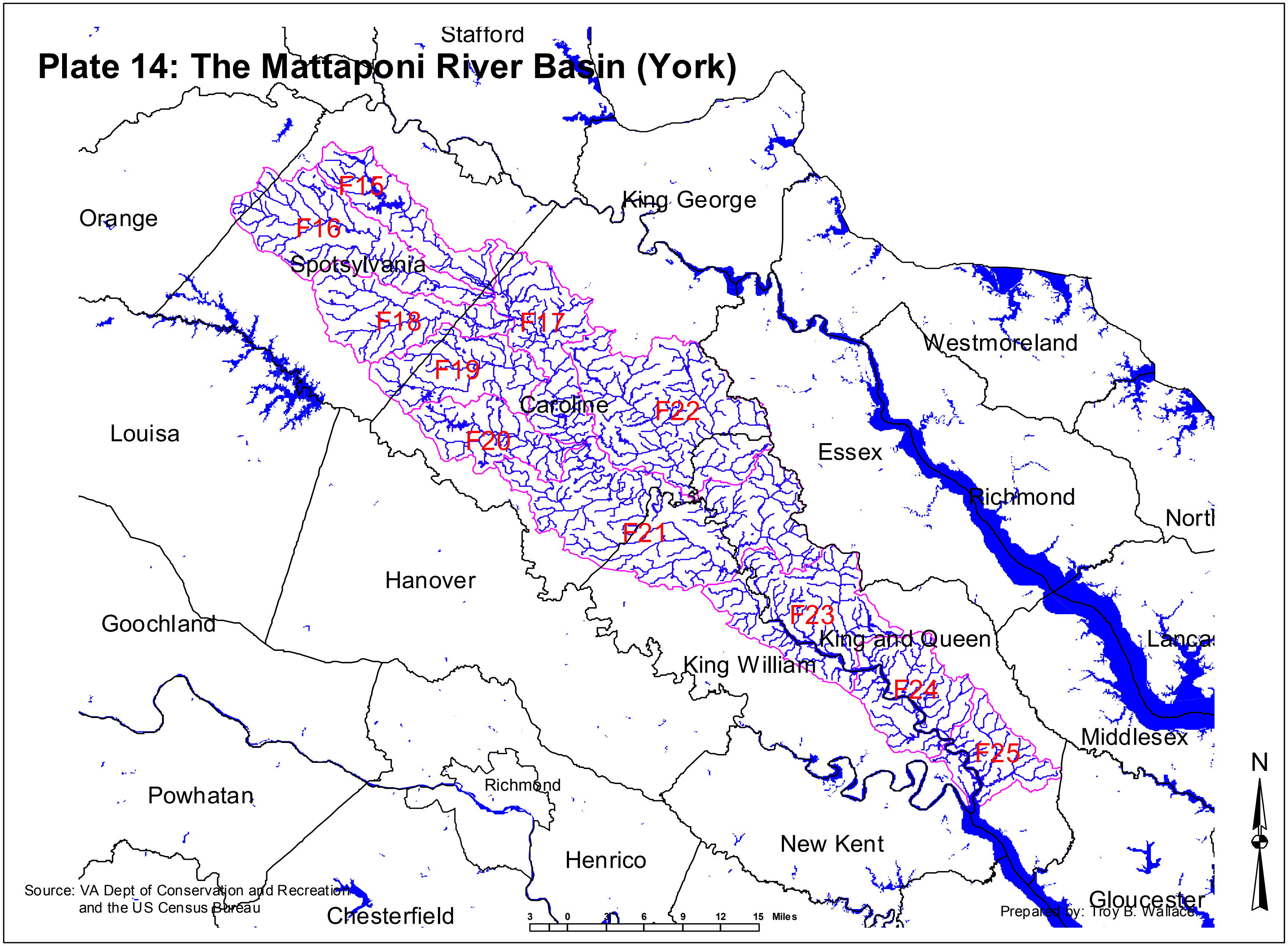


Plate 13: The Pamunkey River Basin (York)
Madison
Orange
Spotsylvania
Fredericksburg
King George
Westmore
Caroline
Essex
Richm
Louisa
Fluvanna
Hanover
King William
King and Queen
Goochland
Cumberland
Powhatan
Richmond
Henrico
New Kent
Chesterfield
Charles City
Amelia
James City
F01
F02
F03
F04
F05
F06
F07
F08
F09
F10
F11
F12
F13
F14
N
3 0 3 6 9 12 15 Miles
Source: VA Dept of Conservation and Recreation
and the US Census Bureau
Prepared by: Troy B. Wallace

Plate 14: The Mattaponi River Basin (York)



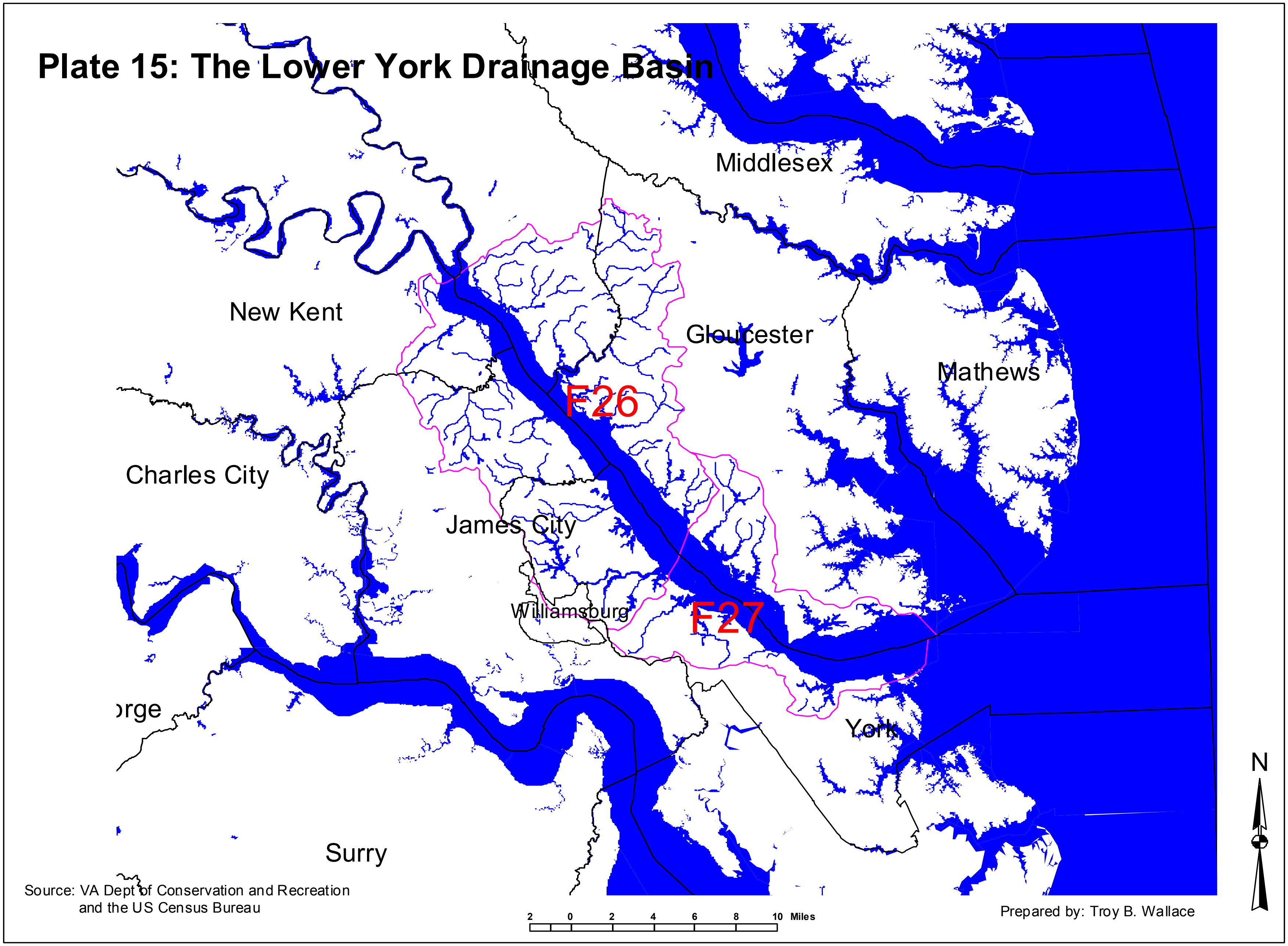
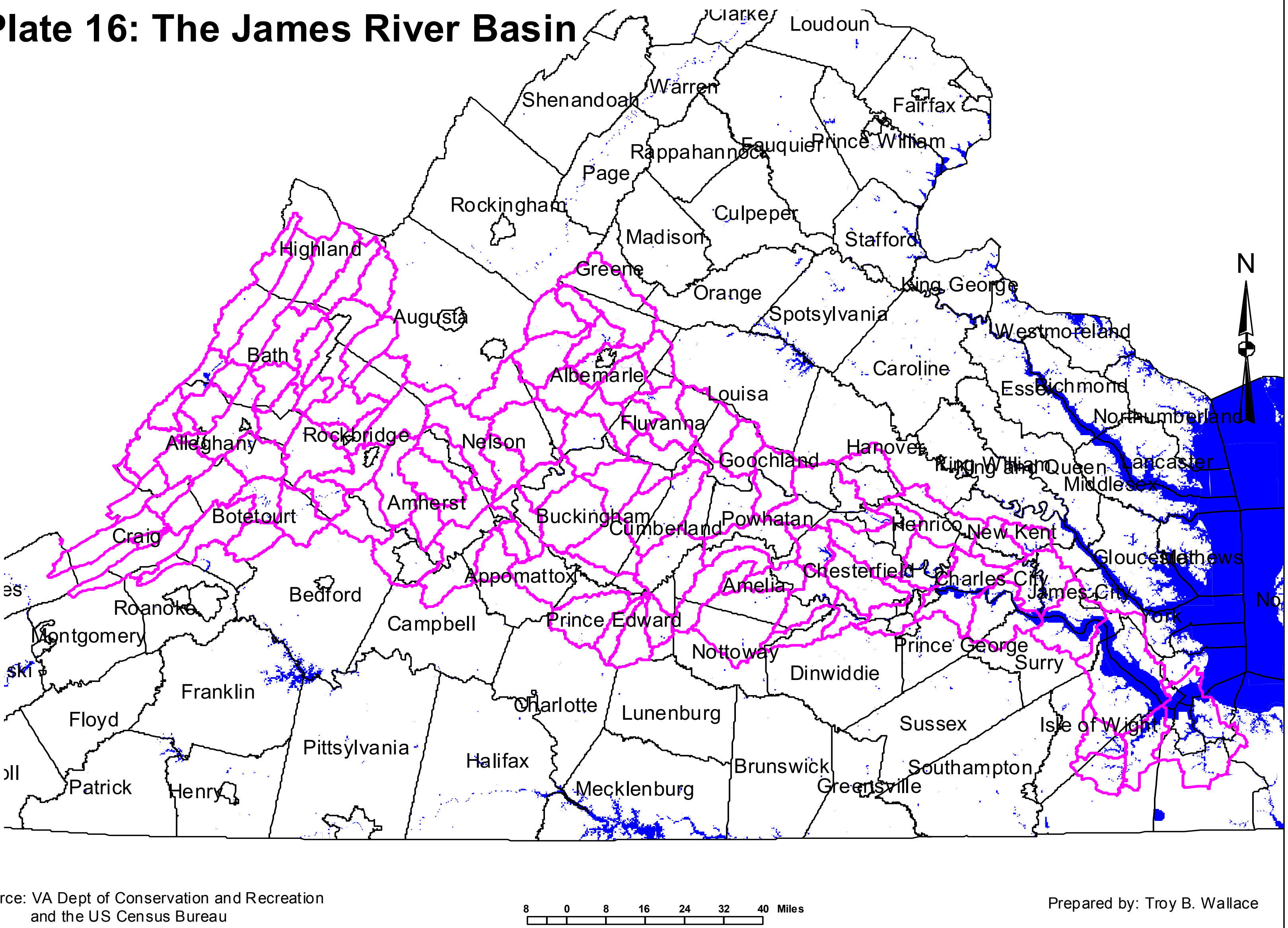


Plate 15: The Lower York Drainage Basin
Middlesex
New Kent
Gloucester
Mathews
F26
Charles City
James City
Williamsburg
F27
York
orge
Surry
N
Source: VA Dept of Conservation and Recreation
and the US Census Bureau
2 0 2 4 6 8 10 Miles
Prepared by: Troy B. Wallace

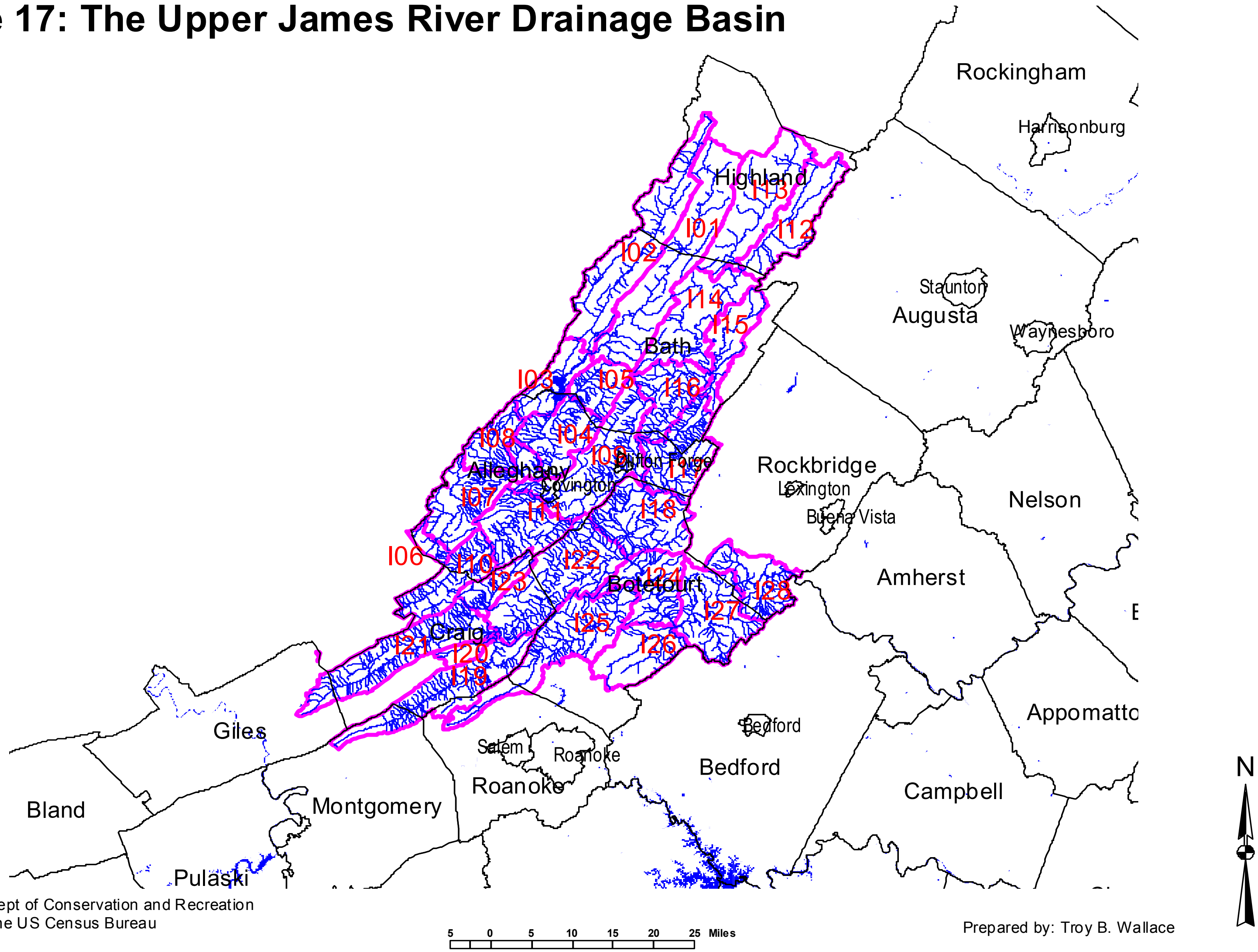
Plate 16: The James River Basin



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 17: The Upper James River Drainage Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

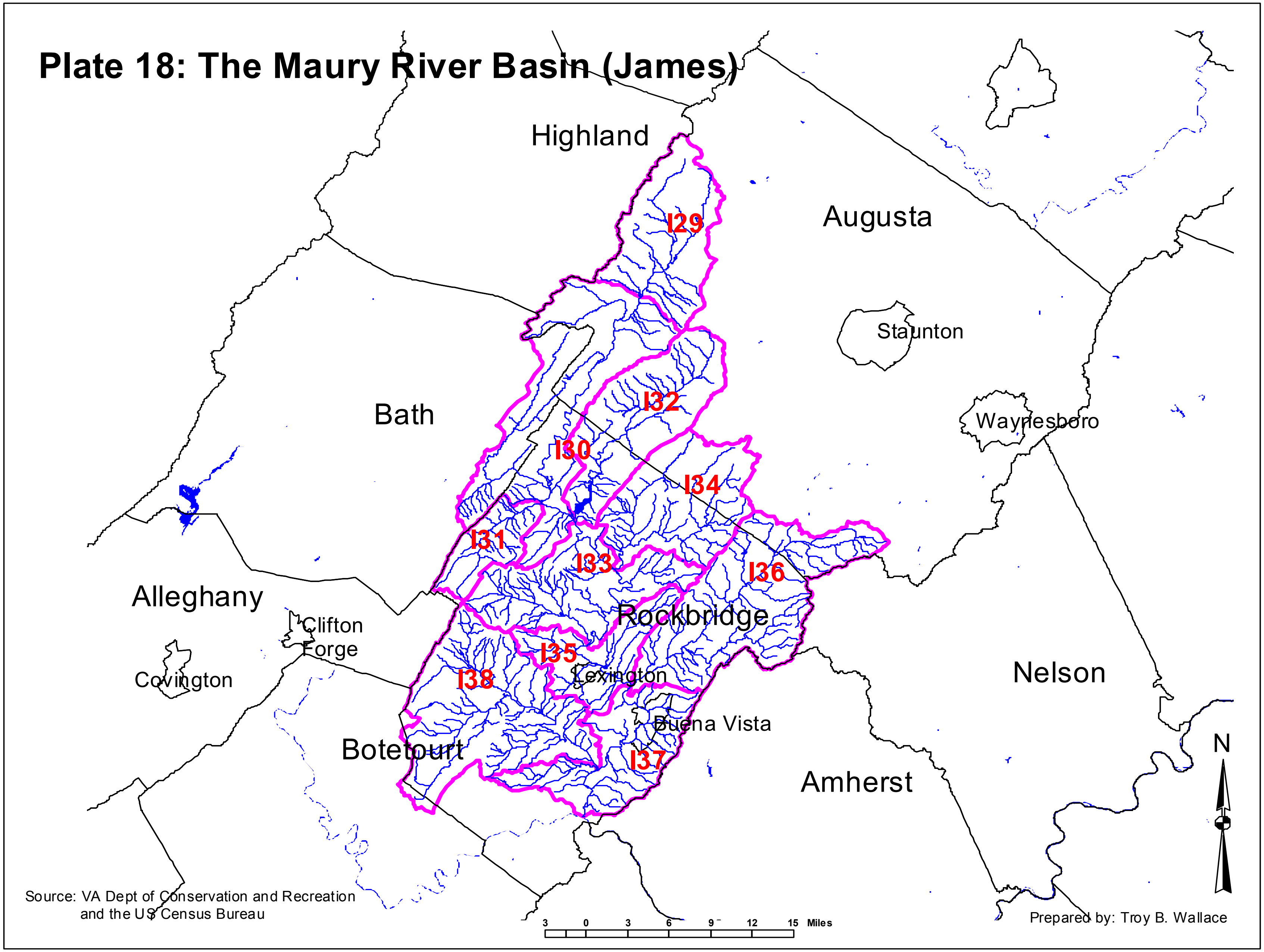
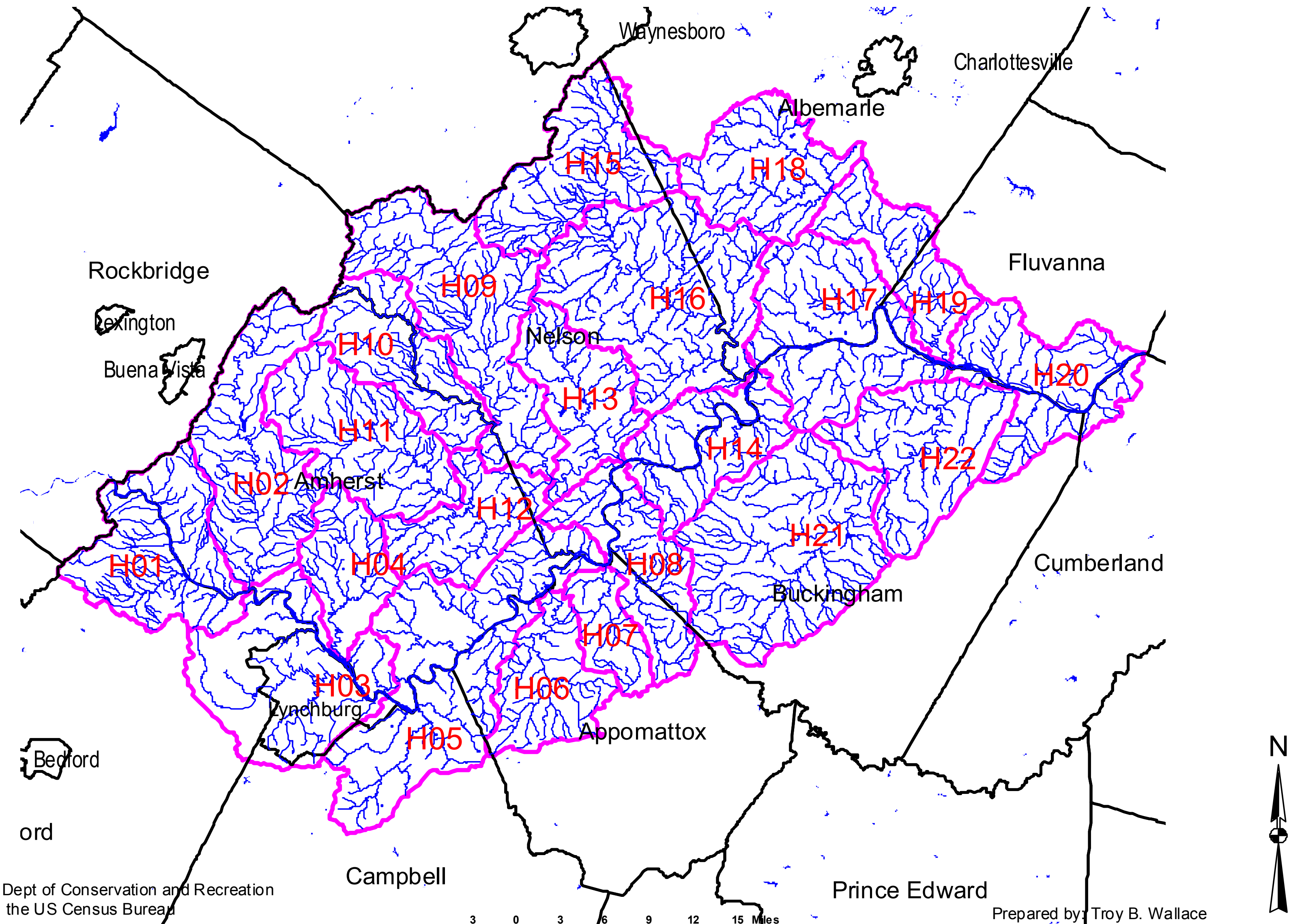


Plate 18: The Maury River Basin (James)
Highland
Augusta
Staunton
Waynesboro
Bath
Alleghany
Clifton
Forge
Covington
Botetourt
Rockbridge
Lexington
Buena Vista
Amherst
Nelson
I29
I30
I31
I32
I33
I34
I35
I36
I37
I38
N
Source: VA Dept of Conservation and Recreation
and the US Census Bureau
3 0 3 6 9 12 15 Miles
Prepared by: Troy B. Wallace

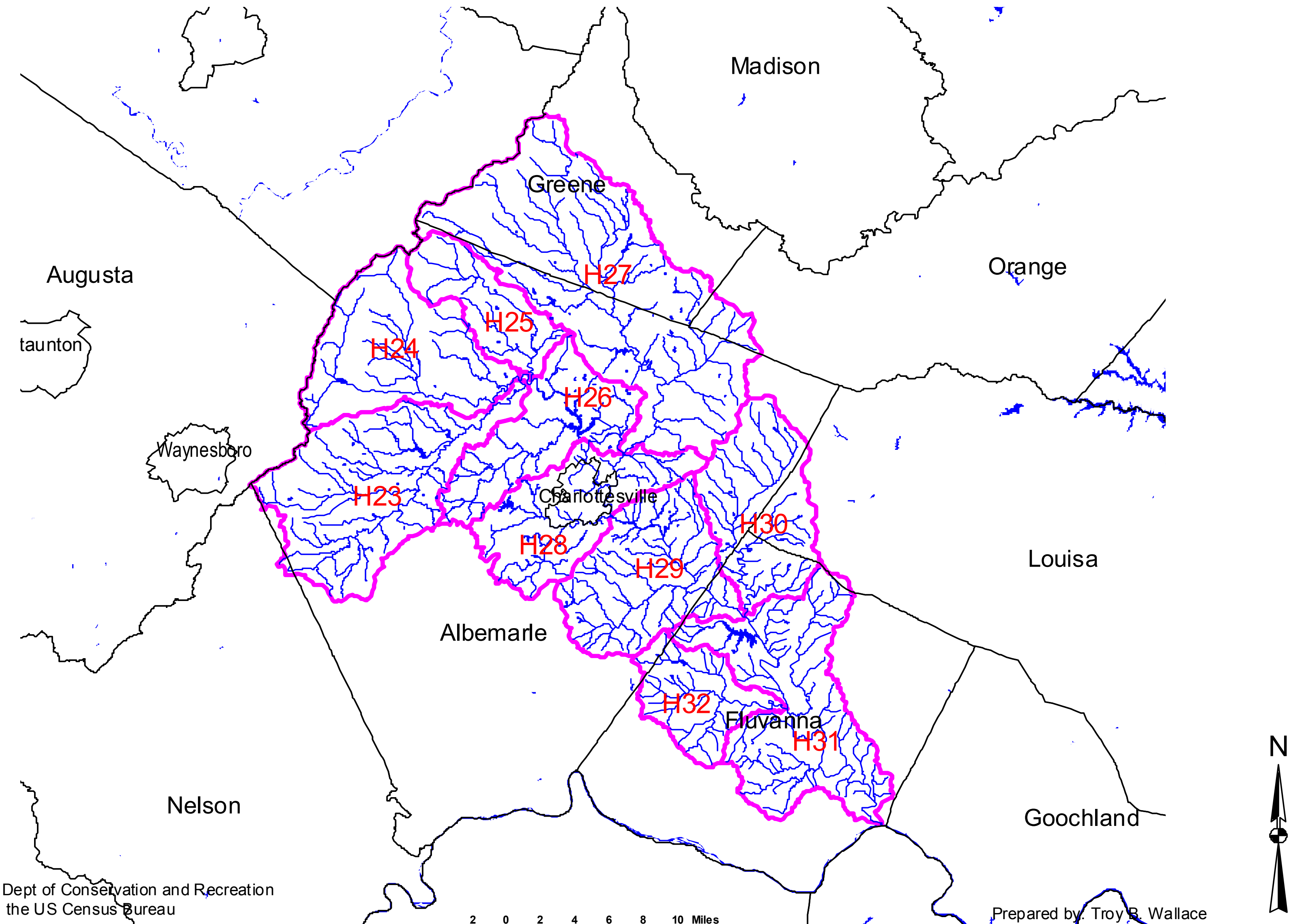
Plate 19: The Upper Middle James Drainage Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

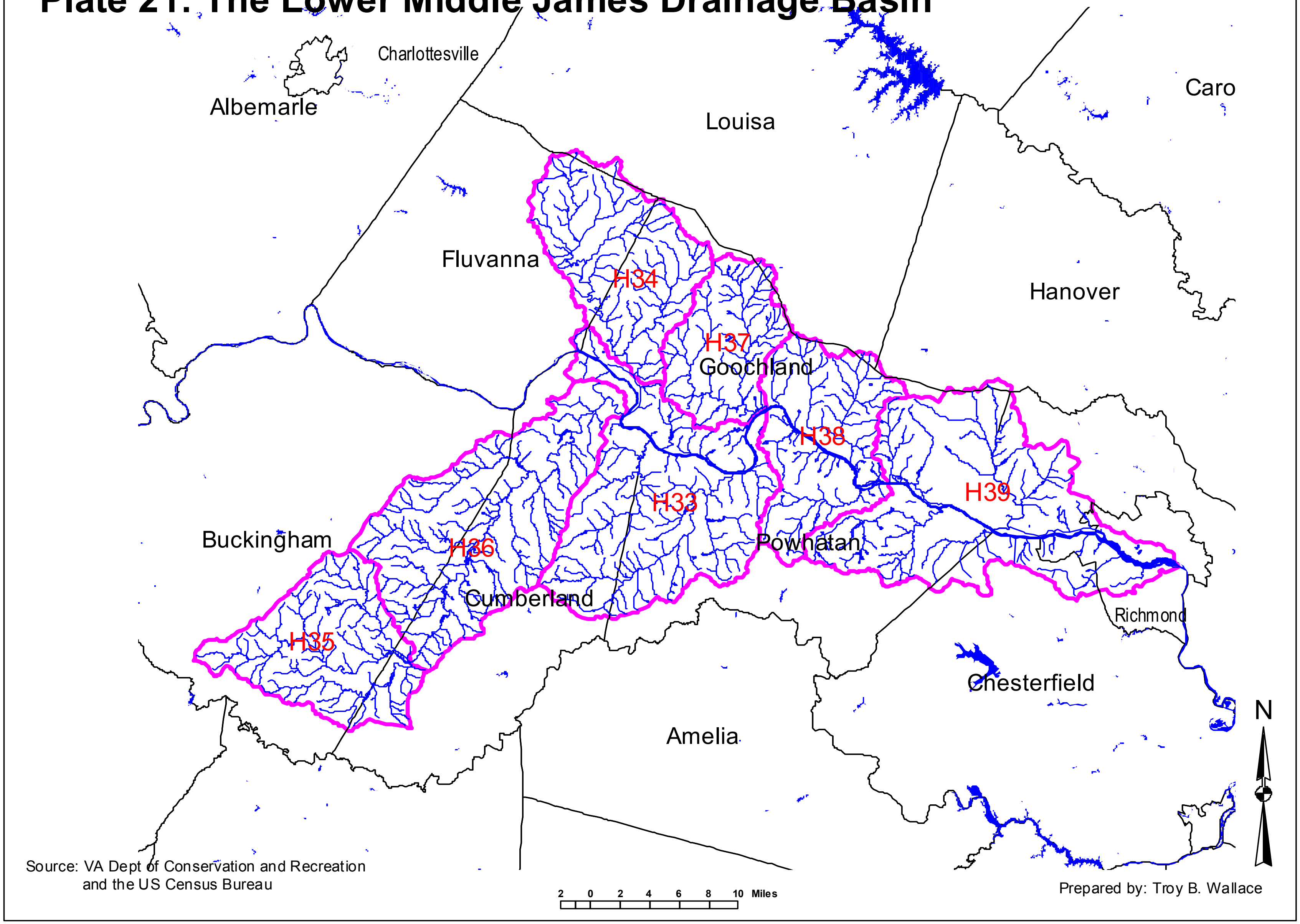
Plate 20: The Rivanna River Basin (James)



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 21: The Lower Middle James Drainage Basin



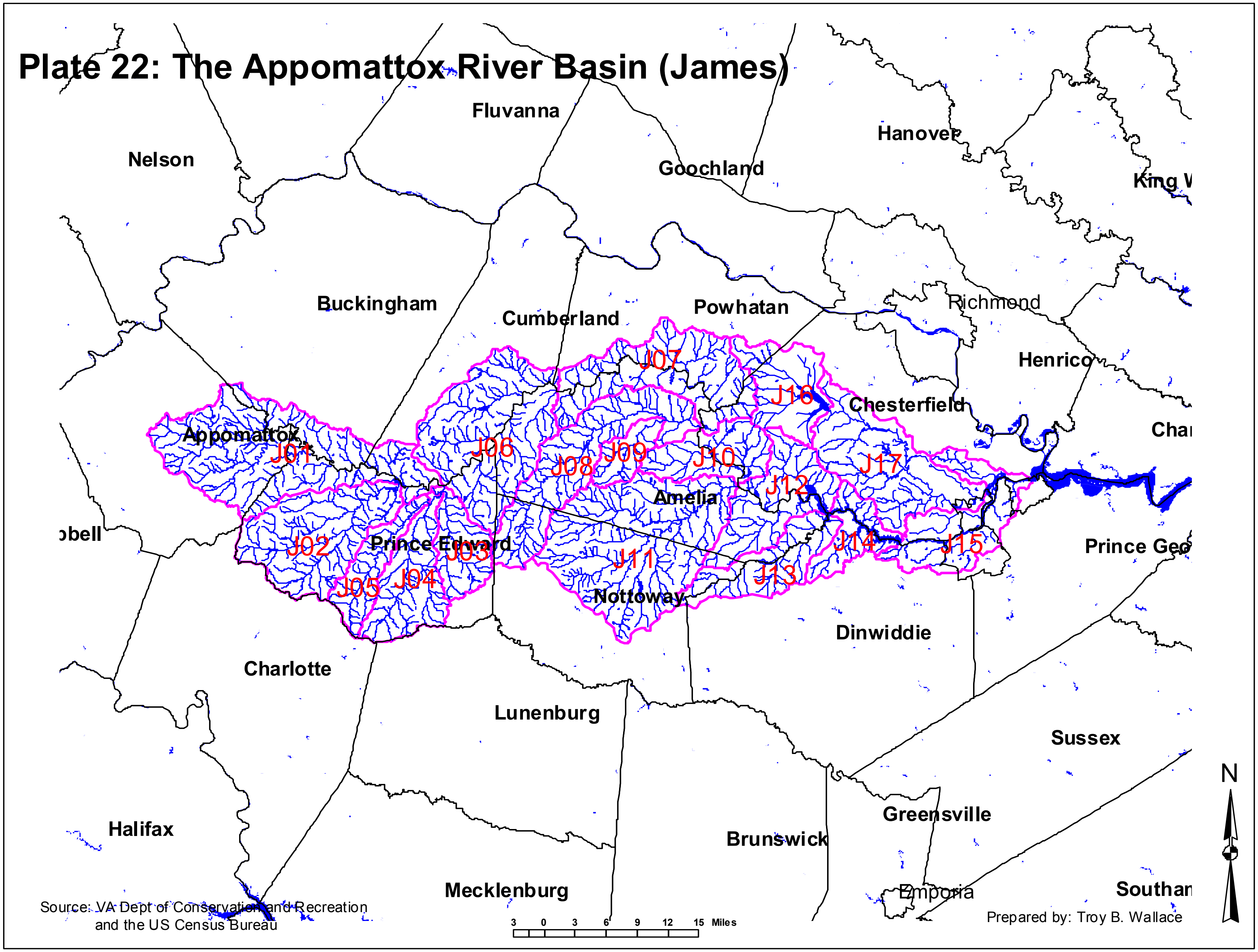
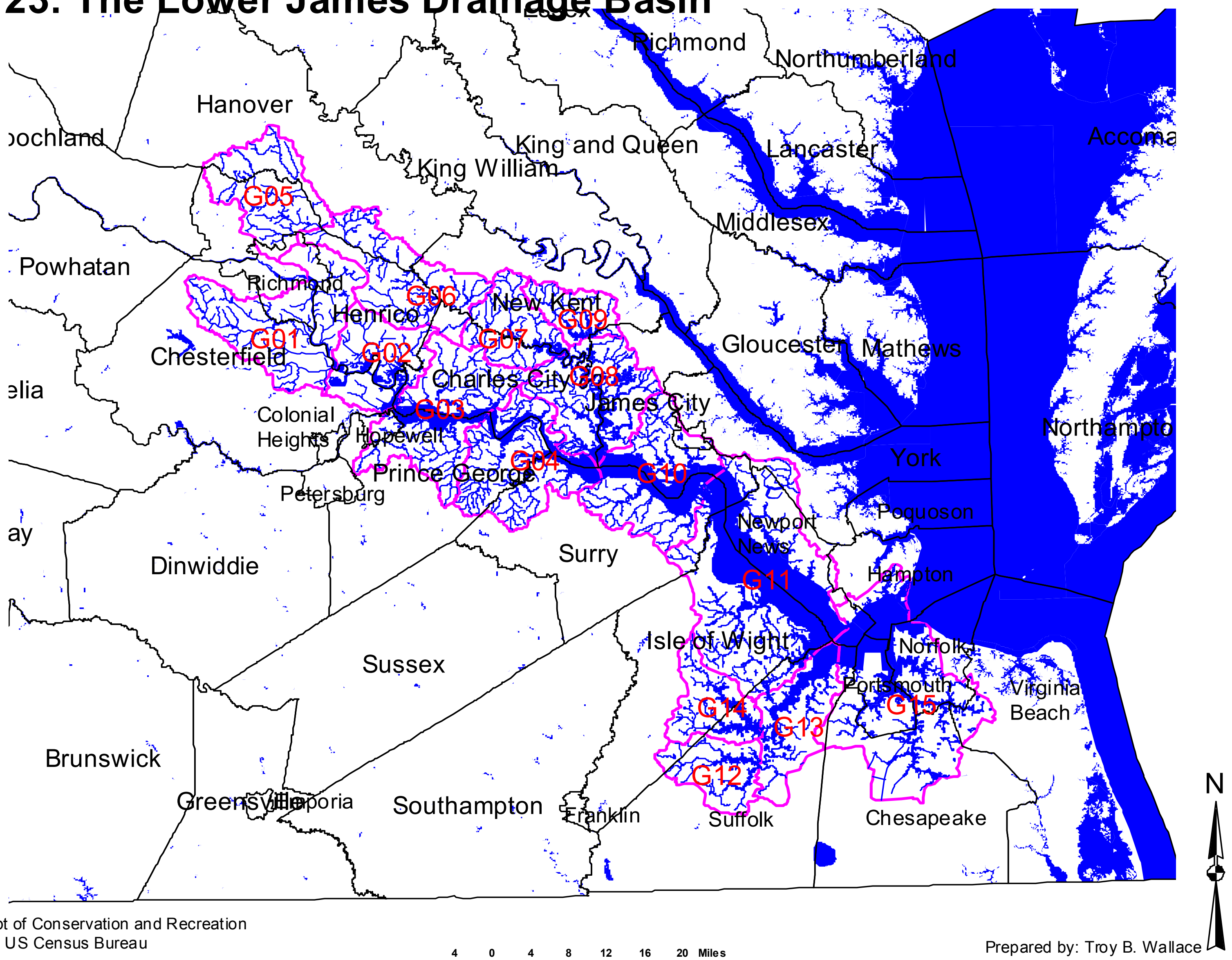


Plate 22: The Appomattox River Basin (James)
Fluvanna
Nelson
Goochland
Hanover
King W
Buckingham
Cumberland
Powhatan
Richmond
Henrico
Chesterfield
Char
Appomattox
J01
J02
J03
J04
J05
J06
J07
J08
J09
J10
J11
J12
J13
J14
J15
J16
J17
Amelia
Prince Edward
Nottoway
bell
Prince Geo
Dinwiddie
Charlotte
Lunenburg
Sussex
Halifax
Greensville
Brunswick
Mecklenburg
Emporia
Southam
N
Source: VA Dept of Conservation and Recreation
and the US Census Bureau
3 0 3 6 9 12 15 Miles
Prepared by: Troy B. Wallace

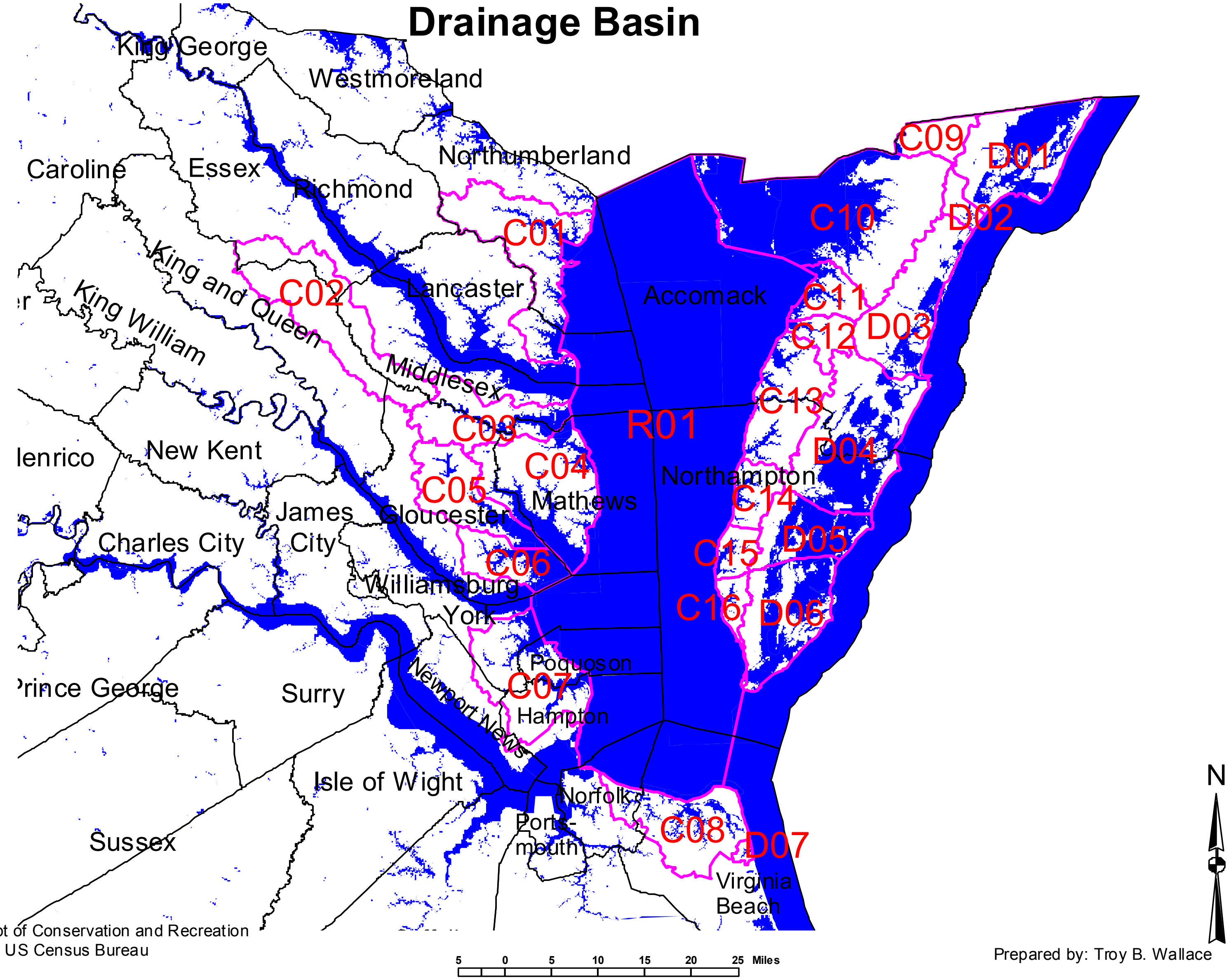
Plate 23: The Lower James Drainage Basin



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 24: The Virginia Portion of the Chesapeake Bay and Atlantic Ocean Drainage Basin



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

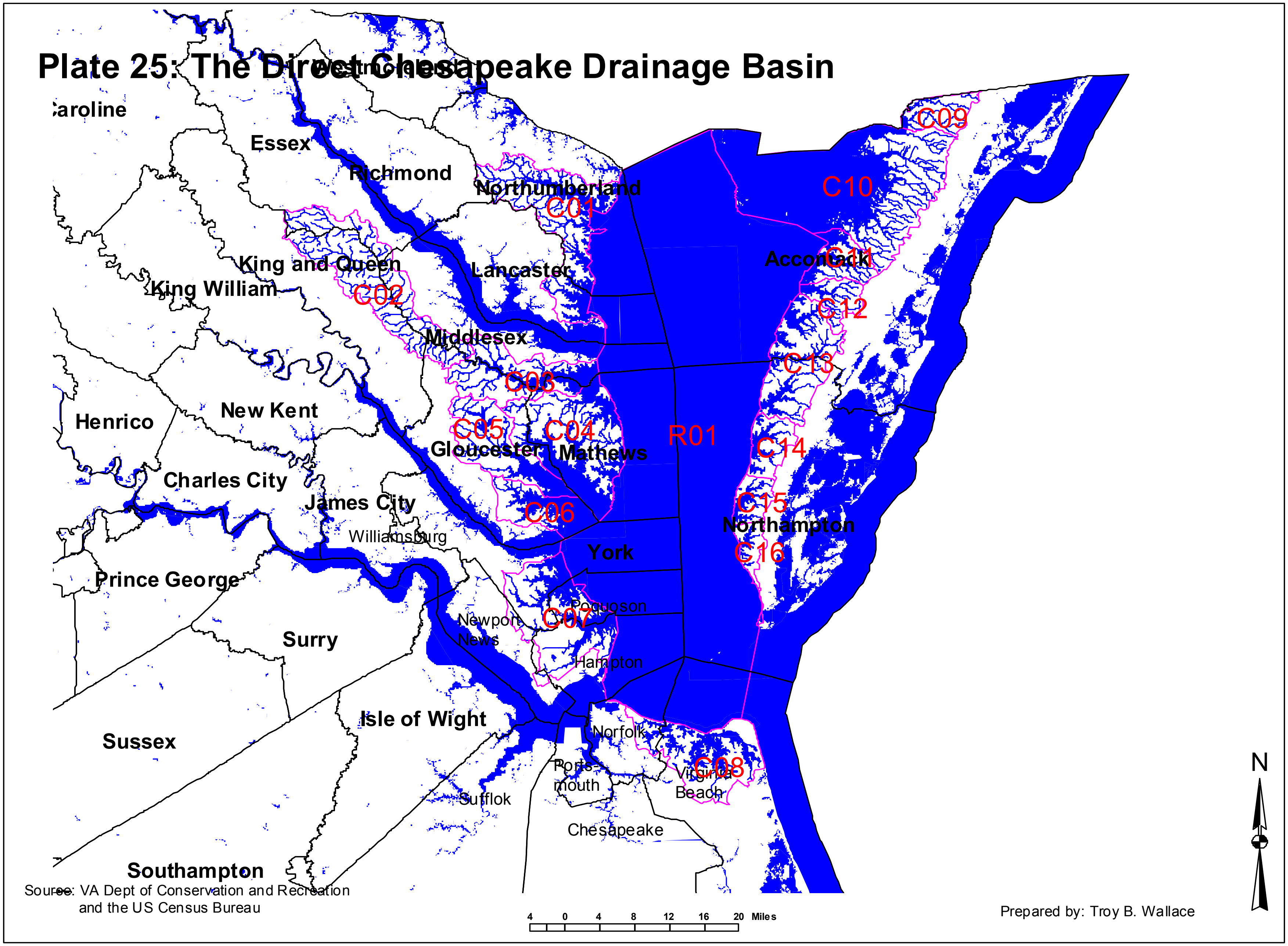
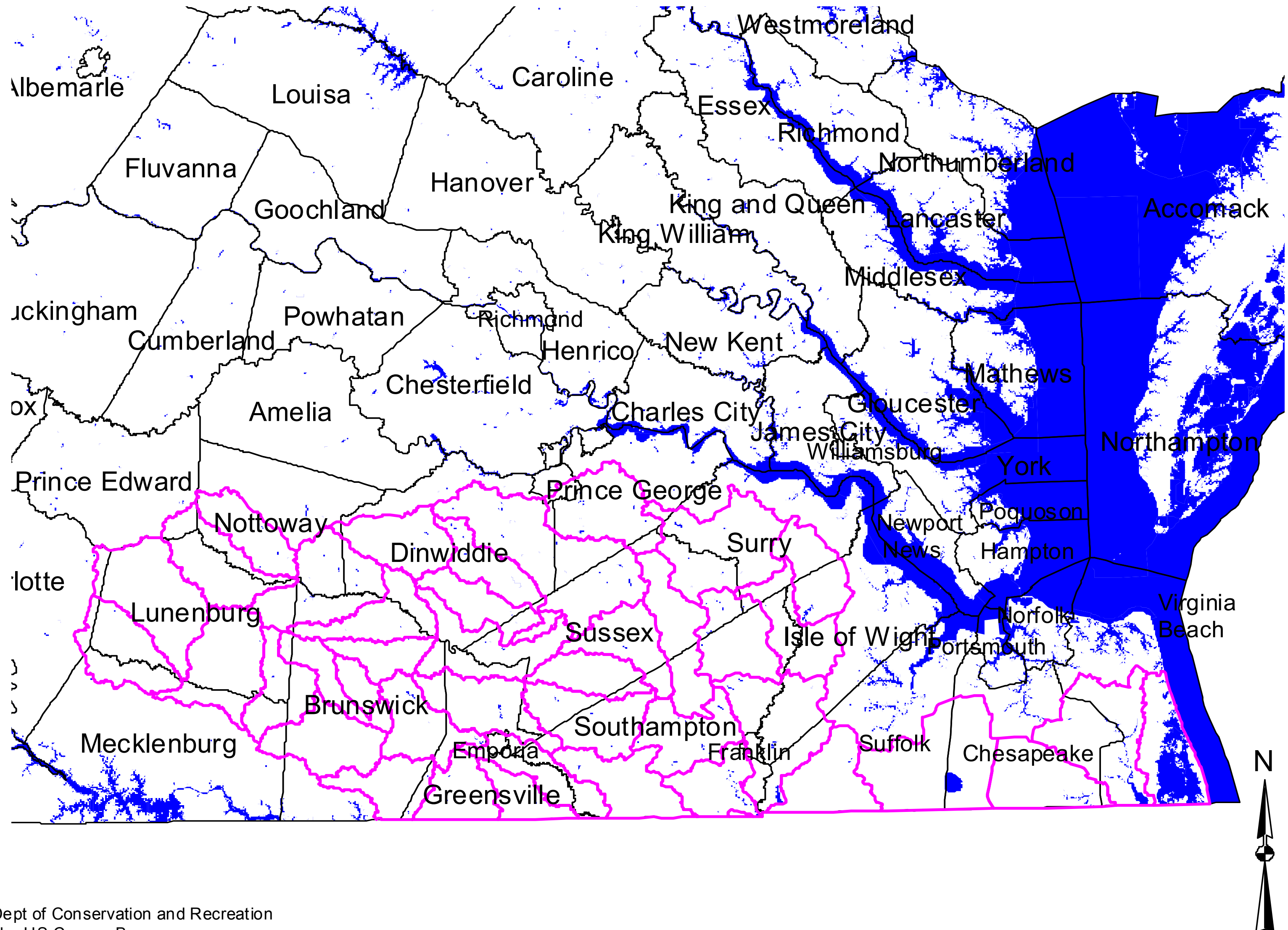


Plate 25: The Direct Chesapeake Drainage Basin
Westmoreland
Caroline
Essex
Richmond
Northumberland
C01
King and Queen
Lancaster
King William
C02
Middlesex
C03
Henrico
New Kent
C05
C04
Gloucester
Mathews
R01
Charles City
James City
C06
Williamsburg
York
Prince George
Poquoson
C07
Newport News
Surry
Hampton
Isle of Wight
Sussex
Norfolk
Ports-mouth
C08
Virginia Beach
Suffolk
Chesapeake
Southampton
C09
C10
Accomack
C11
C12
C13
C14
C15
Northampton
C16
N
4 0 4 8 12 16 20 Miles
Source: VA Dept of Conservation and Recreation and the US Census Bureau
Prepared by: Troy B. Wallace

Plate 27: The Virginia Portion of the Chowan River Basin

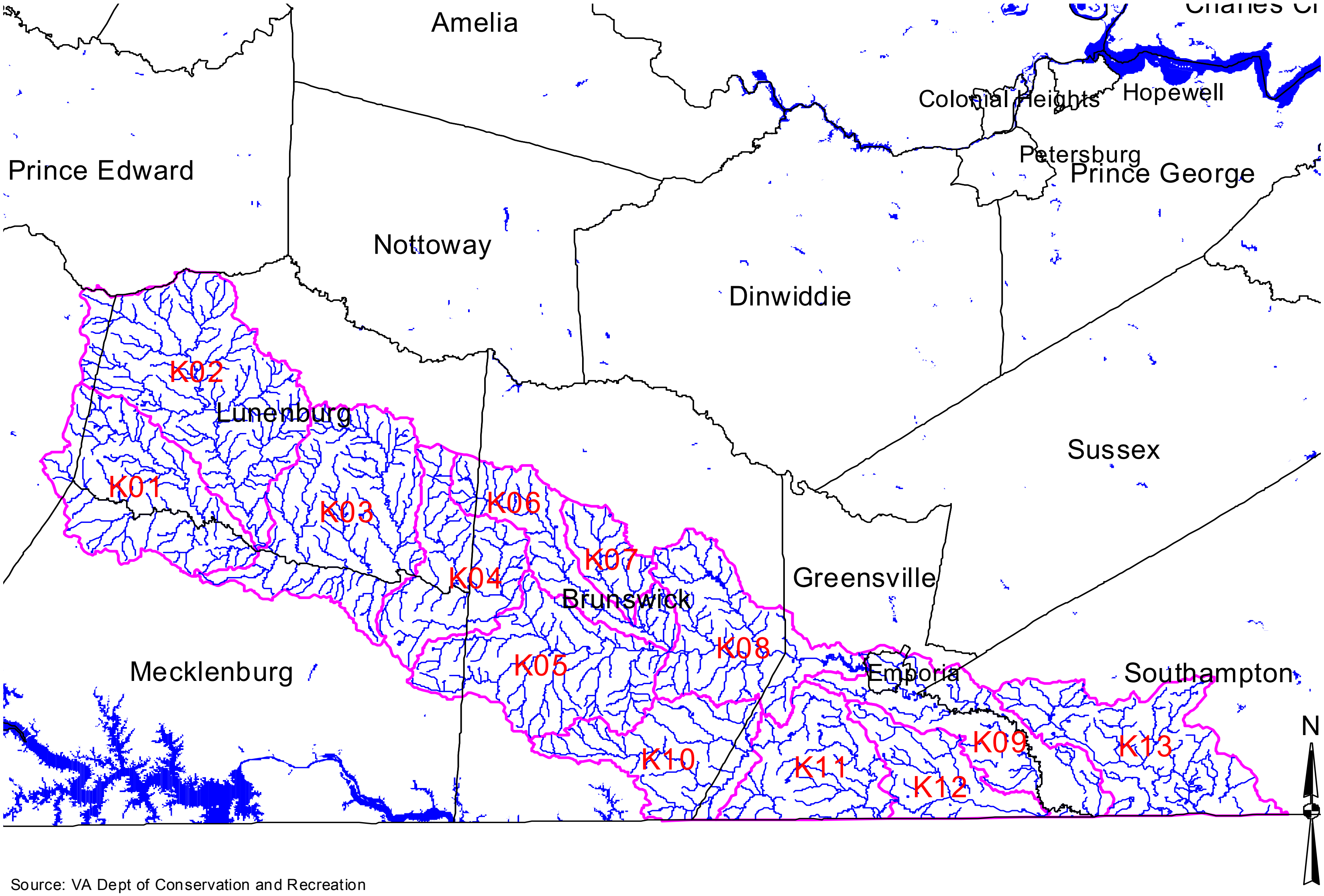


6 0 6 12 18 24 30 Miles

Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 28: The Virginia Portion of the Meherrin River Basin (Chowan)



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

2 0 2 4 6 8 10 Miles

Prepared by: Troy B. Wallace

Plate 29: The Virginia Portion of the Nottoway River Basin (Chowan)

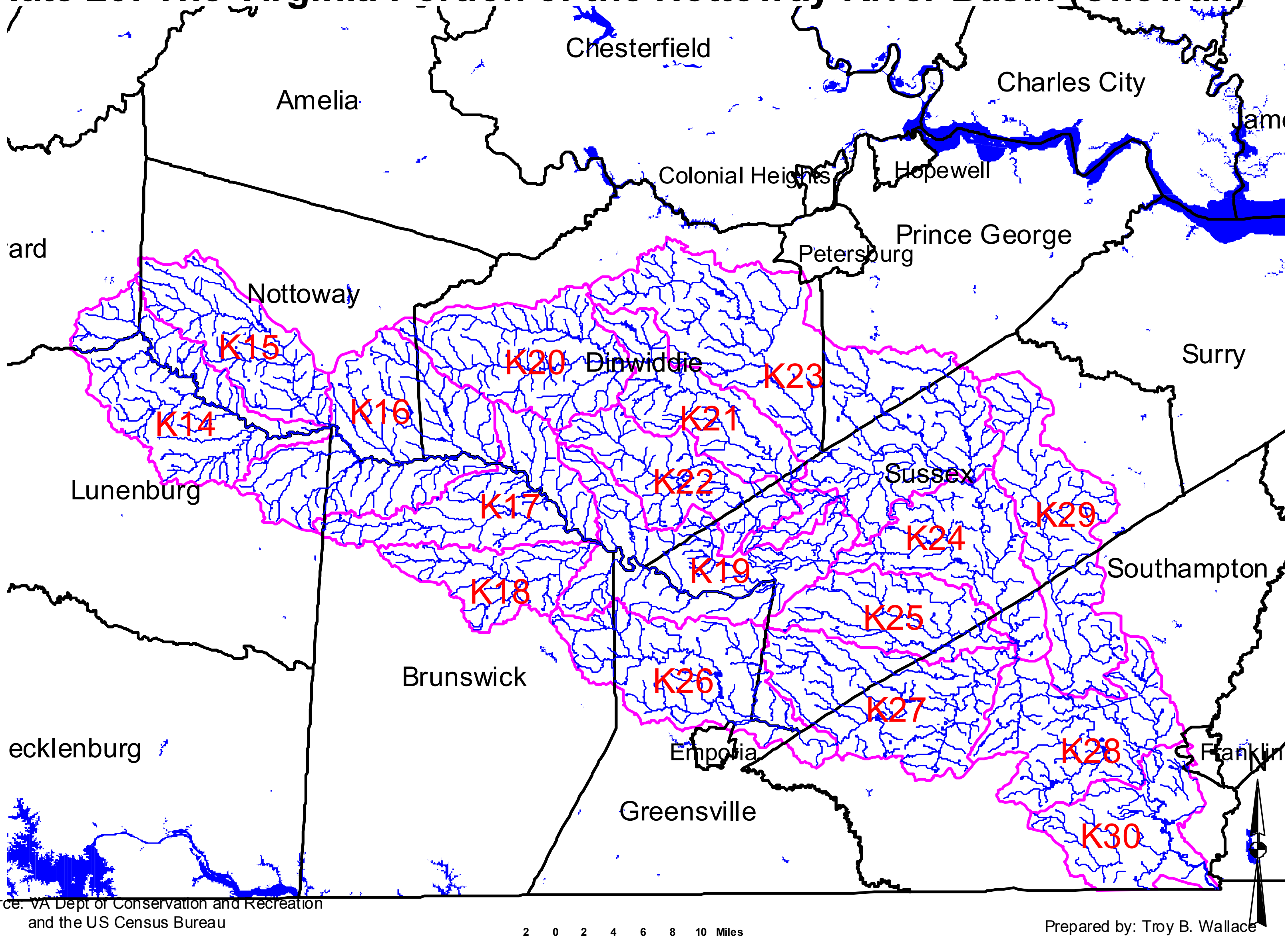
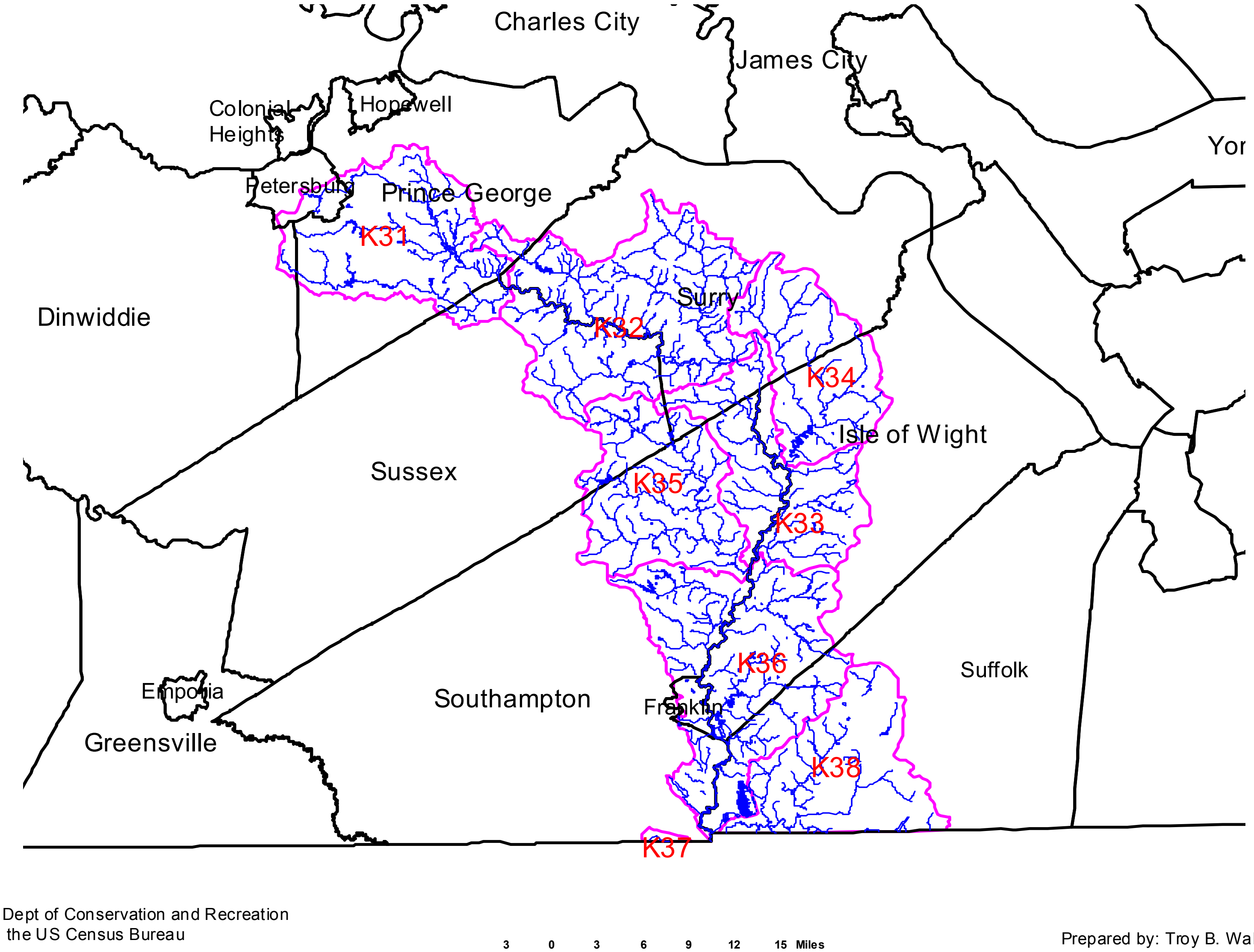


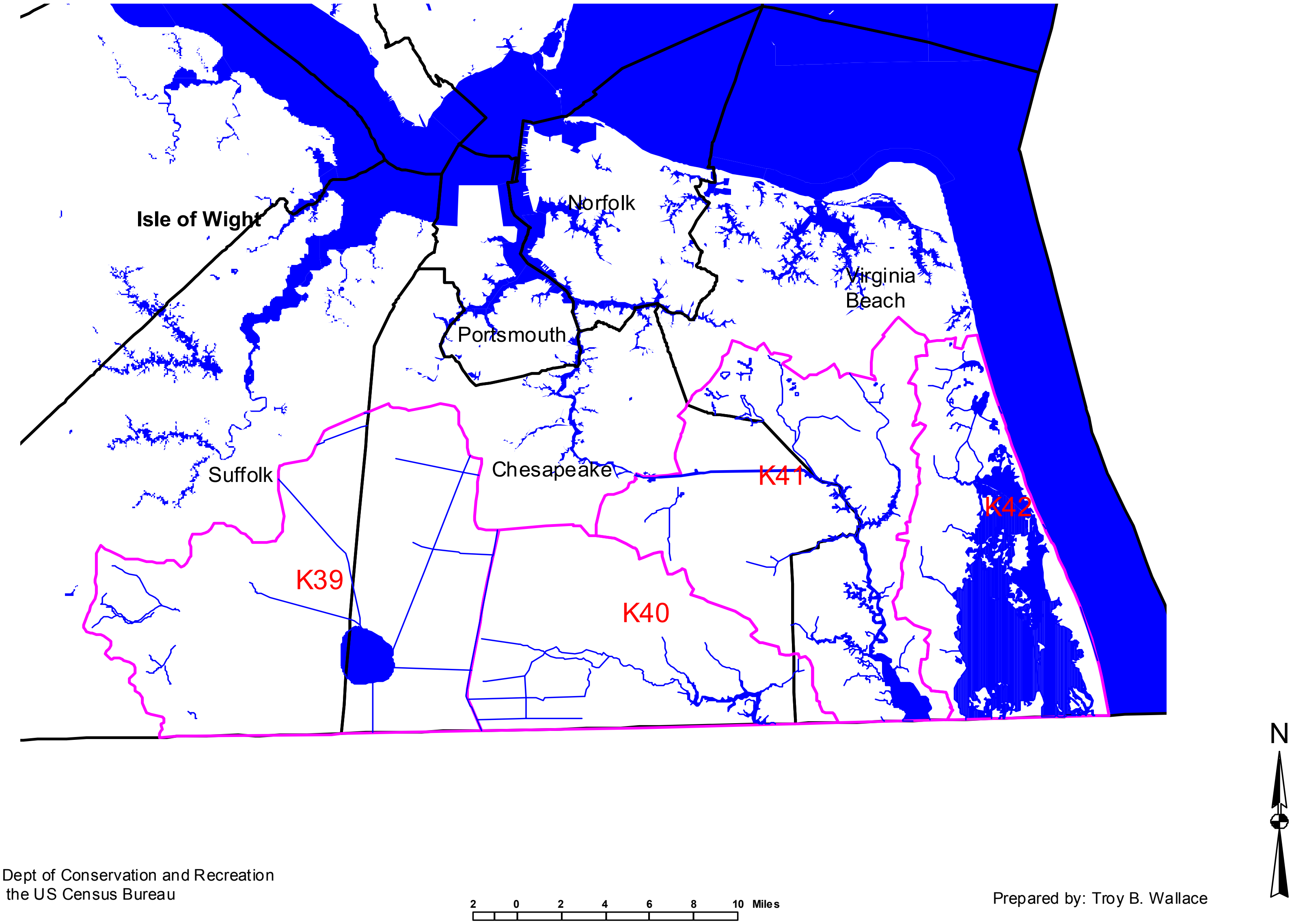
Plate 30: The Virginia Portion of the Blackwater River Basin (Chowan)



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

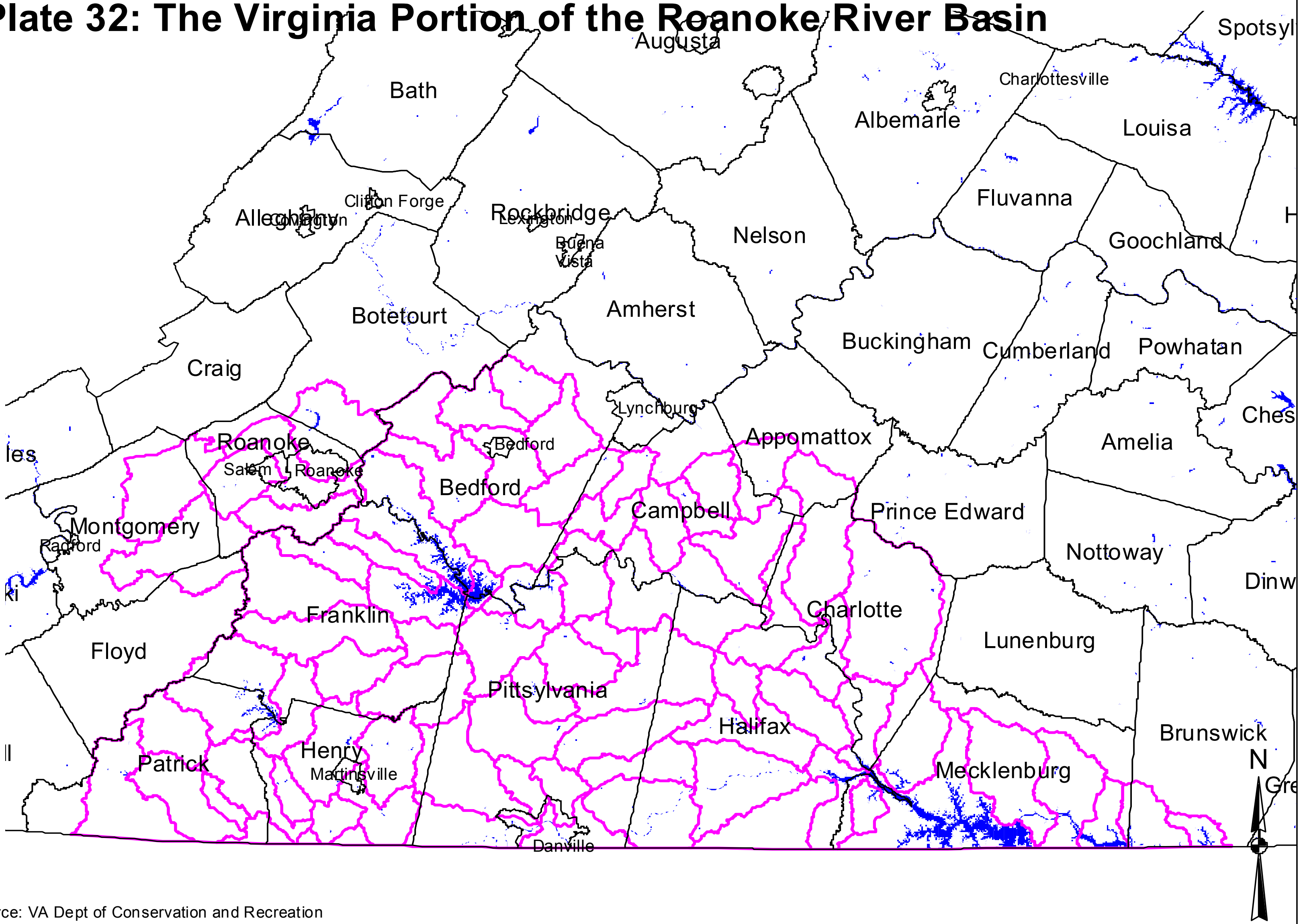
Plate 31: Southeastern Coastal Portion of the Chowan River Basin



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

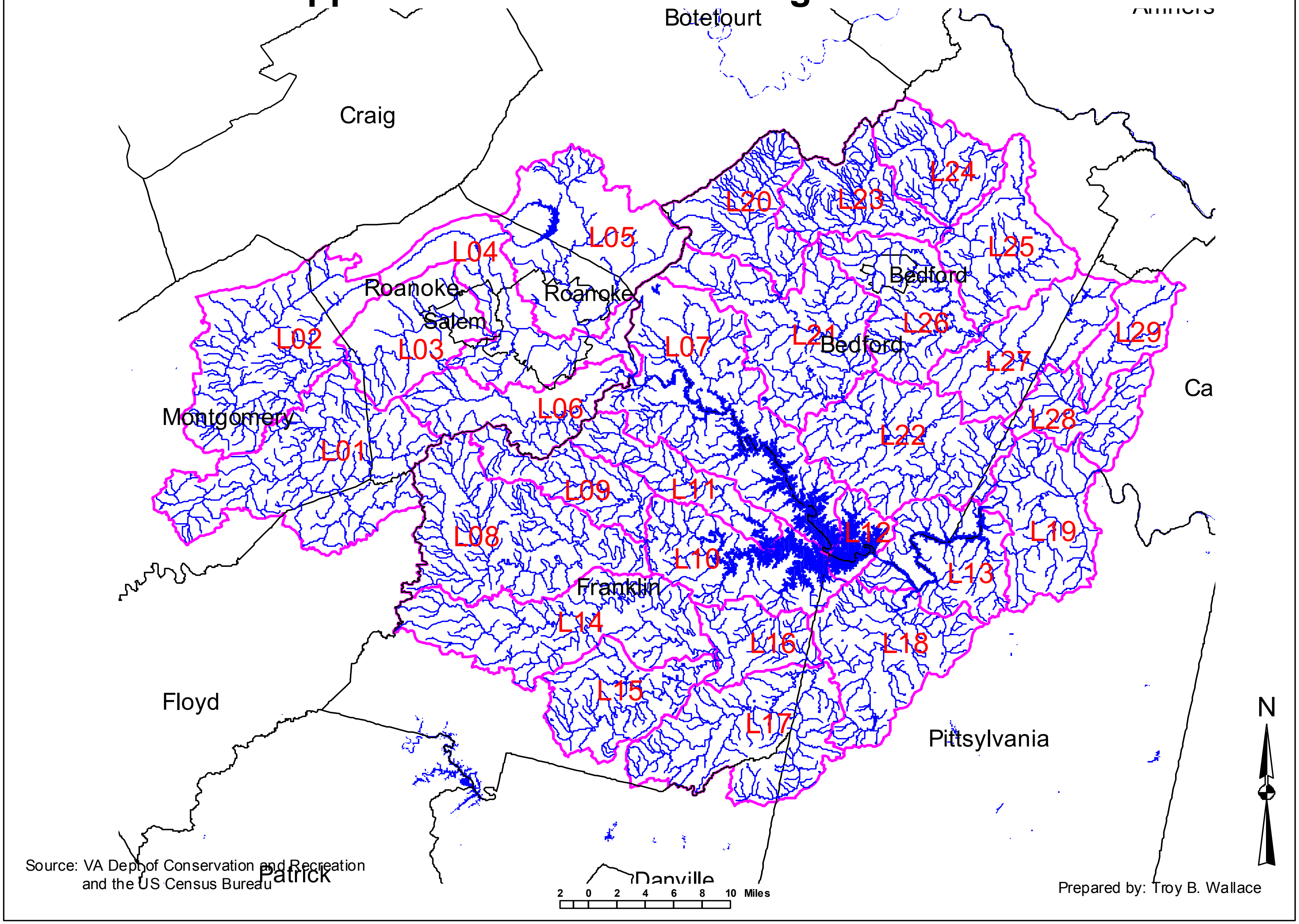
Plate 32: The Virginia Portion of the Roanoke River Basin



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 33: The Upper Roanoke River Drainage Basin



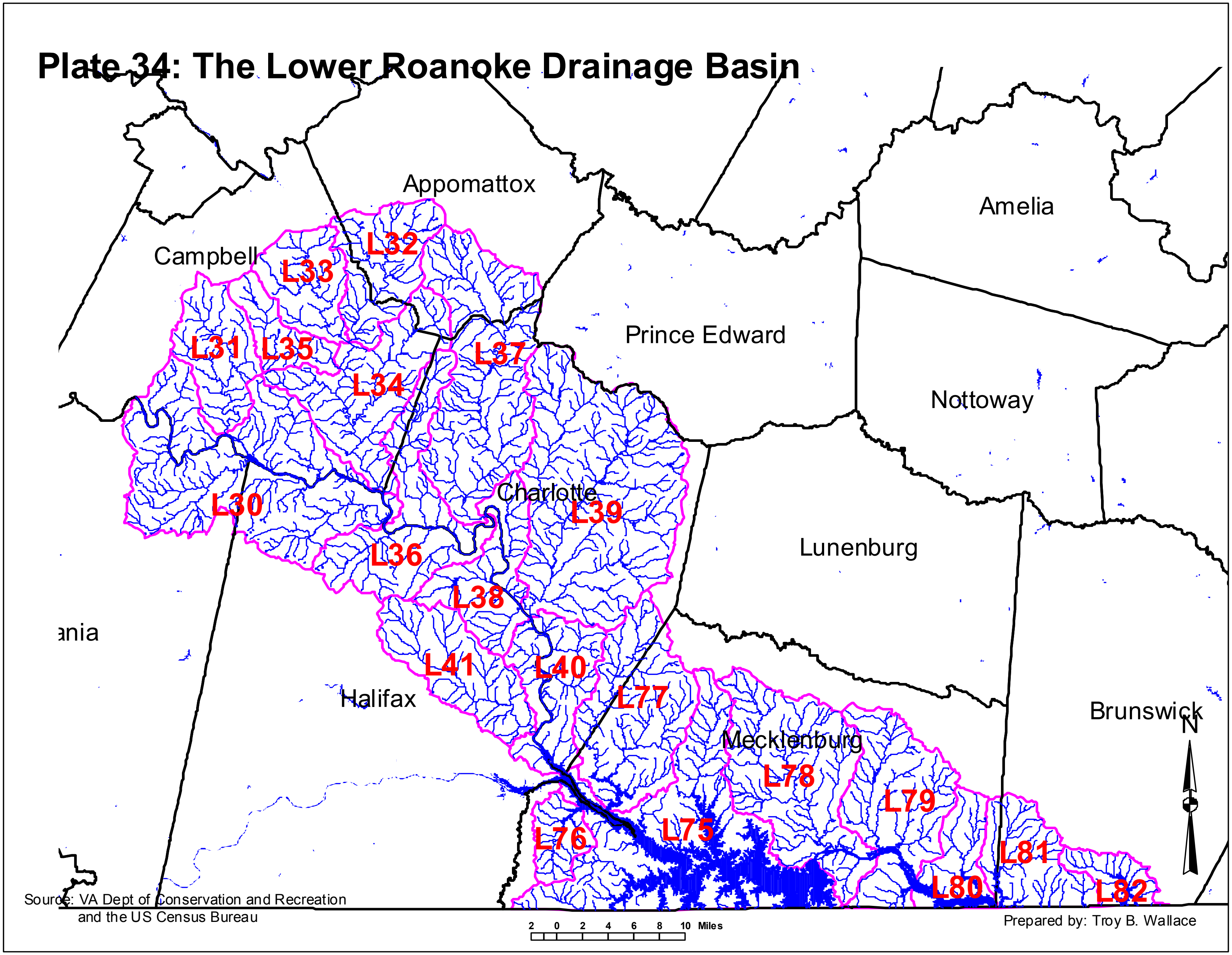
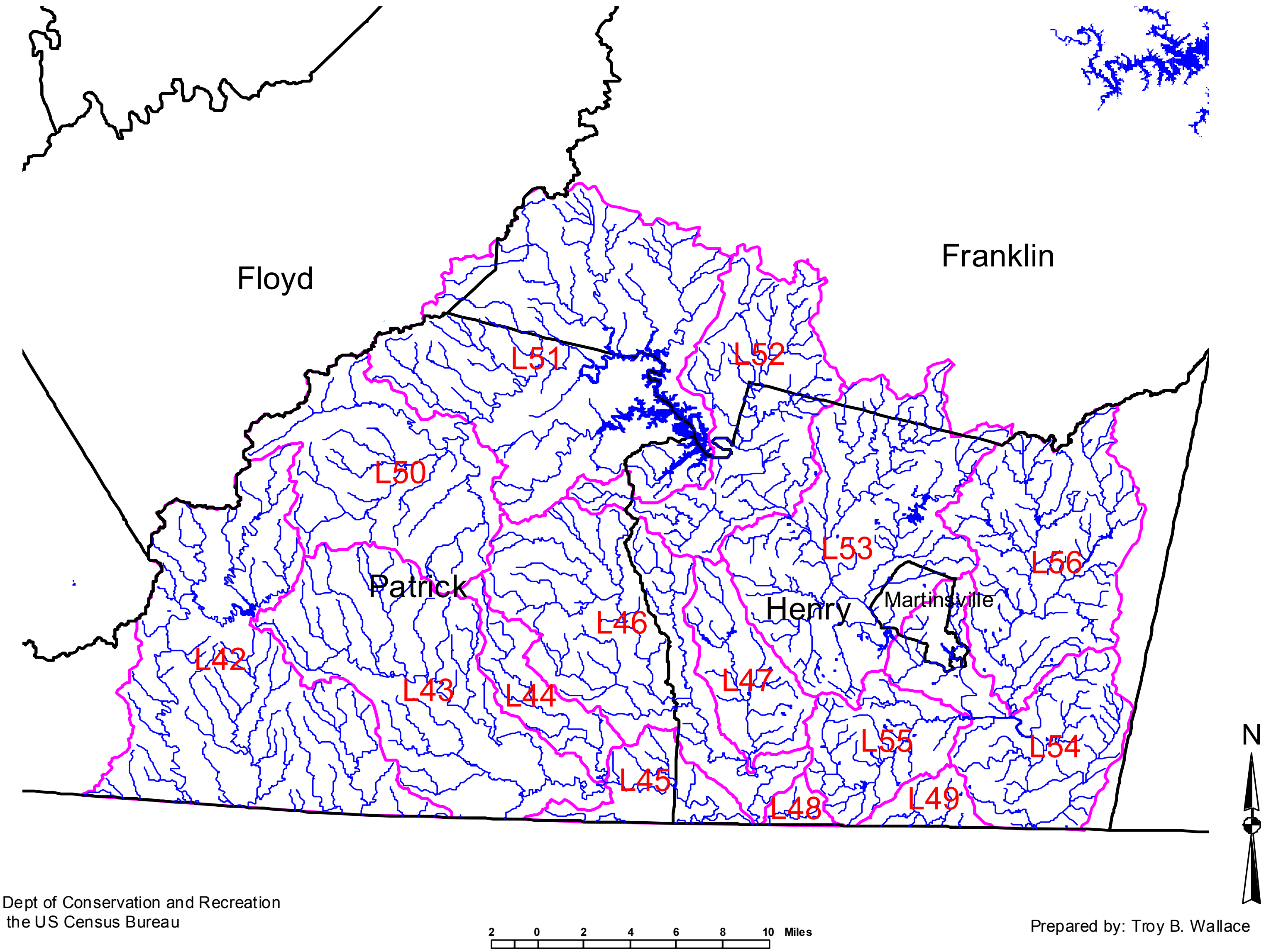


Plate 34: The Lower Roanoke Drainage Basin

Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

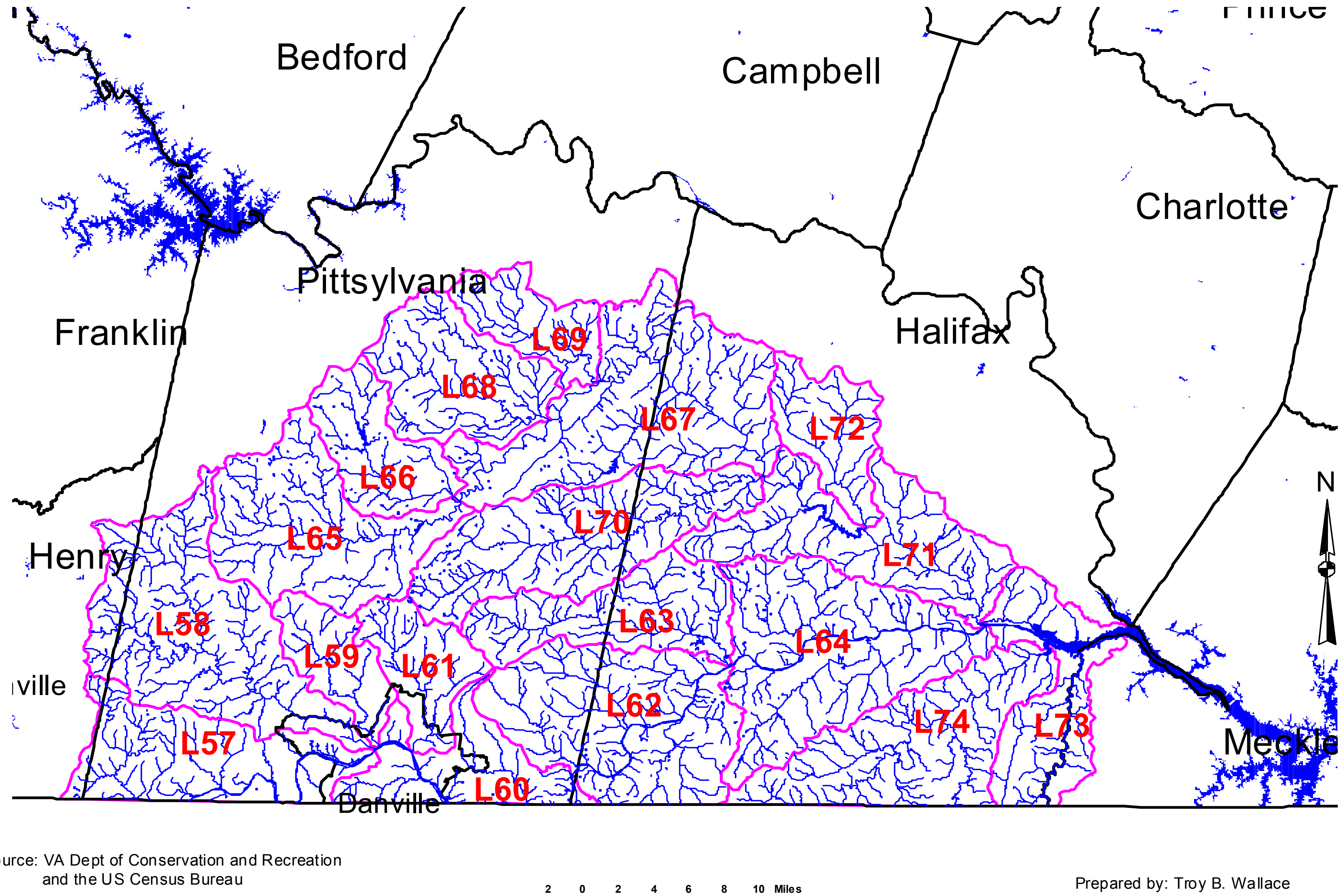
Plate 35: The Martinsville Portion of the Roanoke River Basin: The Dan, Smith and Mayo Rivers



Source: VA Dept of Conservation and Recreation and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 36: The Danville Portion of the Roanoke River Basin: The Dan and Banister Rivers



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 37: The Virginia Portion of the Ararat River Basin

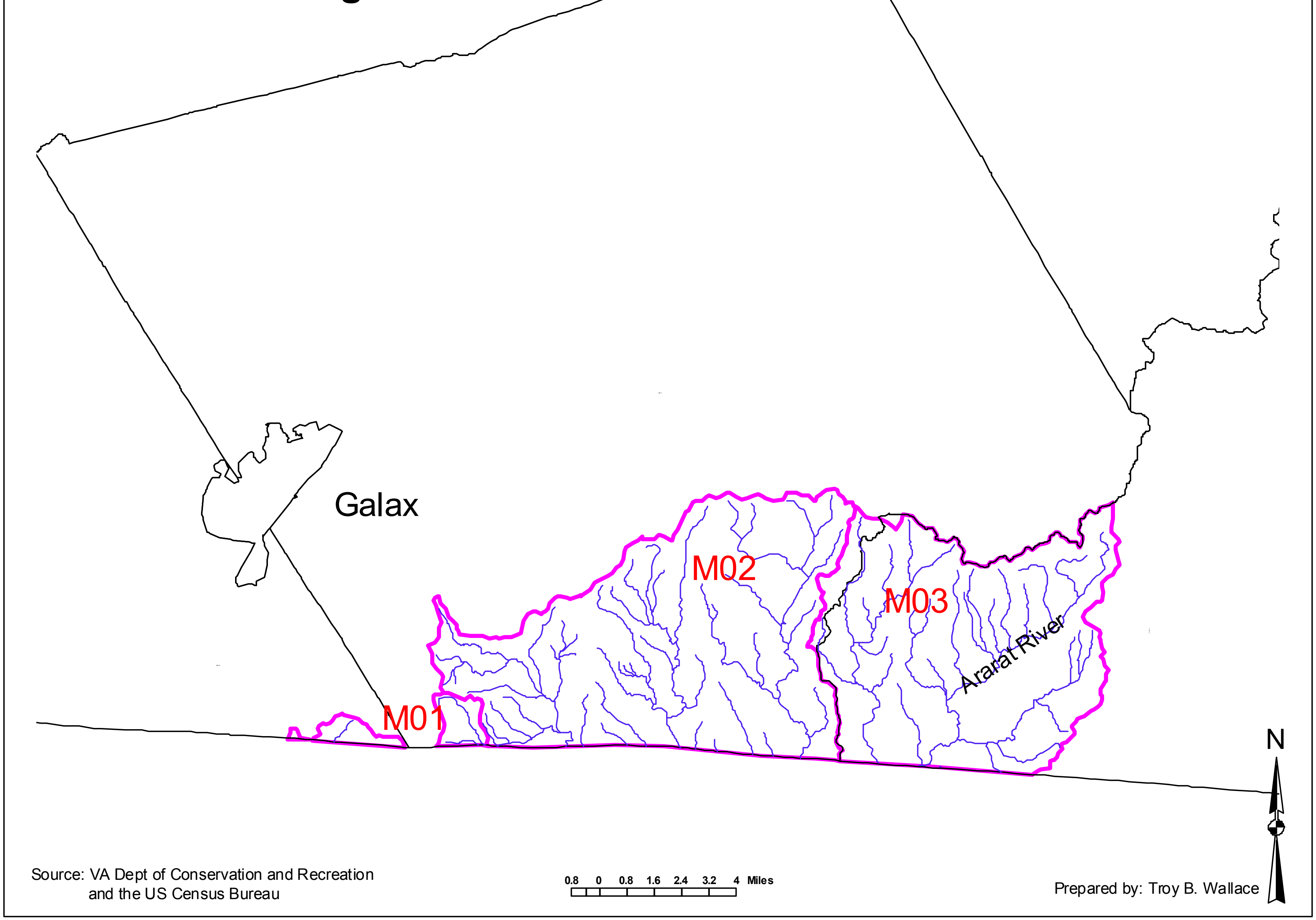
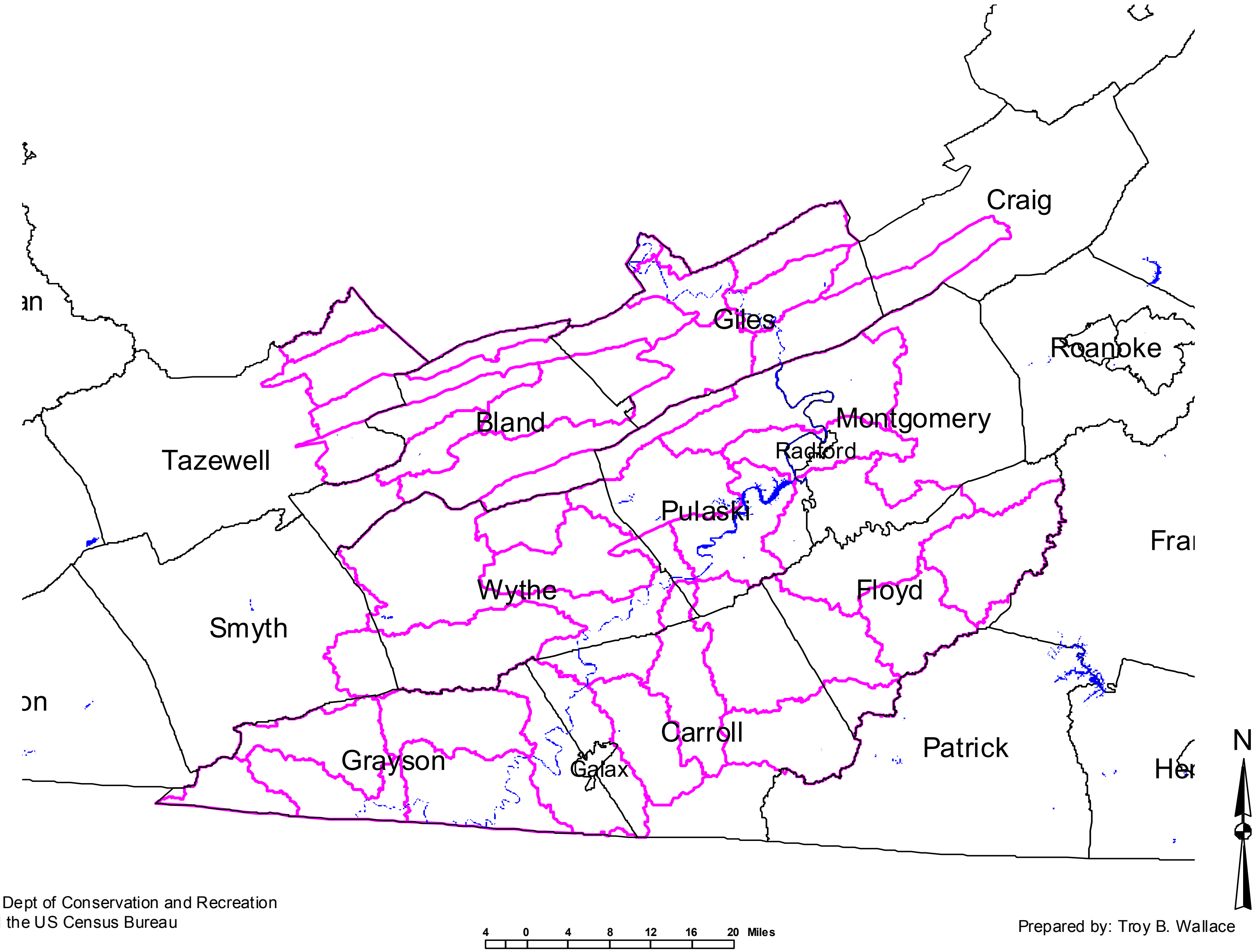


Plate 38: The Virginia Portion of the New River Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

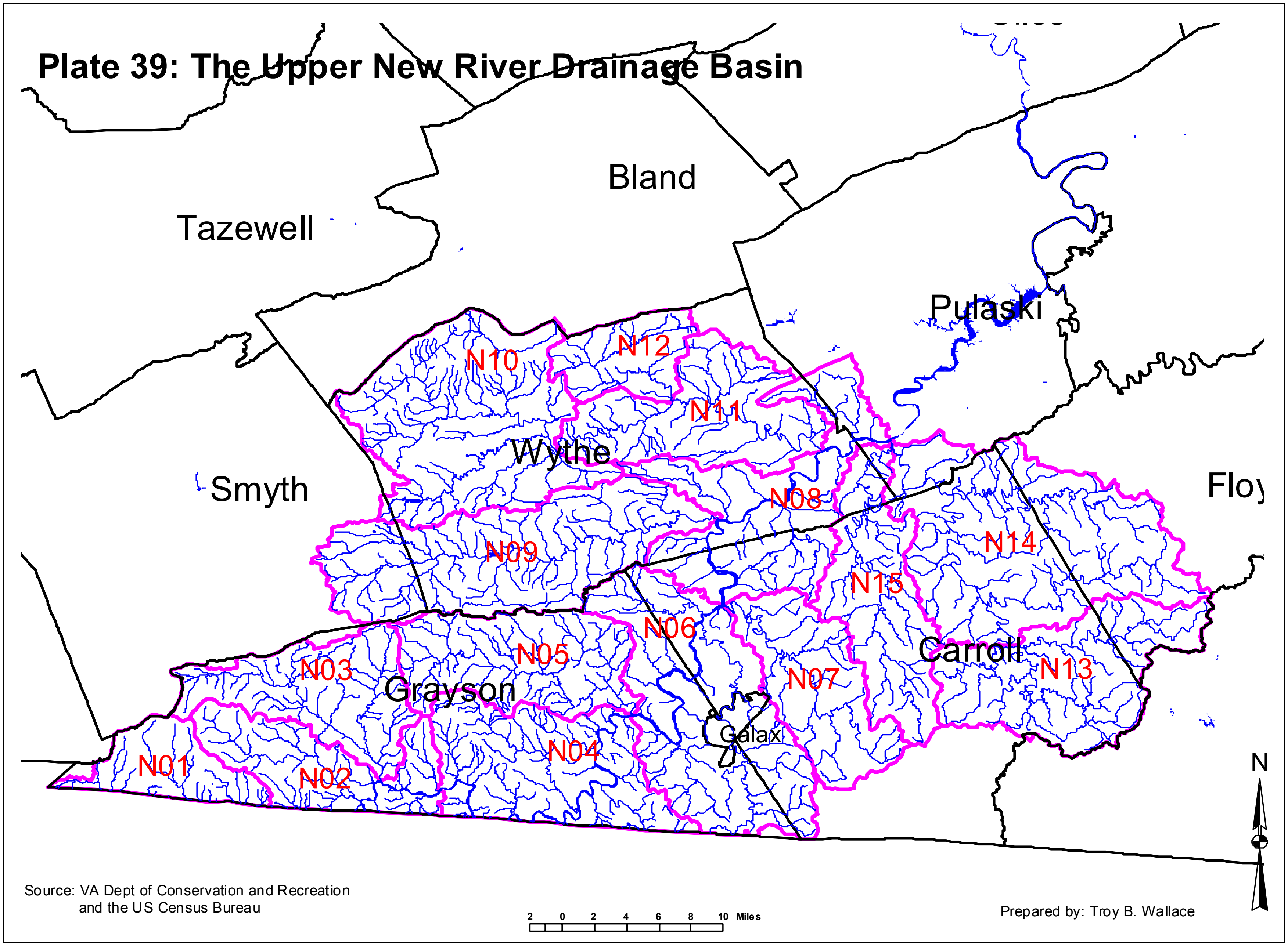


Plate 39: The Upper New River Drainage Basin
Bland
Tazewell
Pulaski
Smyth
Wythe
Floy
Grayson
Carroll
Galax
N01
N02
N03
N04
N05
N06
N07
N08
N09
N10
N11
N12
N13
N14
N15
N
Source: VA Dept of Conservation and Recreation
and the US Census Bureau
2 0 2 4 6 8 10 Miles
Prepared by: Troy B. Wallace

Plate 40: The Lower New River Drainage Basin

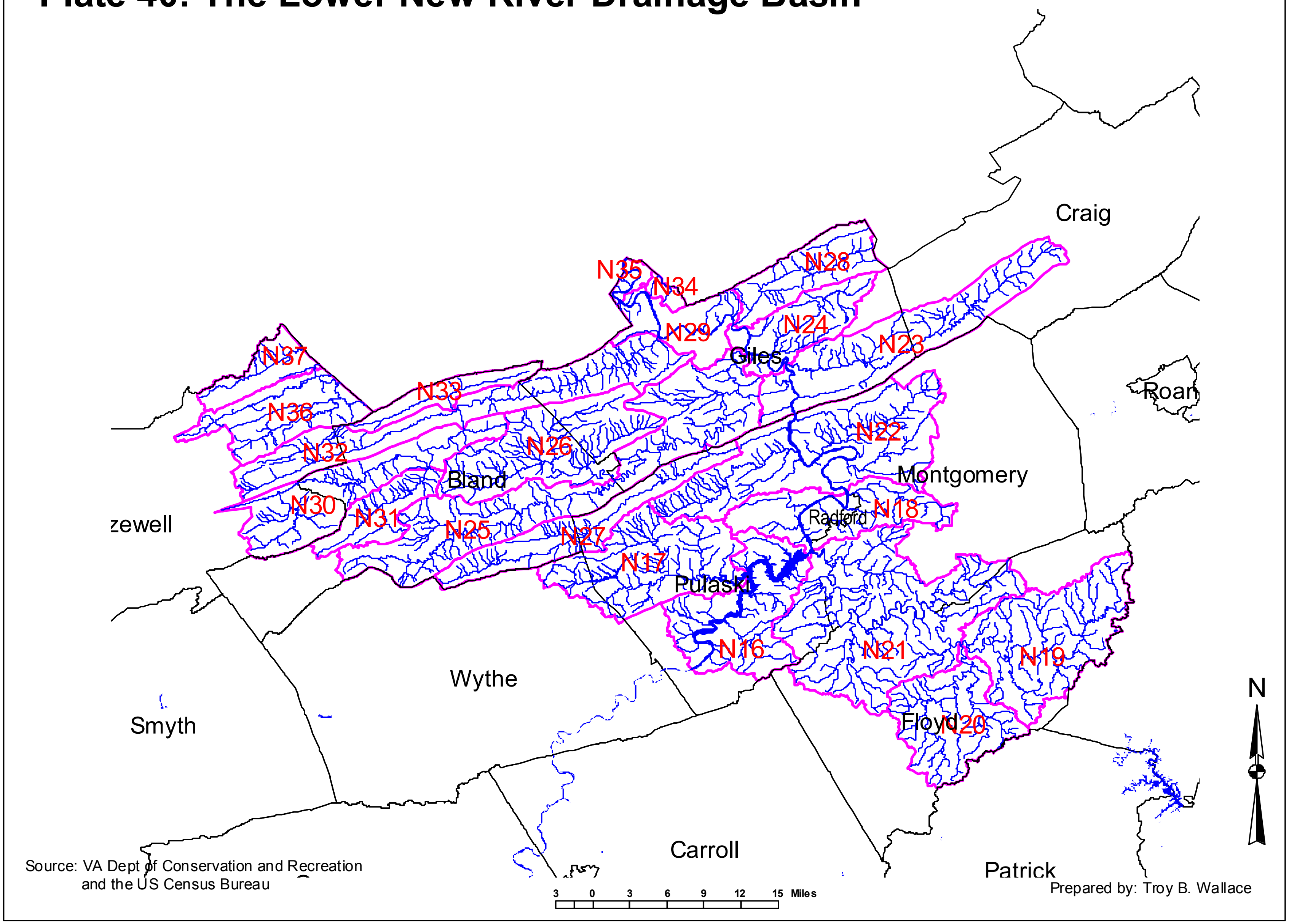
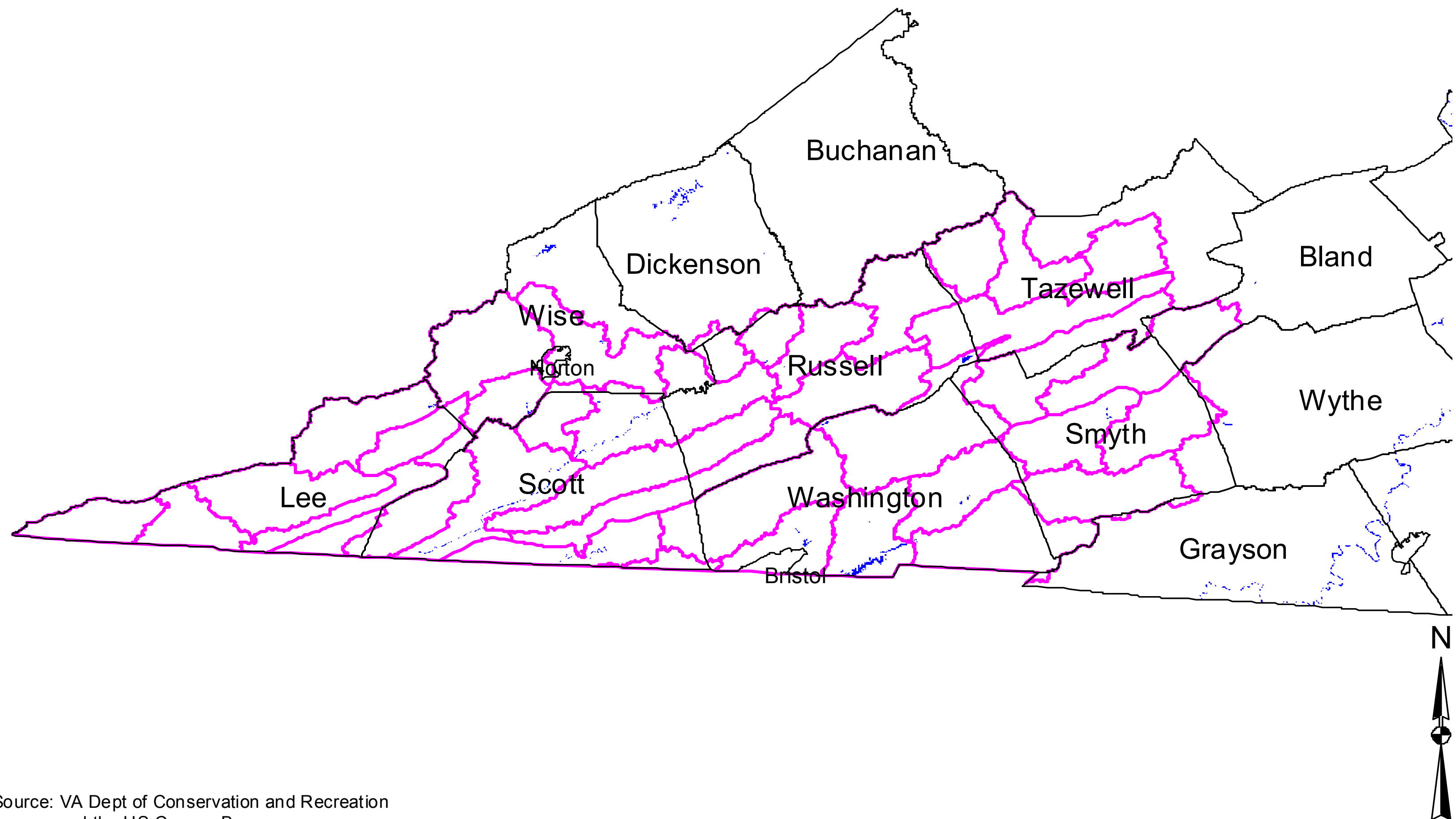


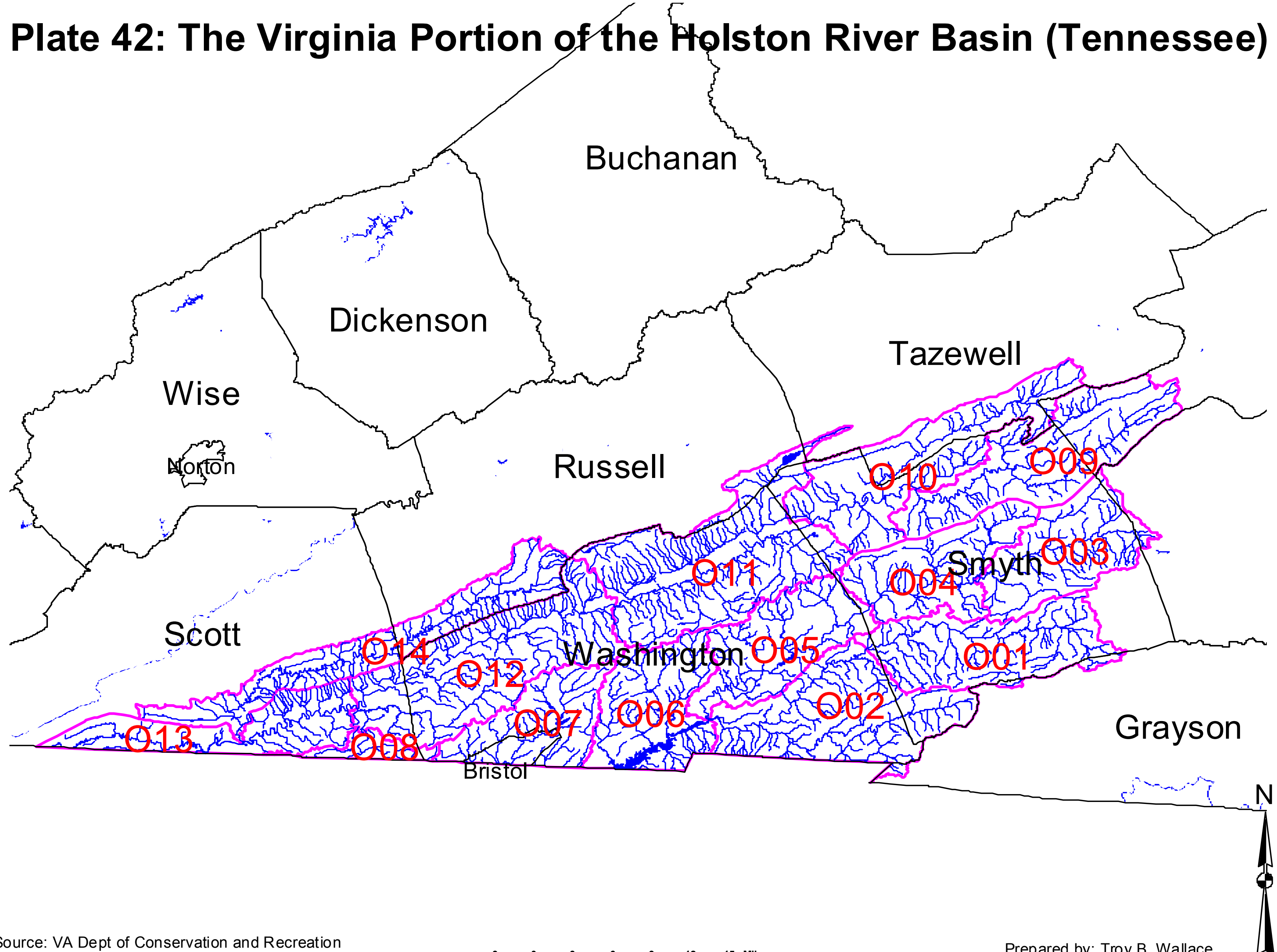
Plate 41: The Virginia Portion of the Tennessee River Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

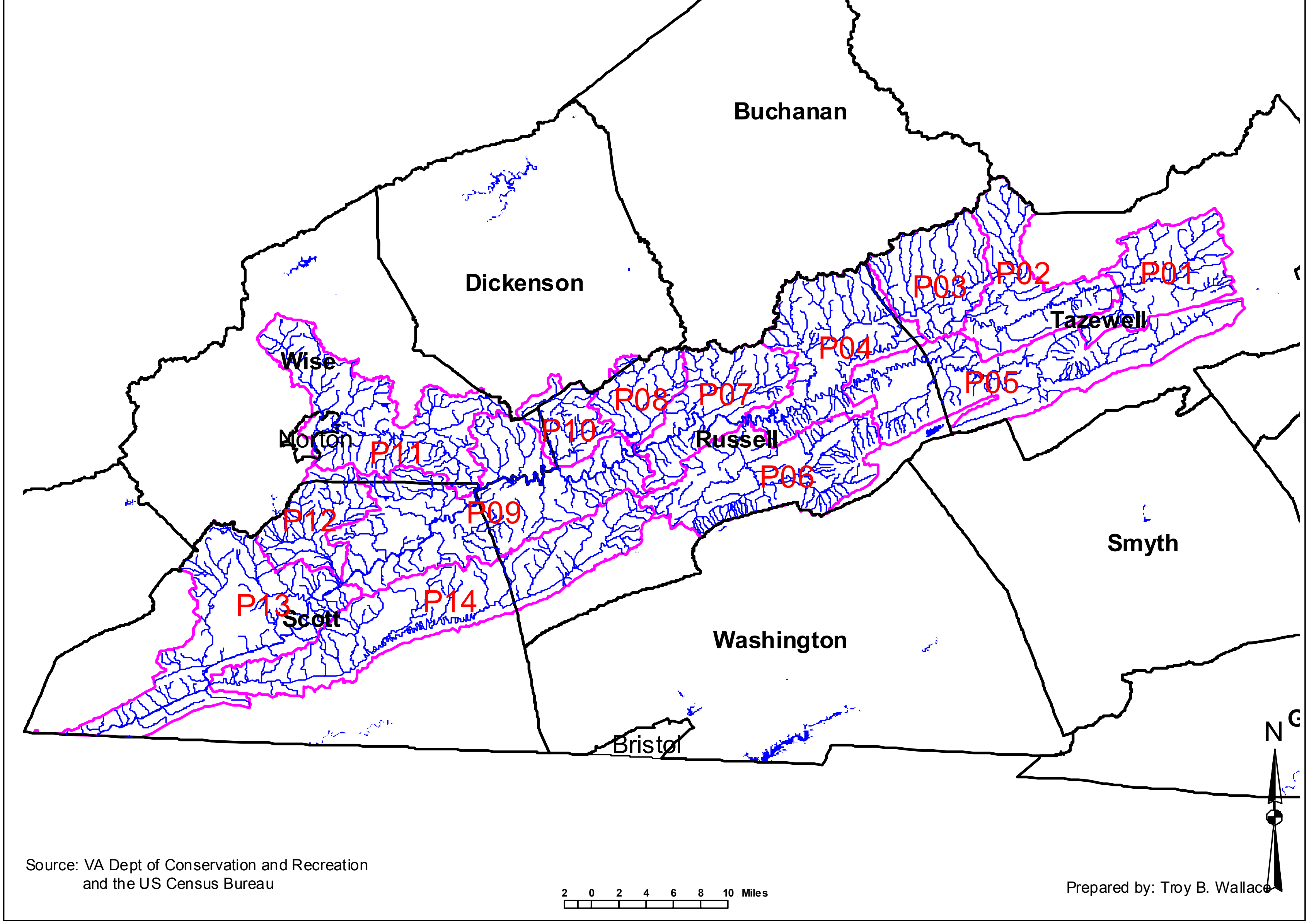
Plate 42: The Virginia Portion of the Holston River Basin (Tennessee)



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 43: The Virginia Portion of the Clinch River Basin (Tennessee)



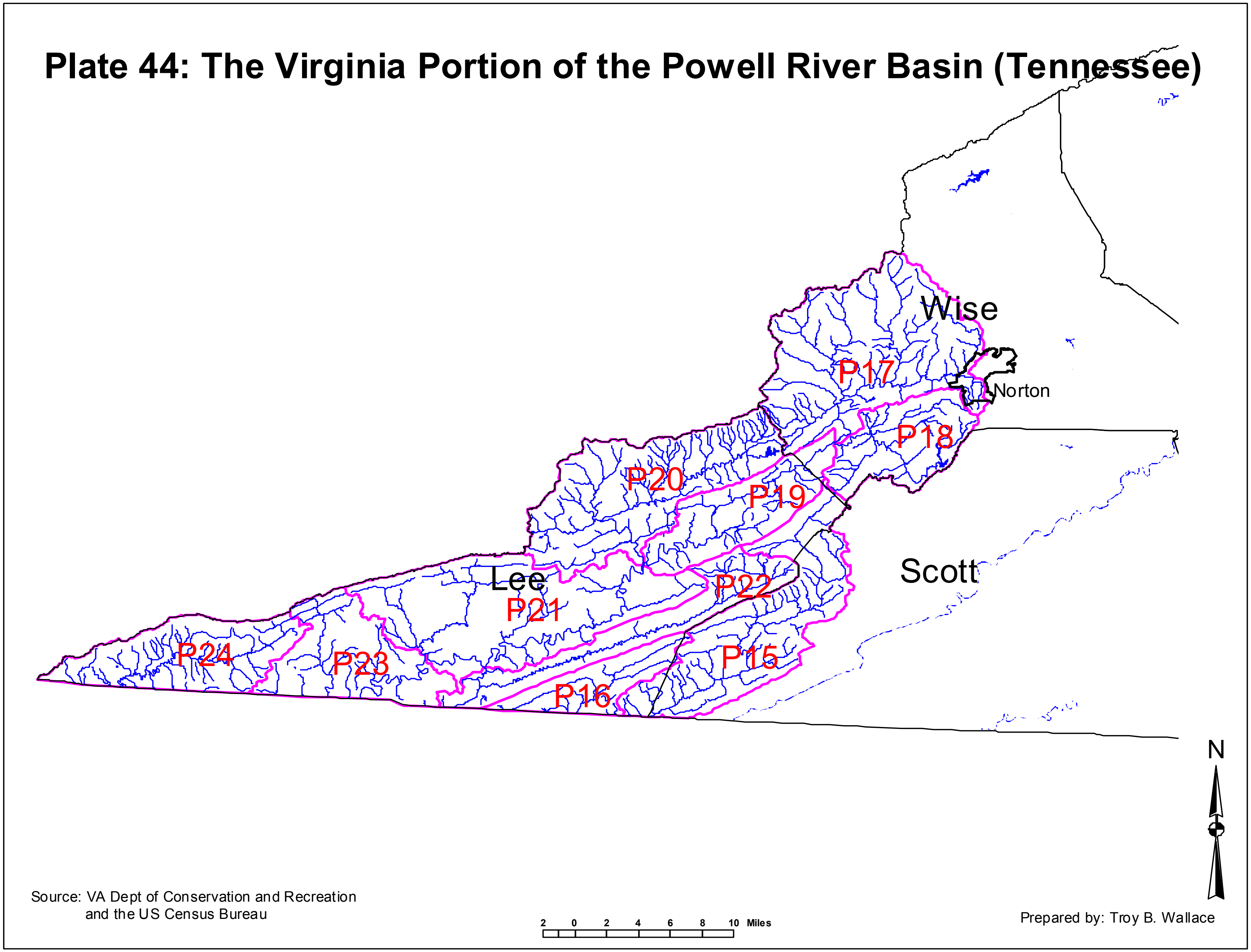
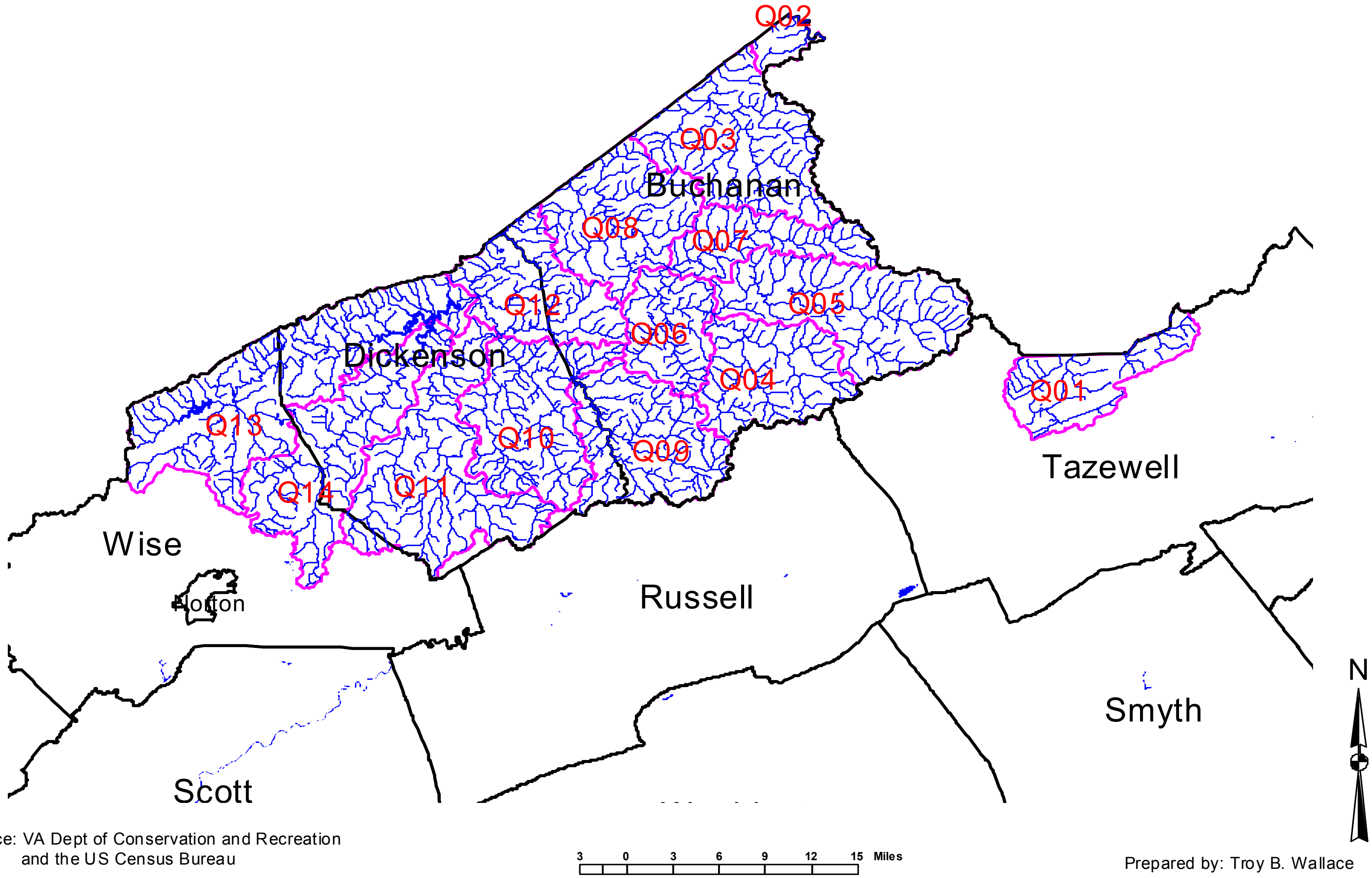


Plate 44: The Virginia Portion of the Powell River Basin (Tennessee)
Wise
Norton
P17
P18
P20
P19
Lee
Scott
P22
P21
P24
P23
P15
P16
N
Source: VA Dept of Conservation and Recreation
and the US Census Bureau
2 0 2 4 6 8 10 Miles
Prepared by: Troy B. Wallace

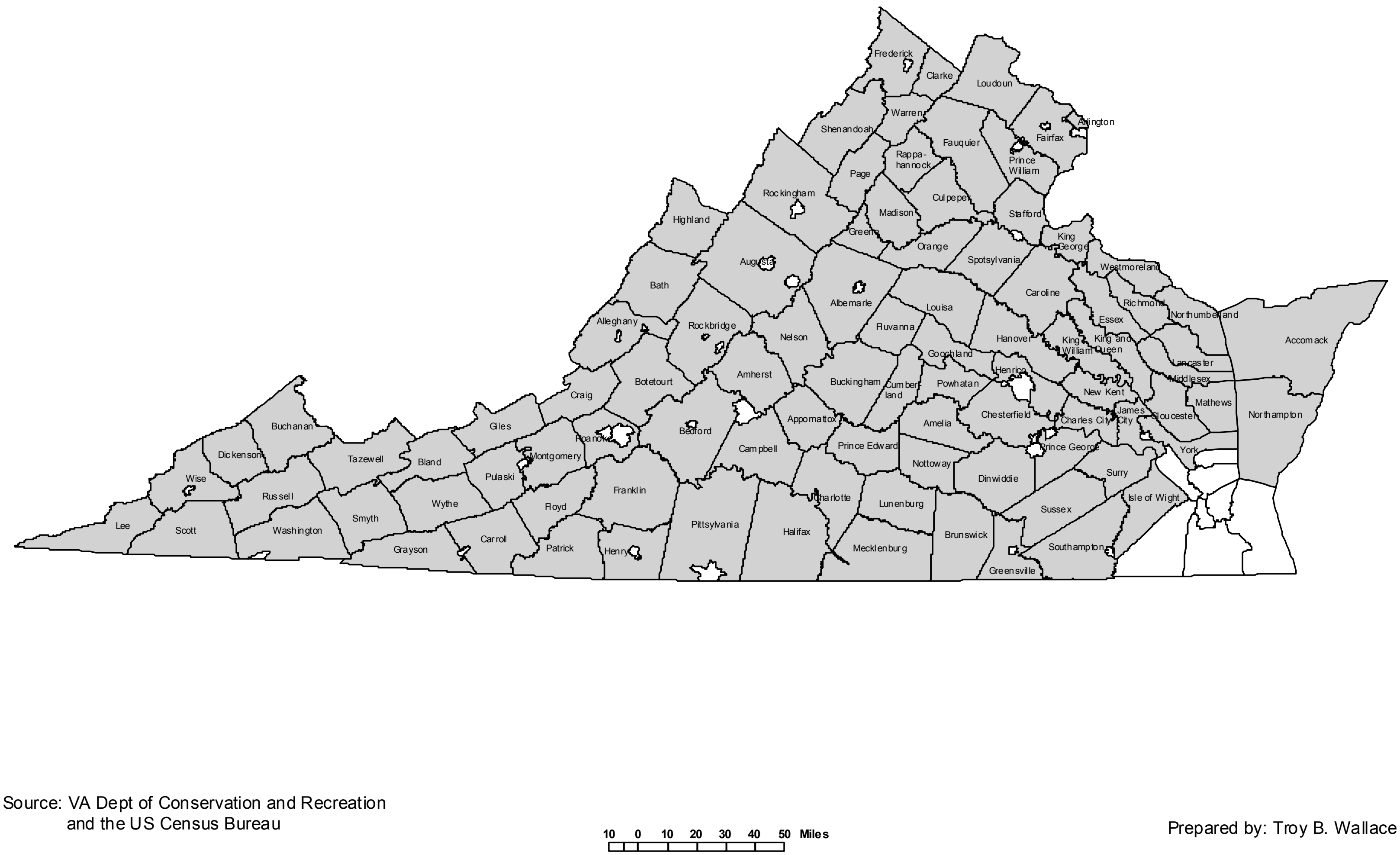
Plate 45: The Virginia Portion of the Big Sandy River Basin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

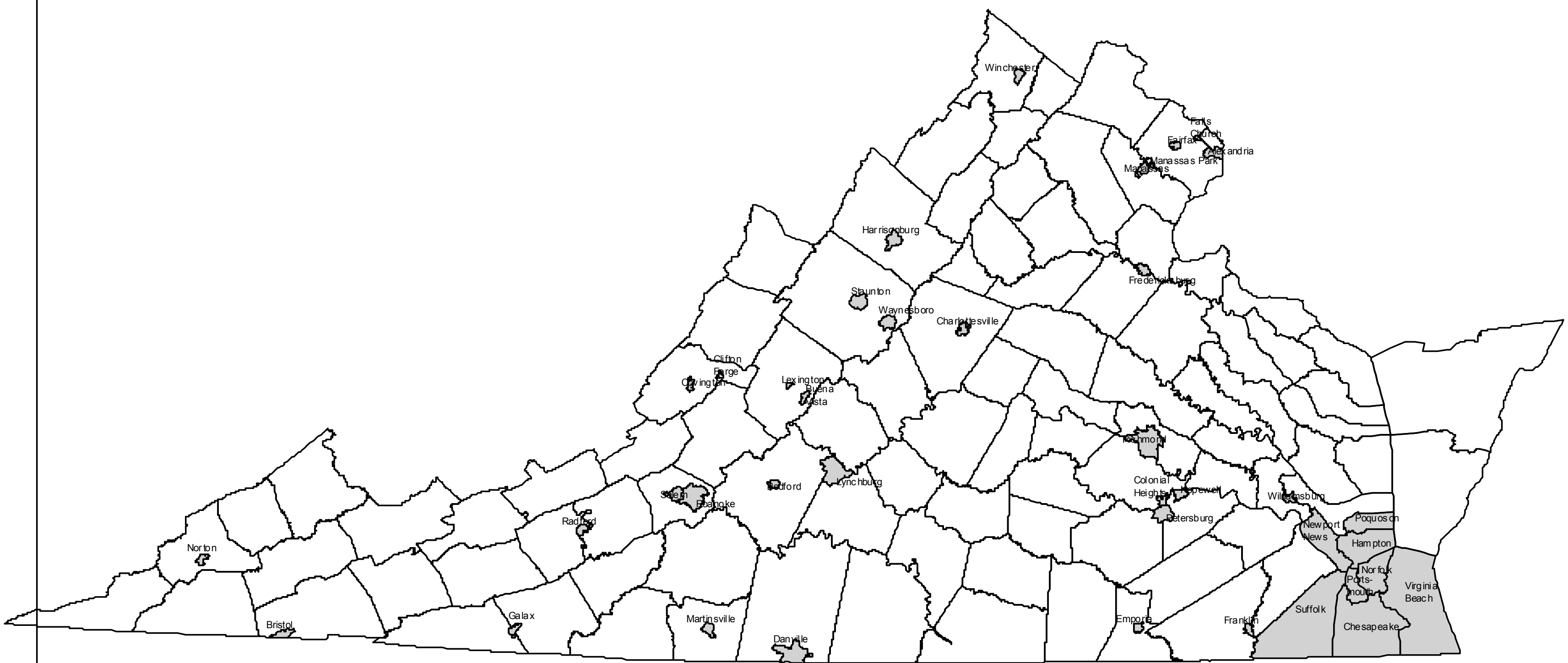
Plate 46: The Counties of Virginia



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate 47: The Cities of Virginia

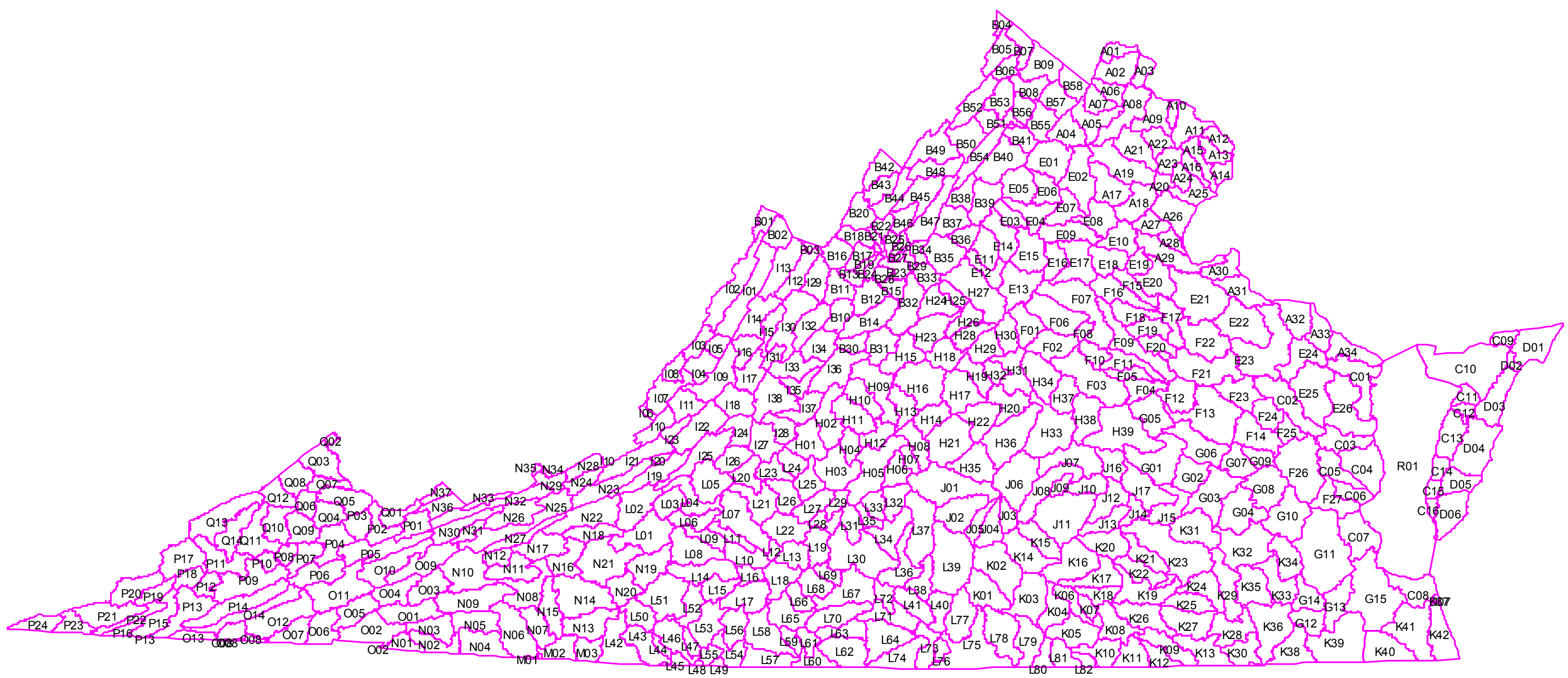


Source: VA Dept of Conservation and Recreation
and the US Census Bureau

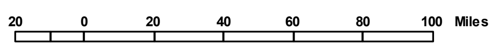
10 0 10 20 30 40 50 Miles

Prepared by: Troy B. Wallace

Plate 48: Virginia Hydrologic Units

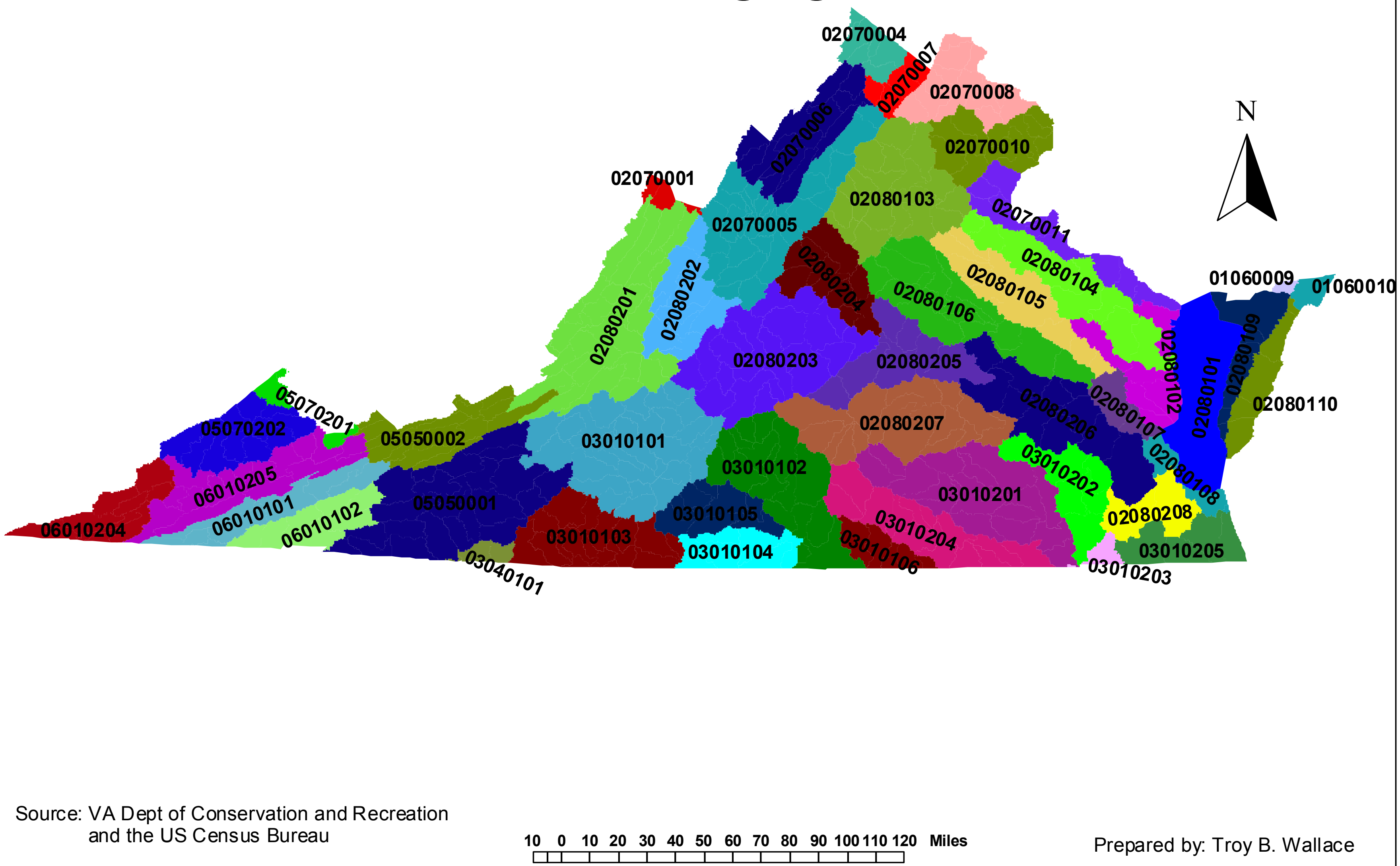


Source: VA Dept of Conservation and Recreation
and the US Census Bureau



Prepared by: Troy B. Wallace

Plate 49: USGS Demand Cataloging Units



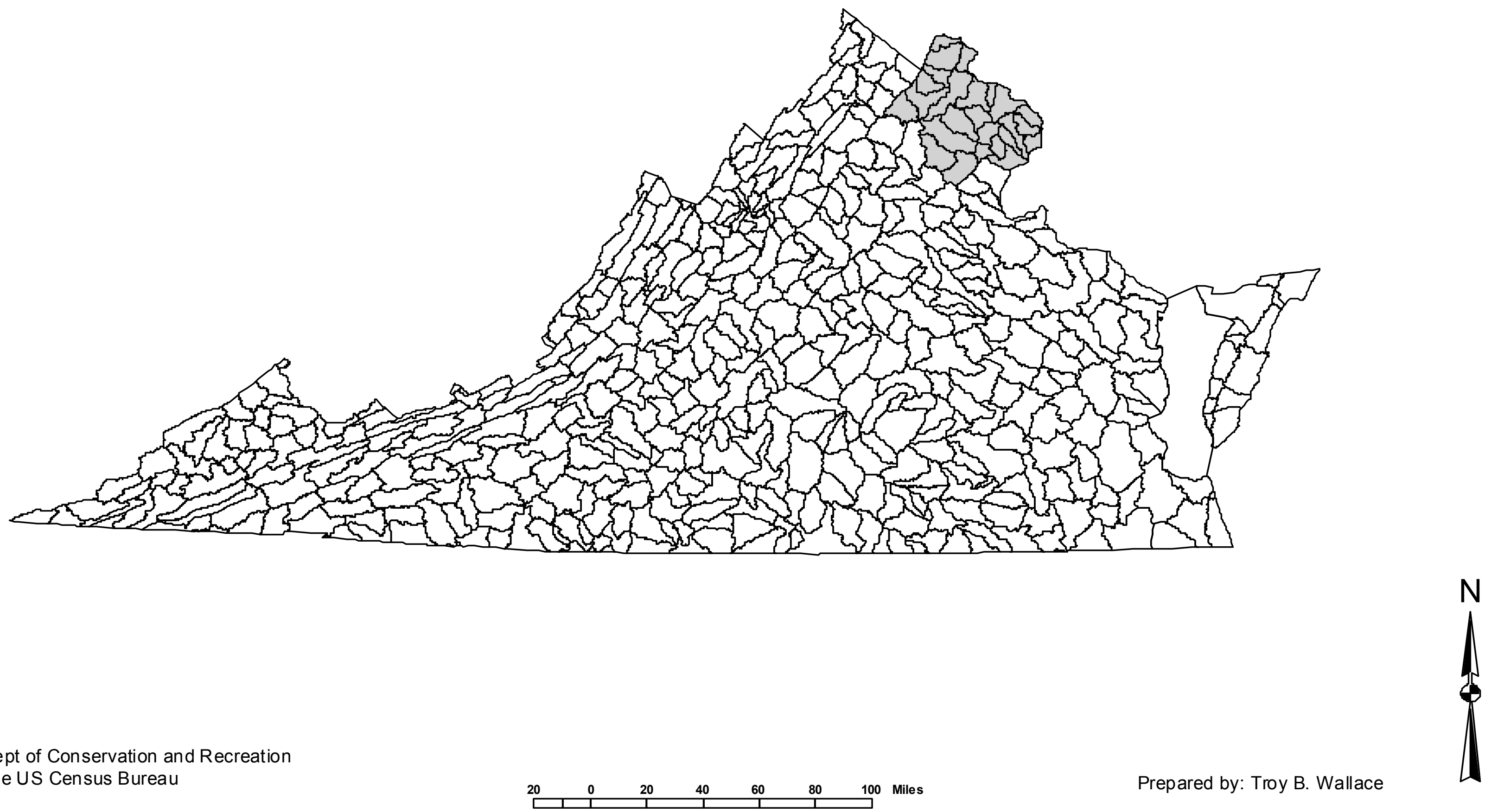
Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

B.2: MAPS OF THE PLANNING AREAS USED IN THE PRELIMINARY ASSESSMENT

OF WATER SUPPLY AVAILABILITY IN VIRGINIA

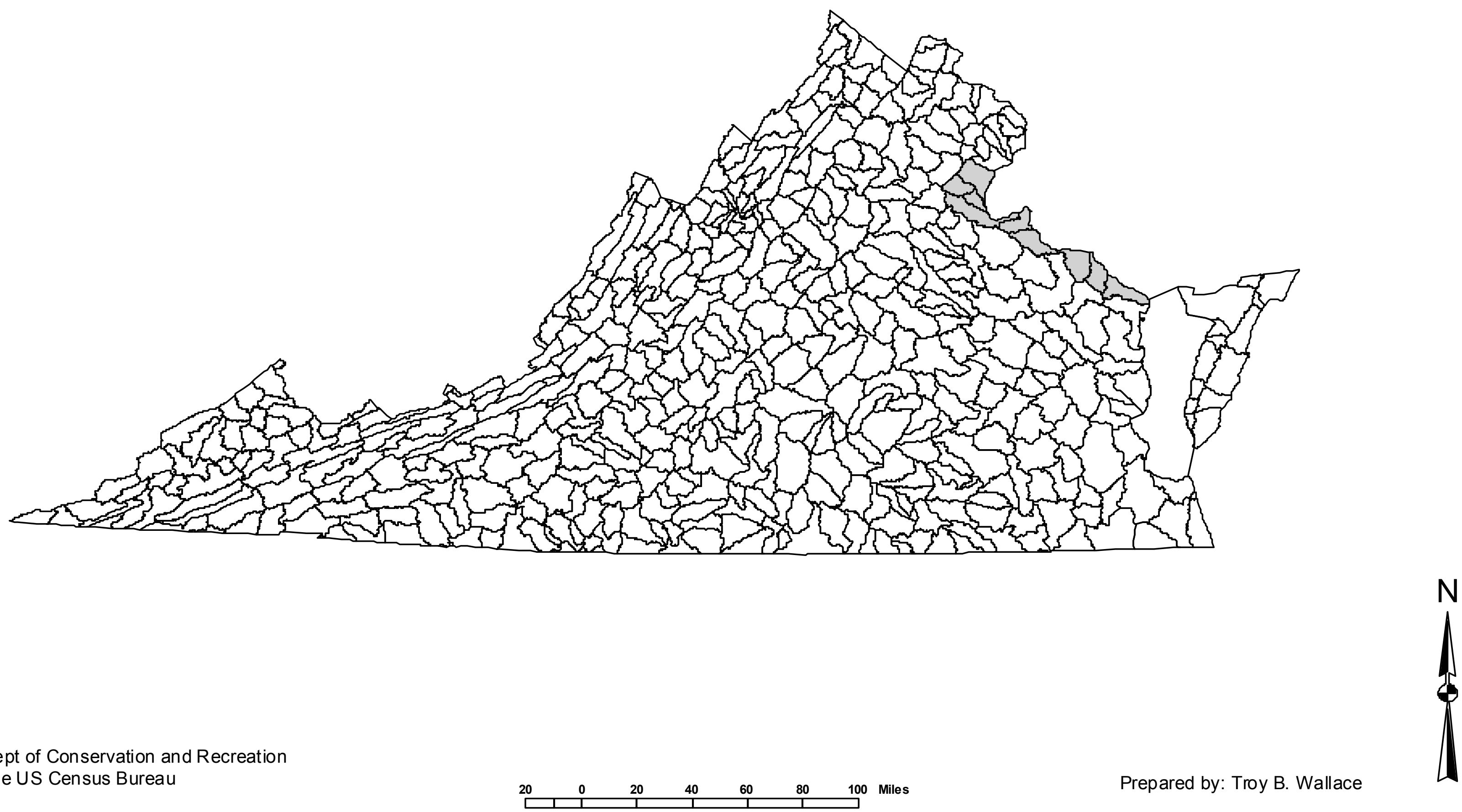
Plate I: Planning Area 1: Upper Potomac



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

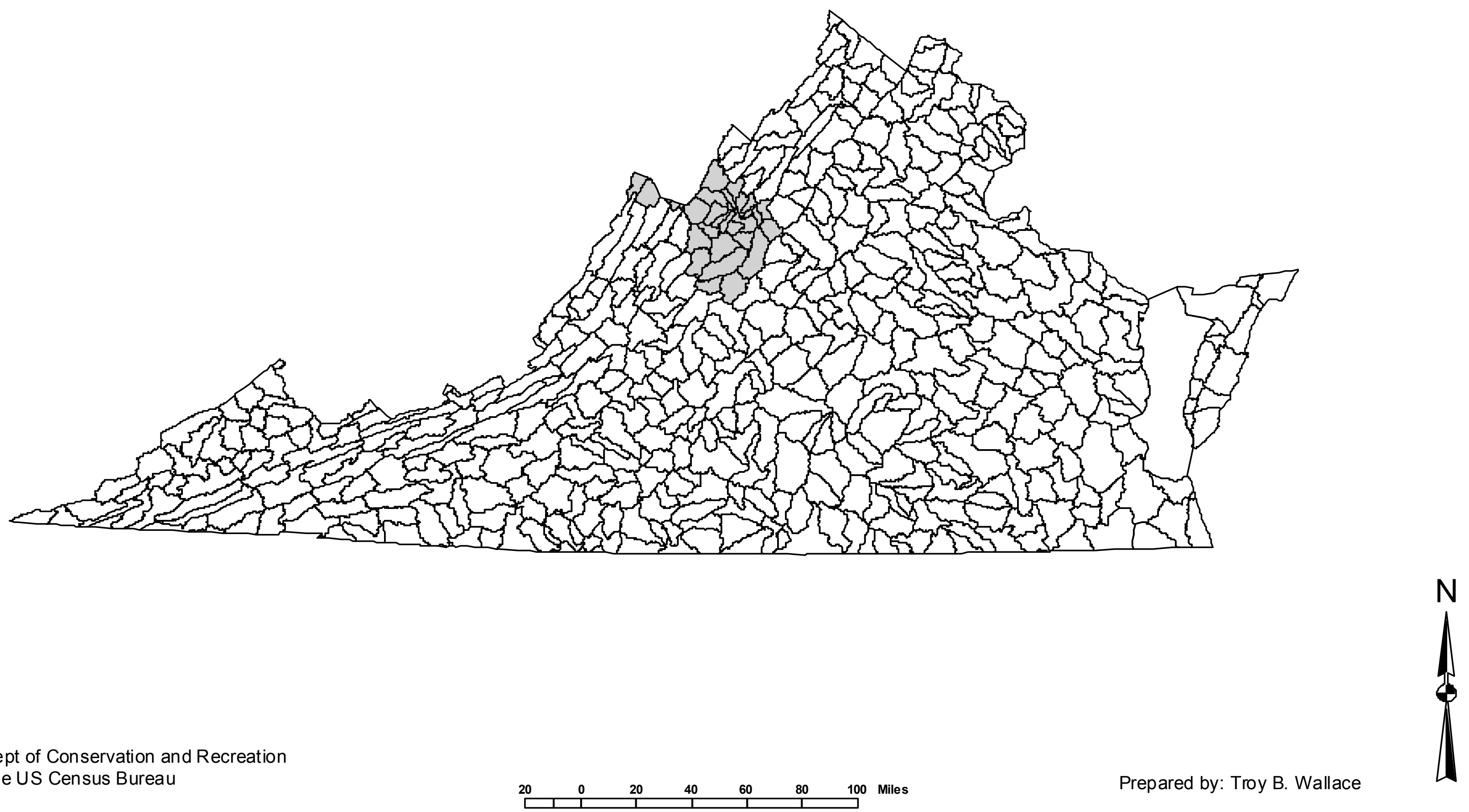
Plate II: Planning Area 2: Lower Potomac



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

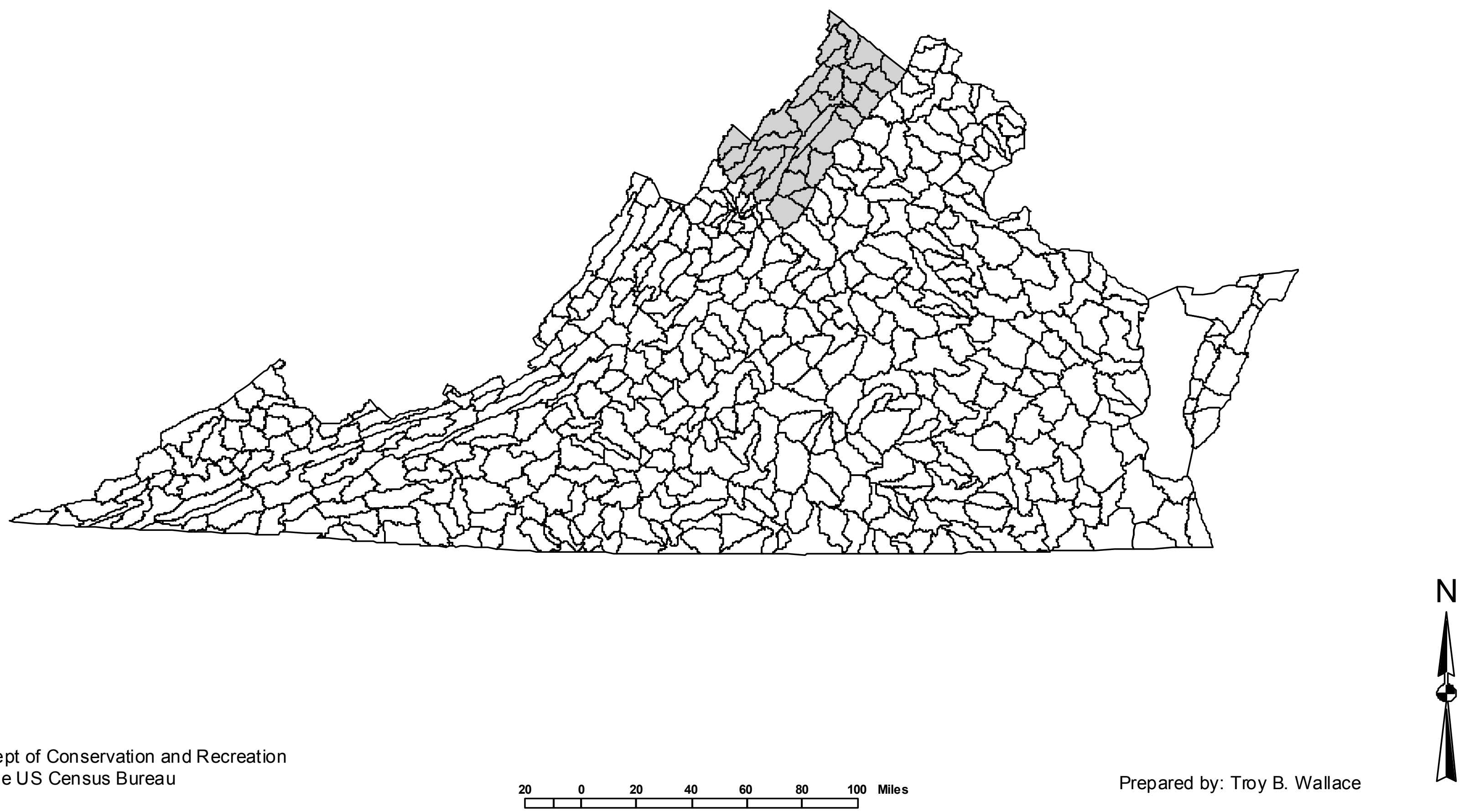
Plate III: Planning Area 3: Upper Shenandoah/ Laurel



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate IV: Planning Area 4: Lower Shenandoah/Opequon



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate V: Planning Area 5: Upper Rappahannock

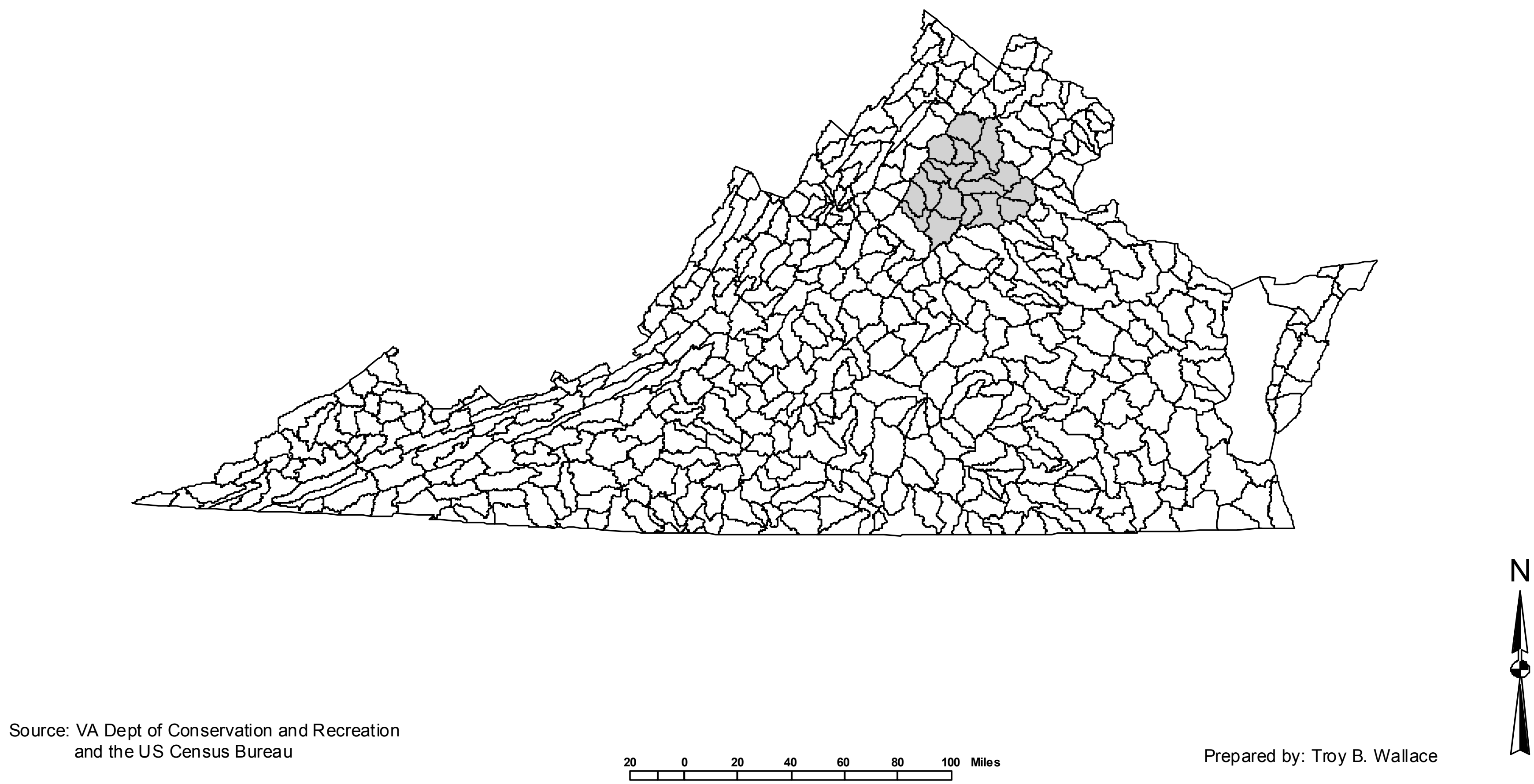
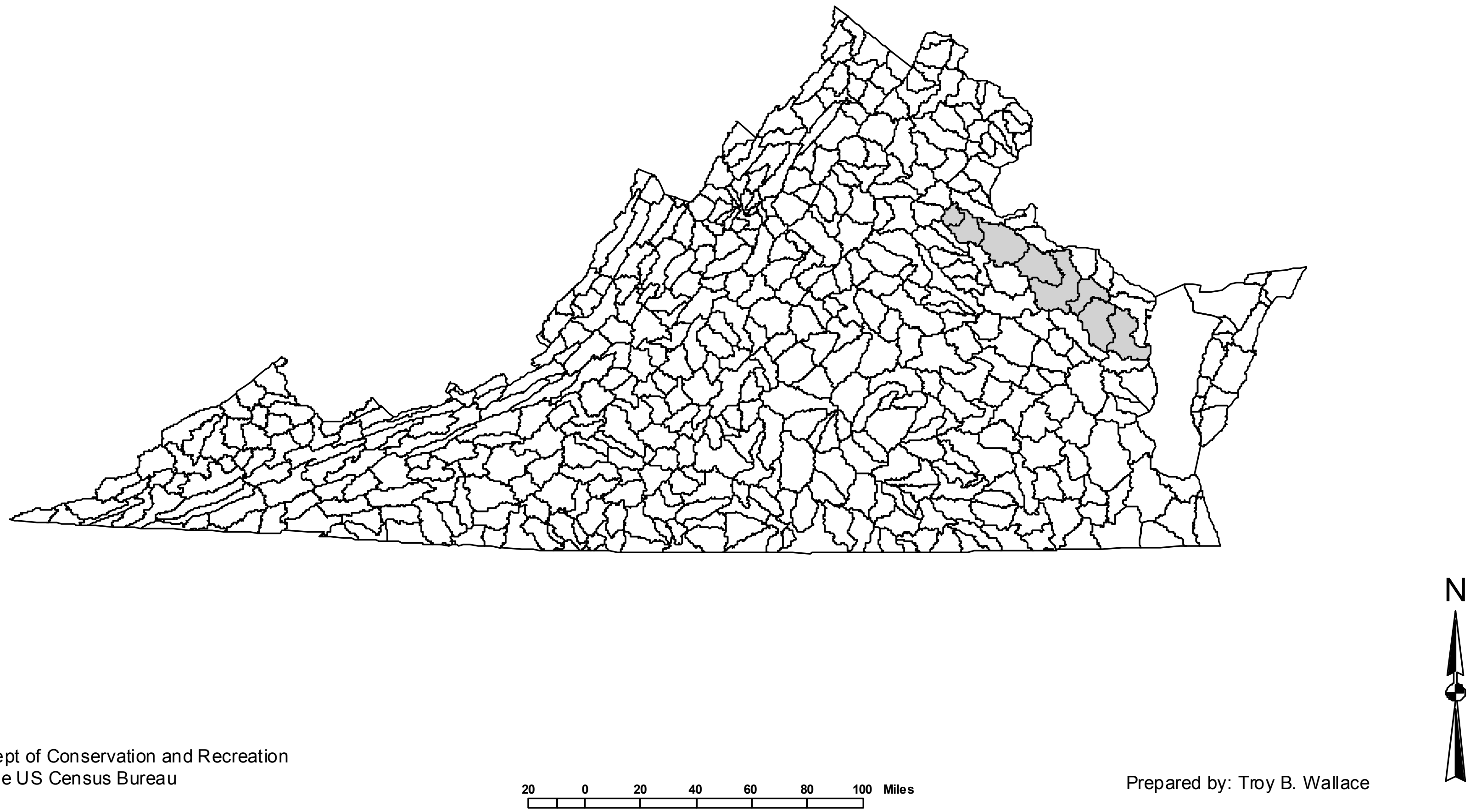


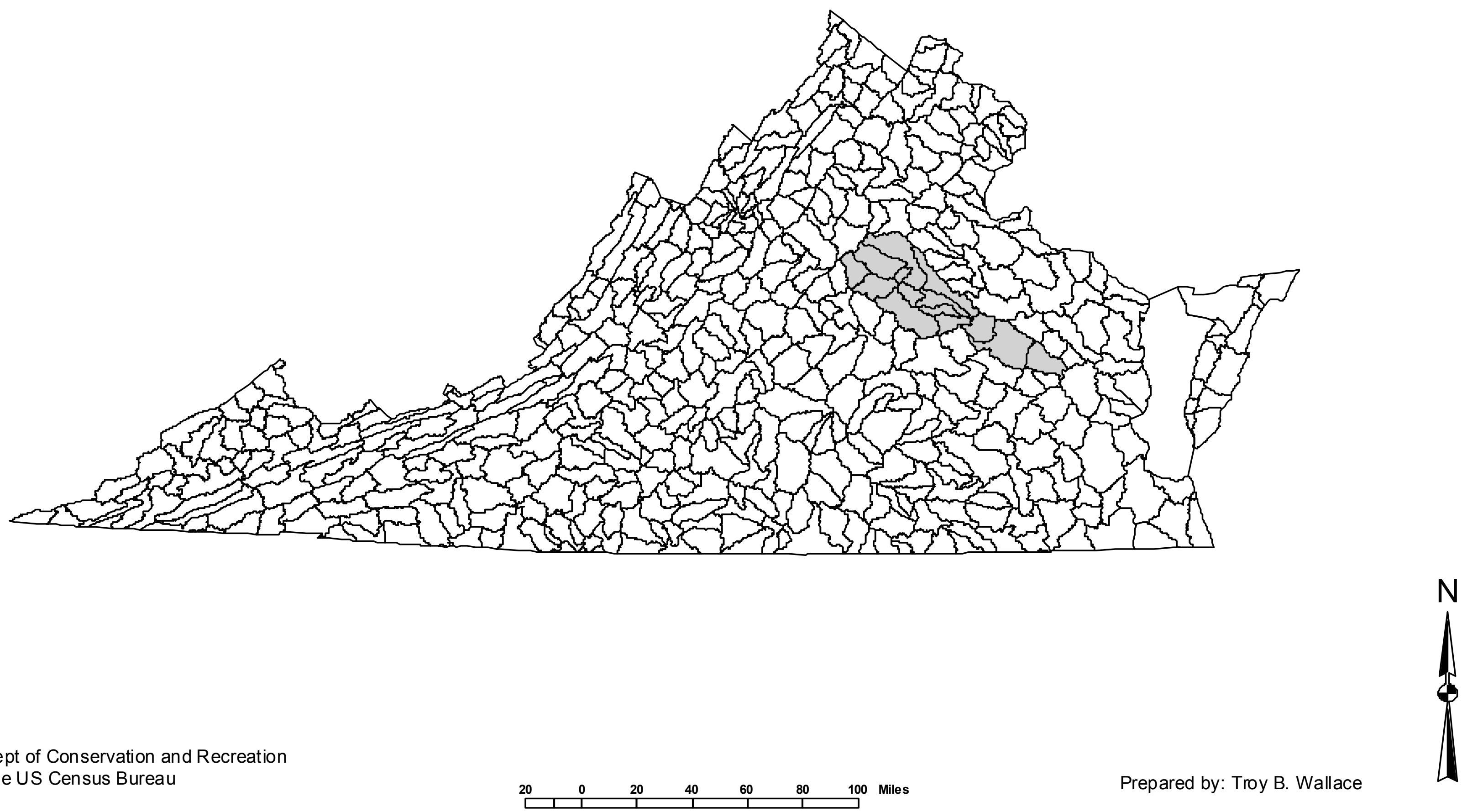
Plate VI: Planning Area 6: Lower Rappahannock



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

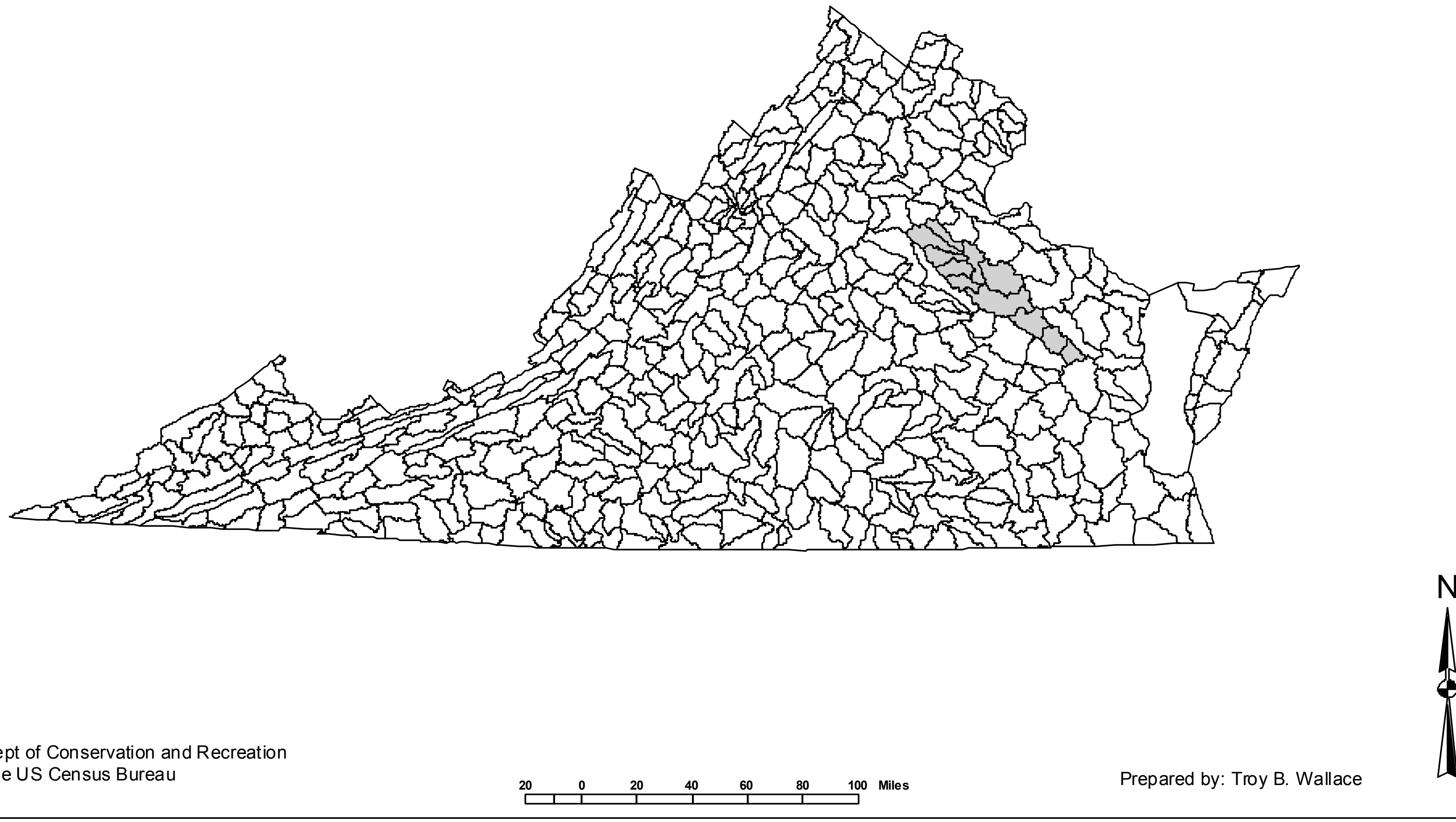
Plate VII: Planning Area 7: Pamunkey



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

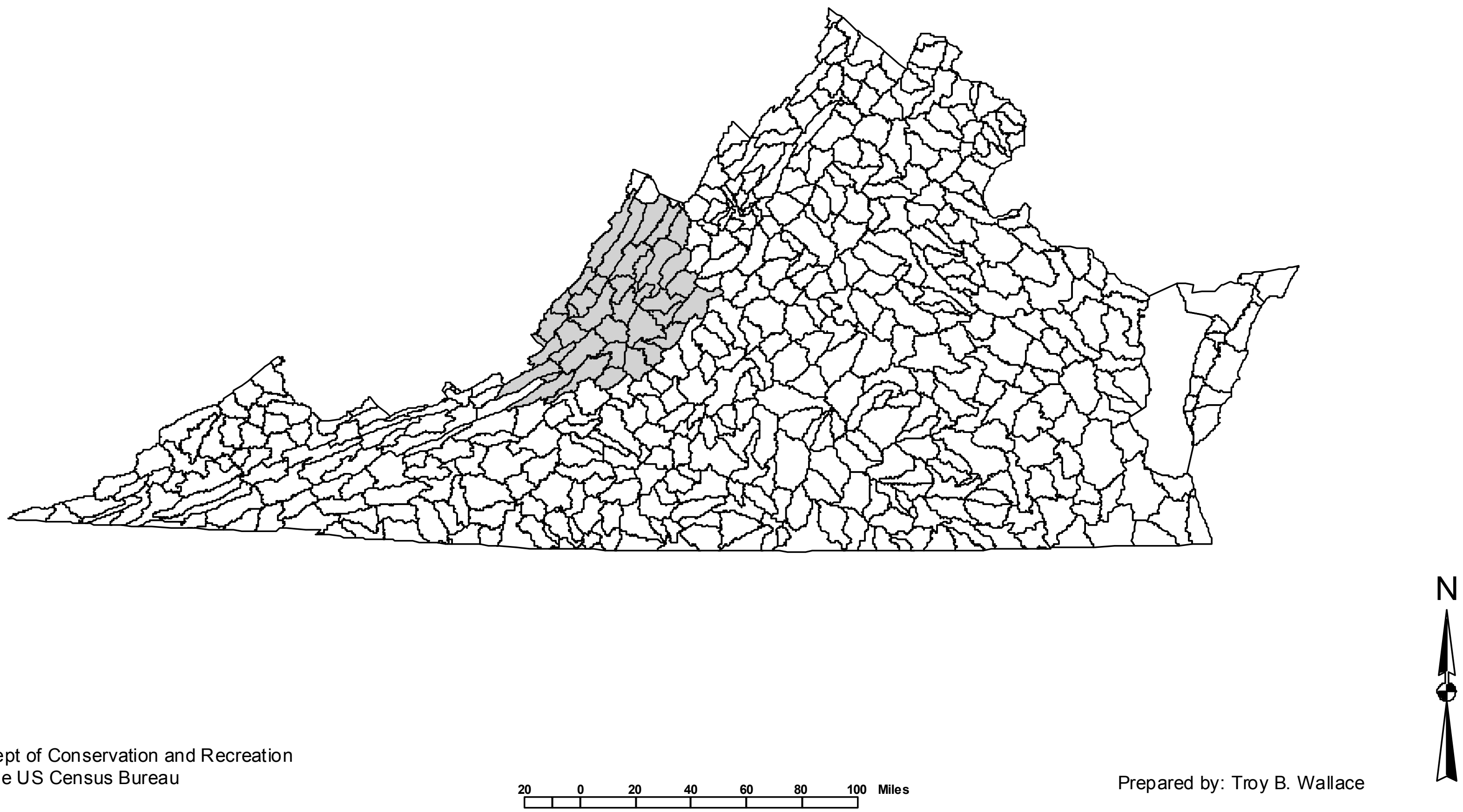
Plate VIII: Planning Area 8: Mattaponi



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

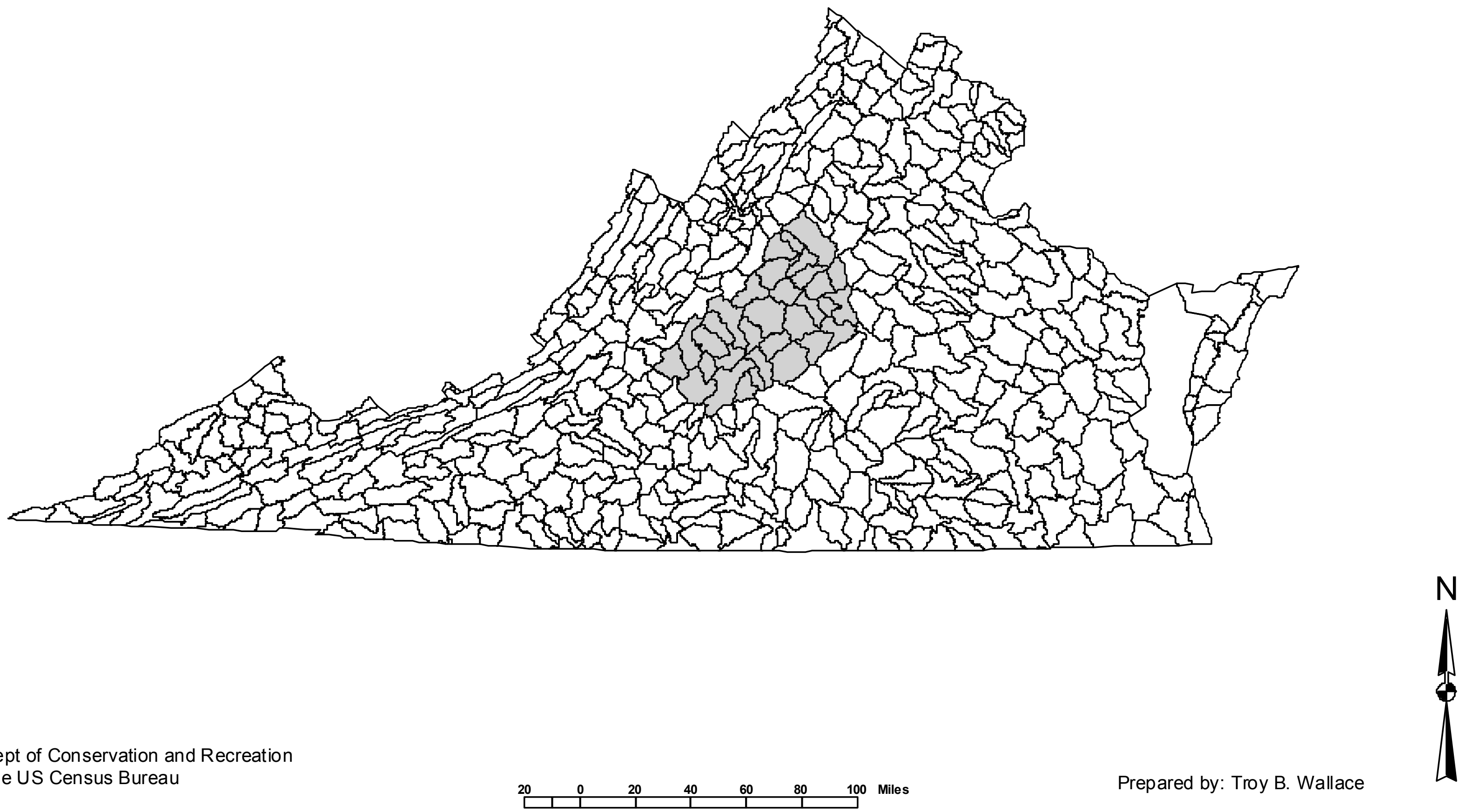
Plate IX: Planning Area 9: Upper James/Maury



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

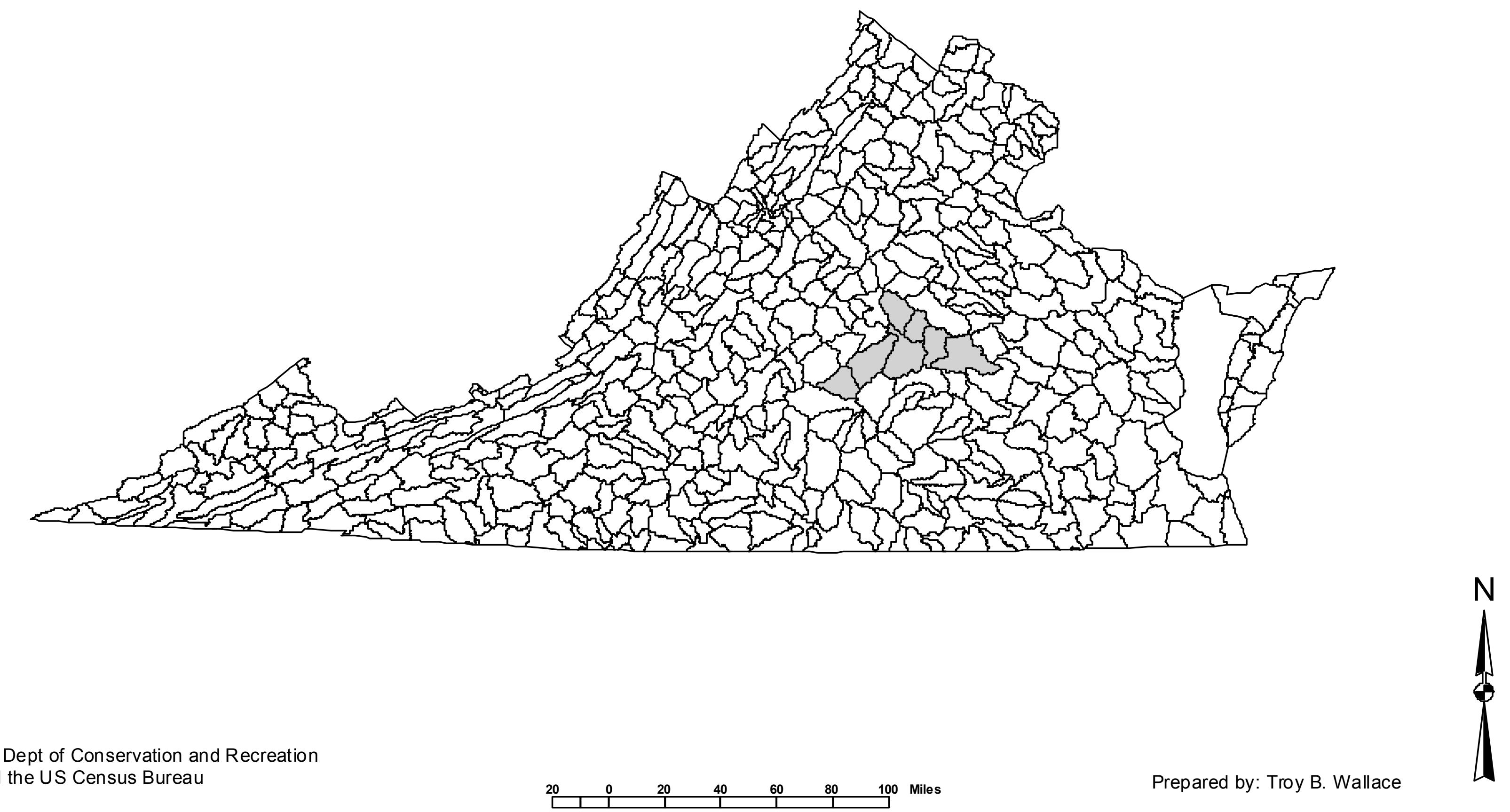
Plate X: Planning Area 10: Upper Middle James/Rivanna



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

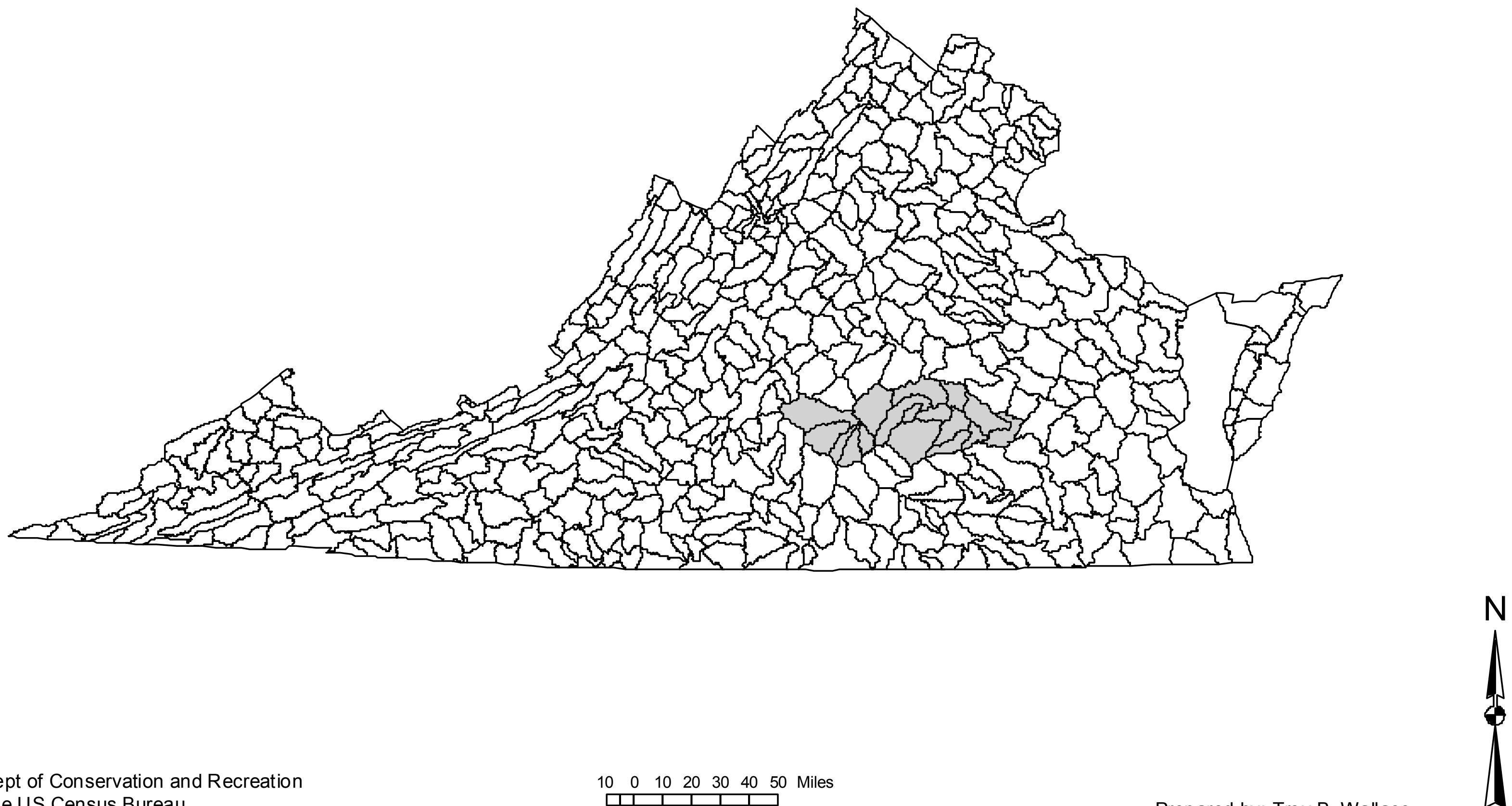
Plate XI: Planning Area 11: Lower Middle James



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

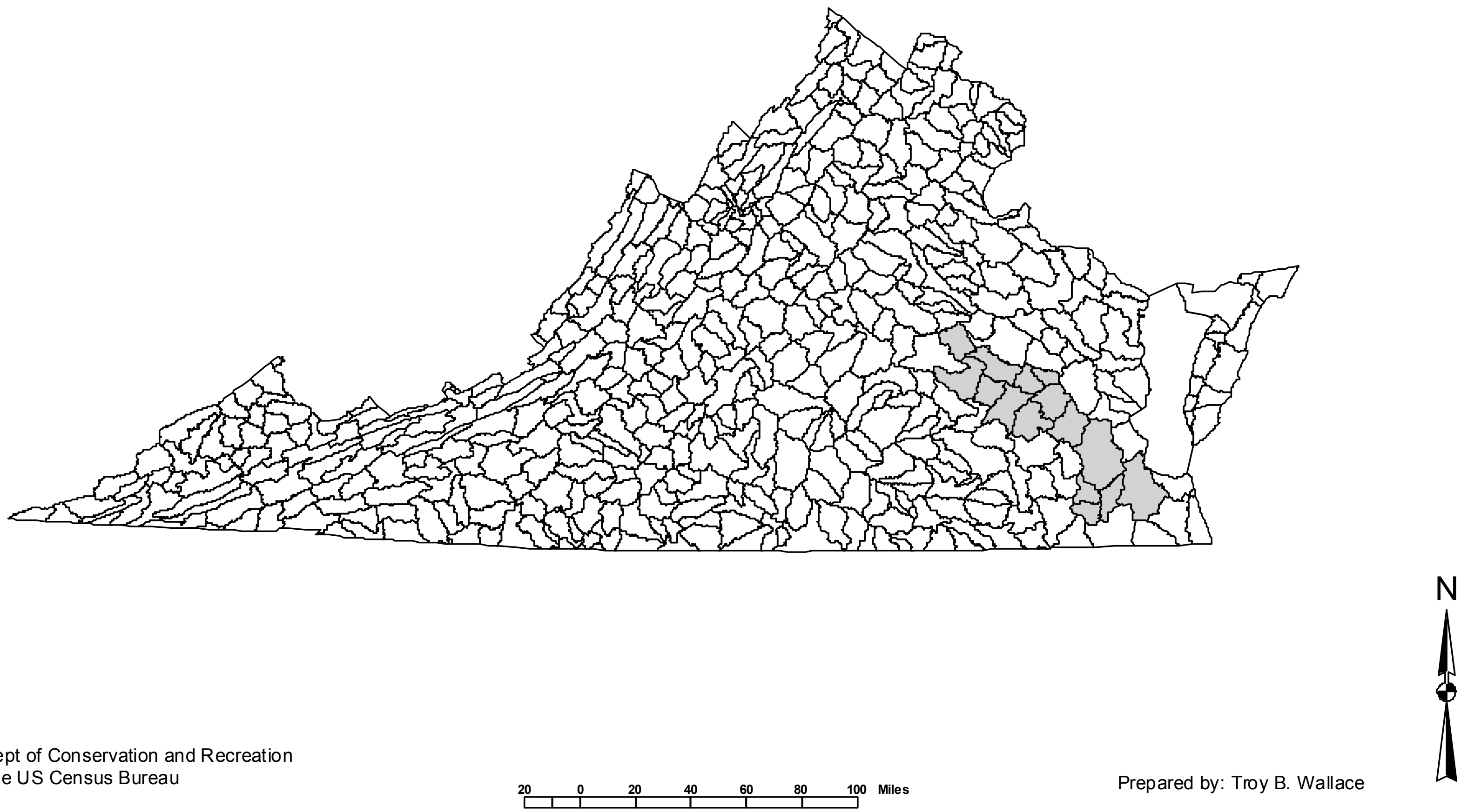
Plate XII: Planning Area 12: Appomattox



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

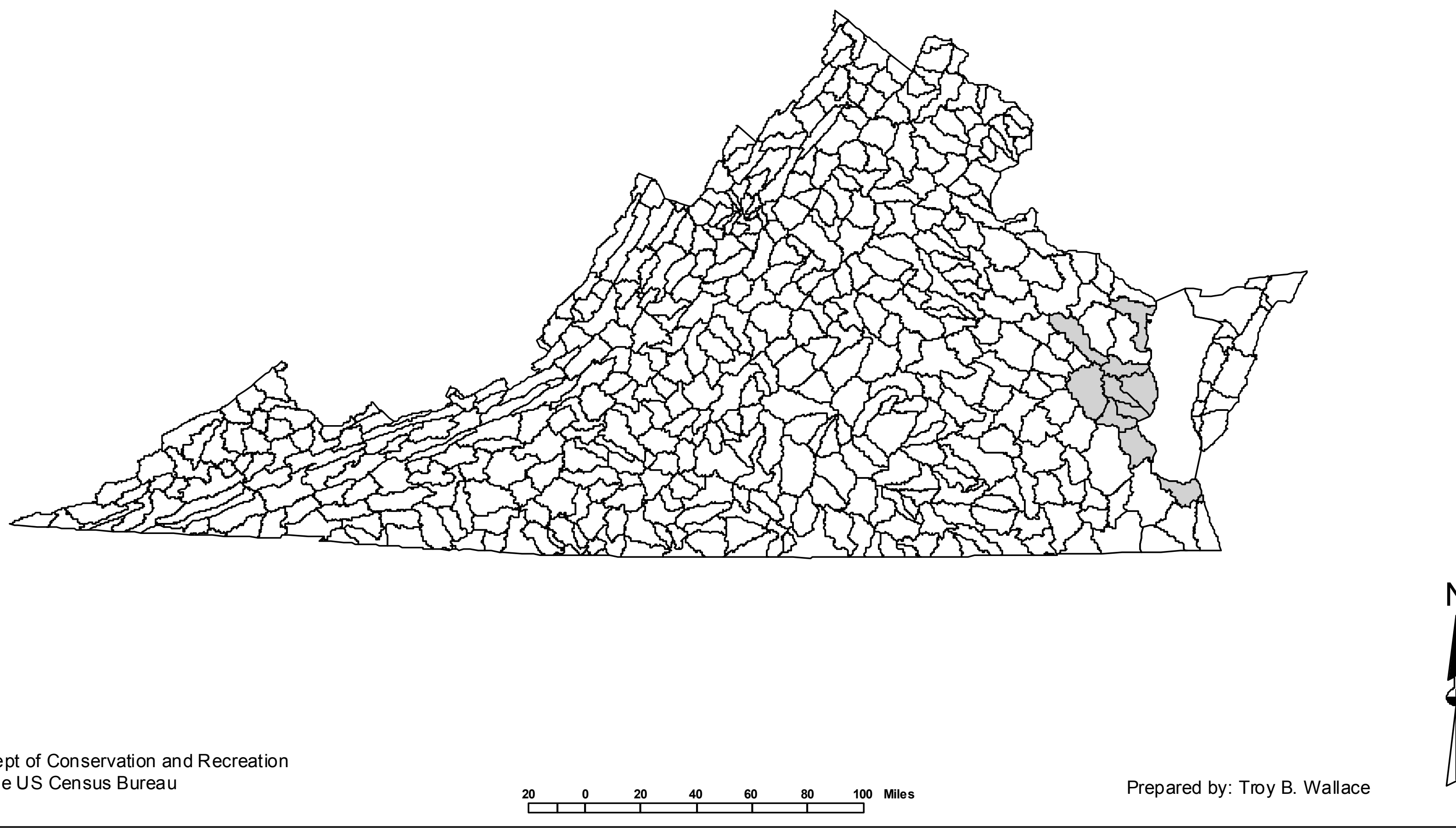
Plate XIII: Planning Area 13: Lower James



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

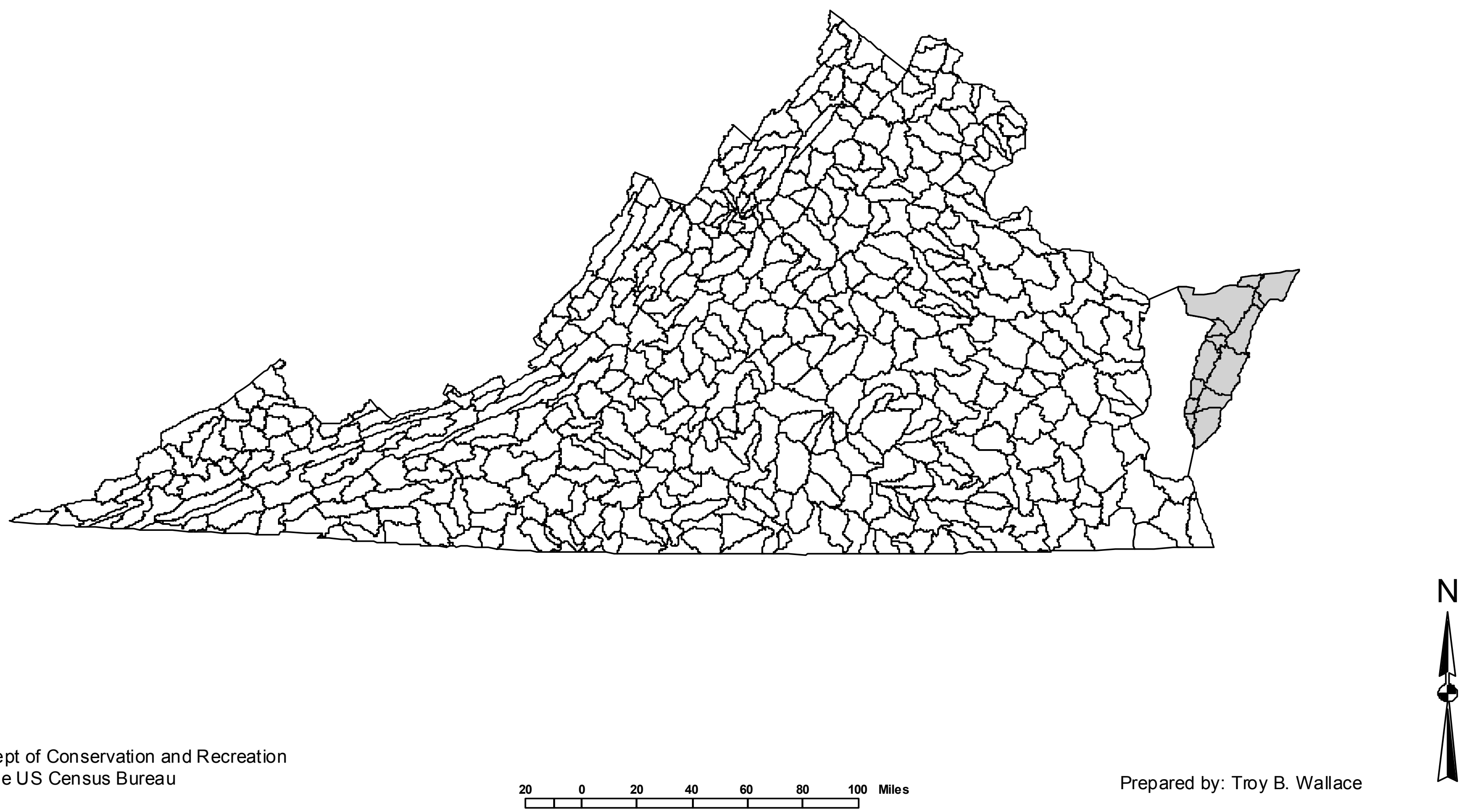
Plate XIV: Planning Area 14: Mainland Chesapeake Bay/Lower York



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

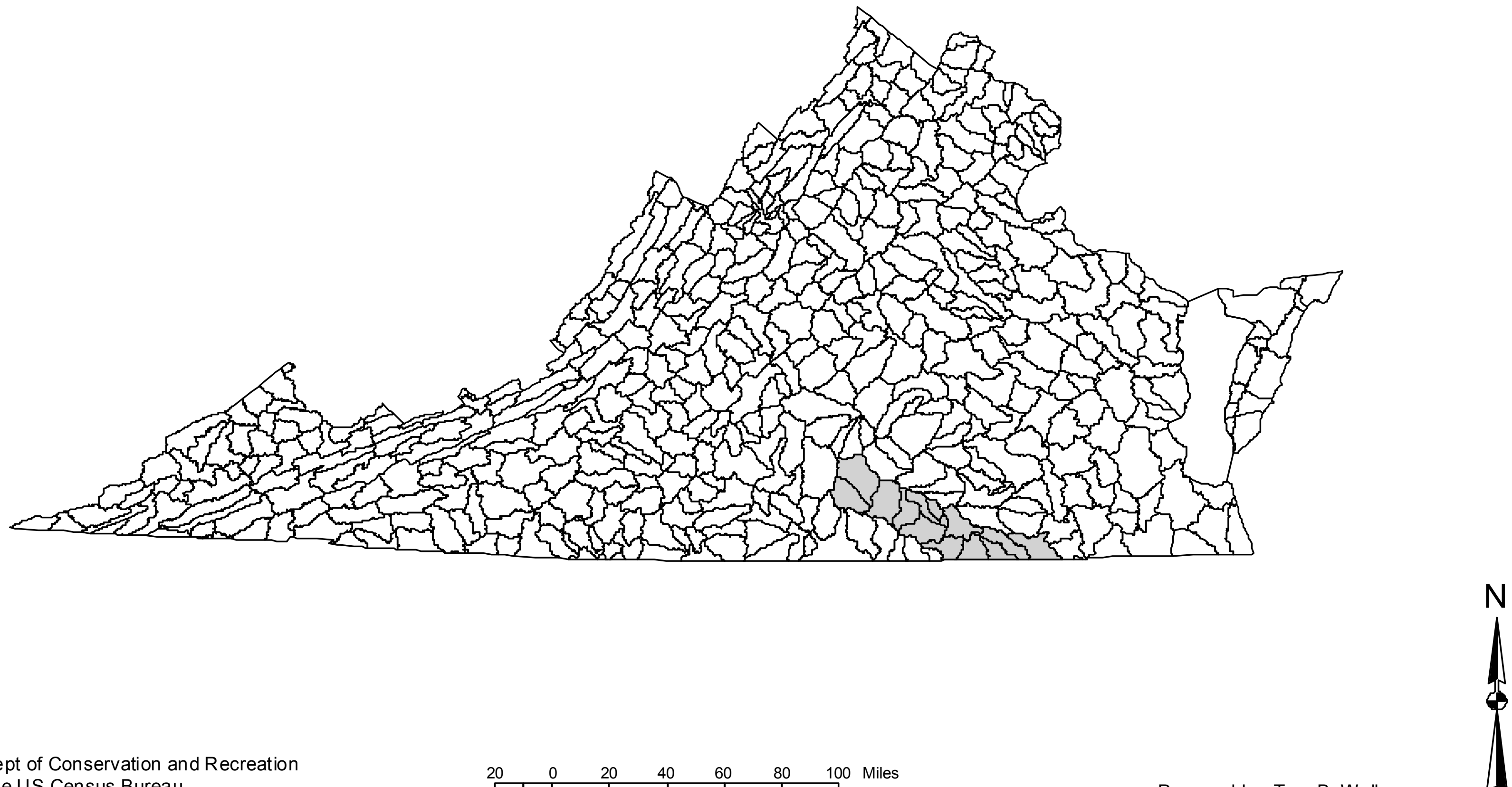
Plate XV: Planning Area 15: Eastern Shore



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

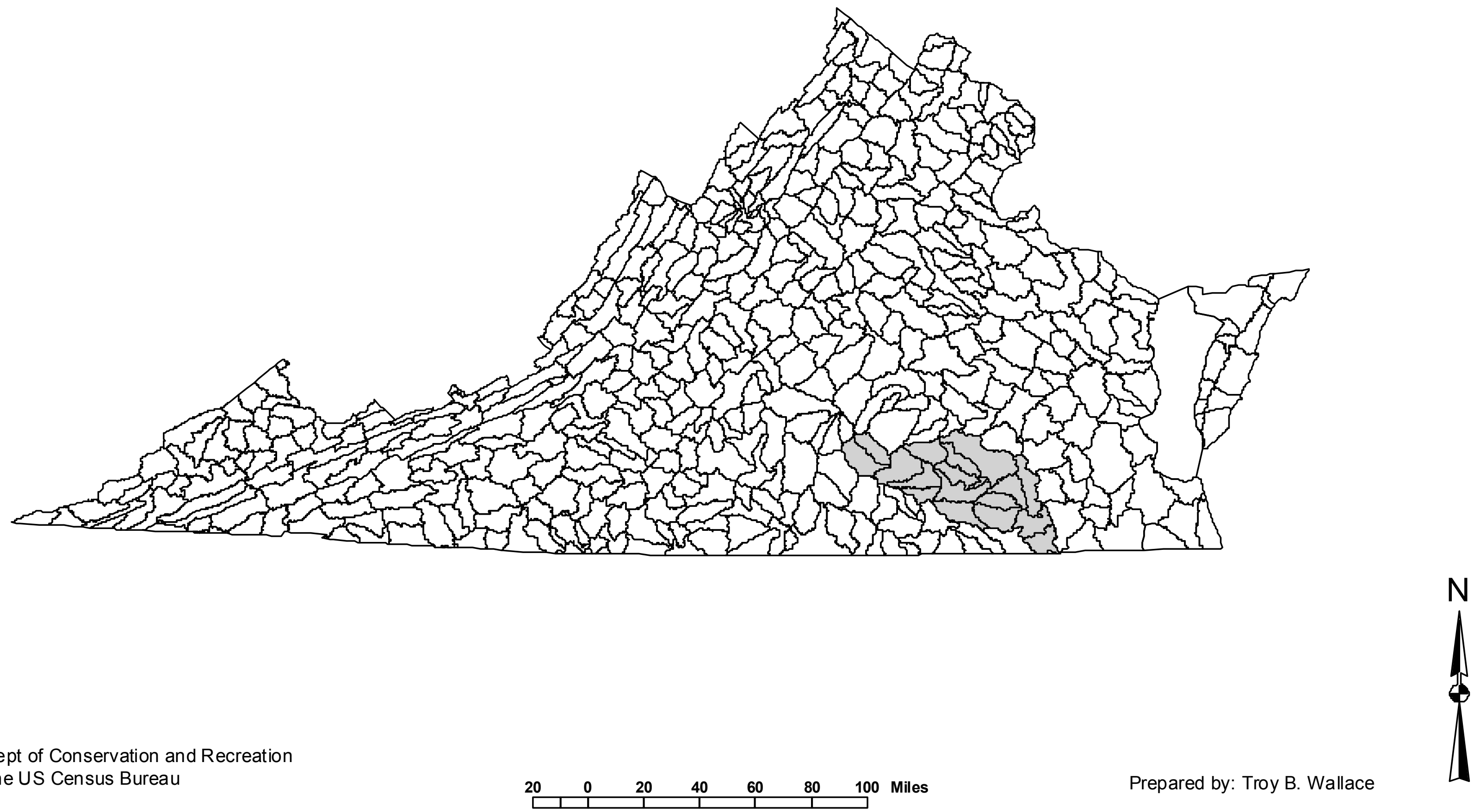
Plate XVI: Planning Area 16: Meherrin



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate XVII: Planning Area 17: Nottoway



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate XVIII: Planning Area 18: Blackwater/Southeast Coastal

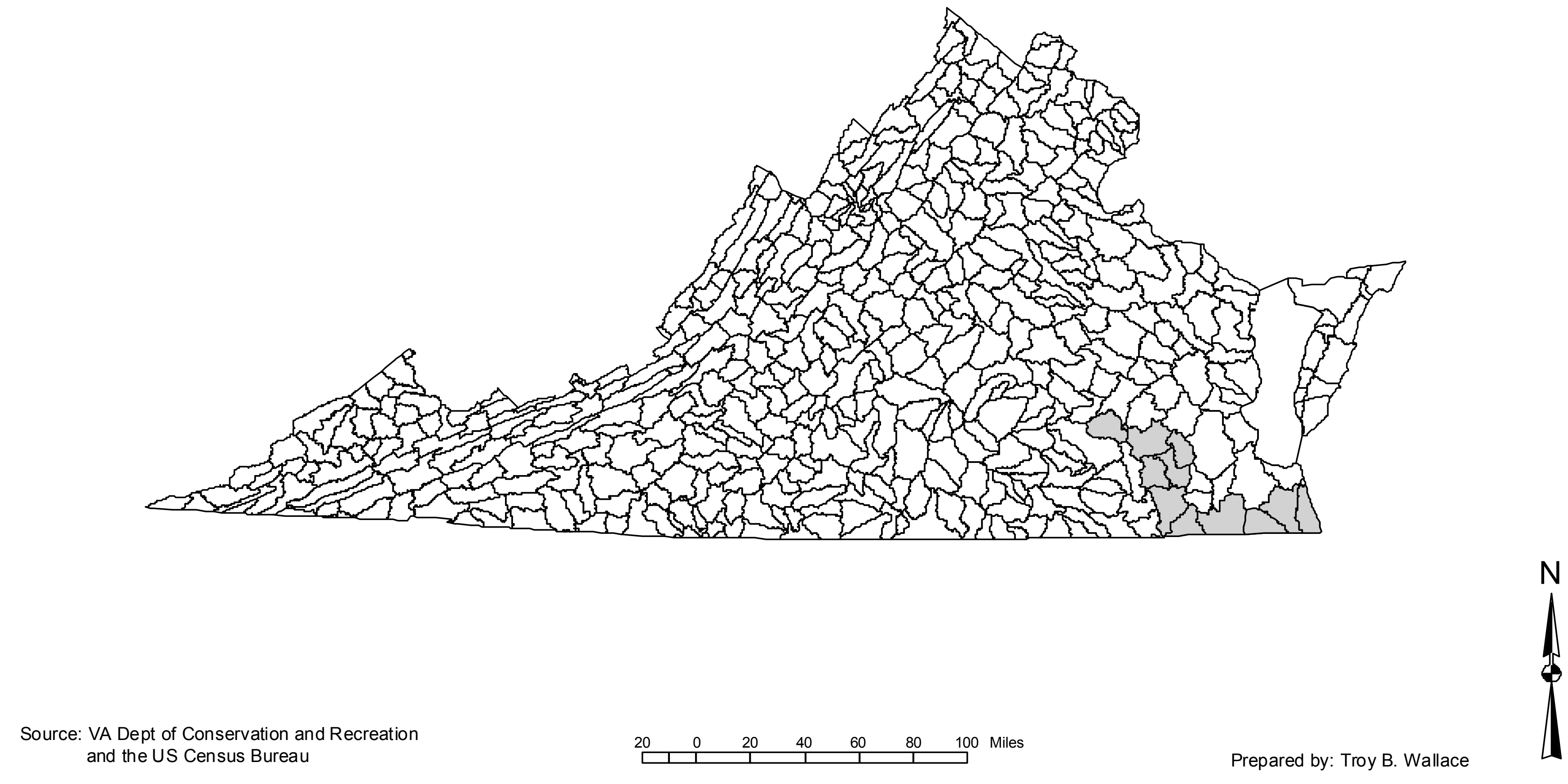
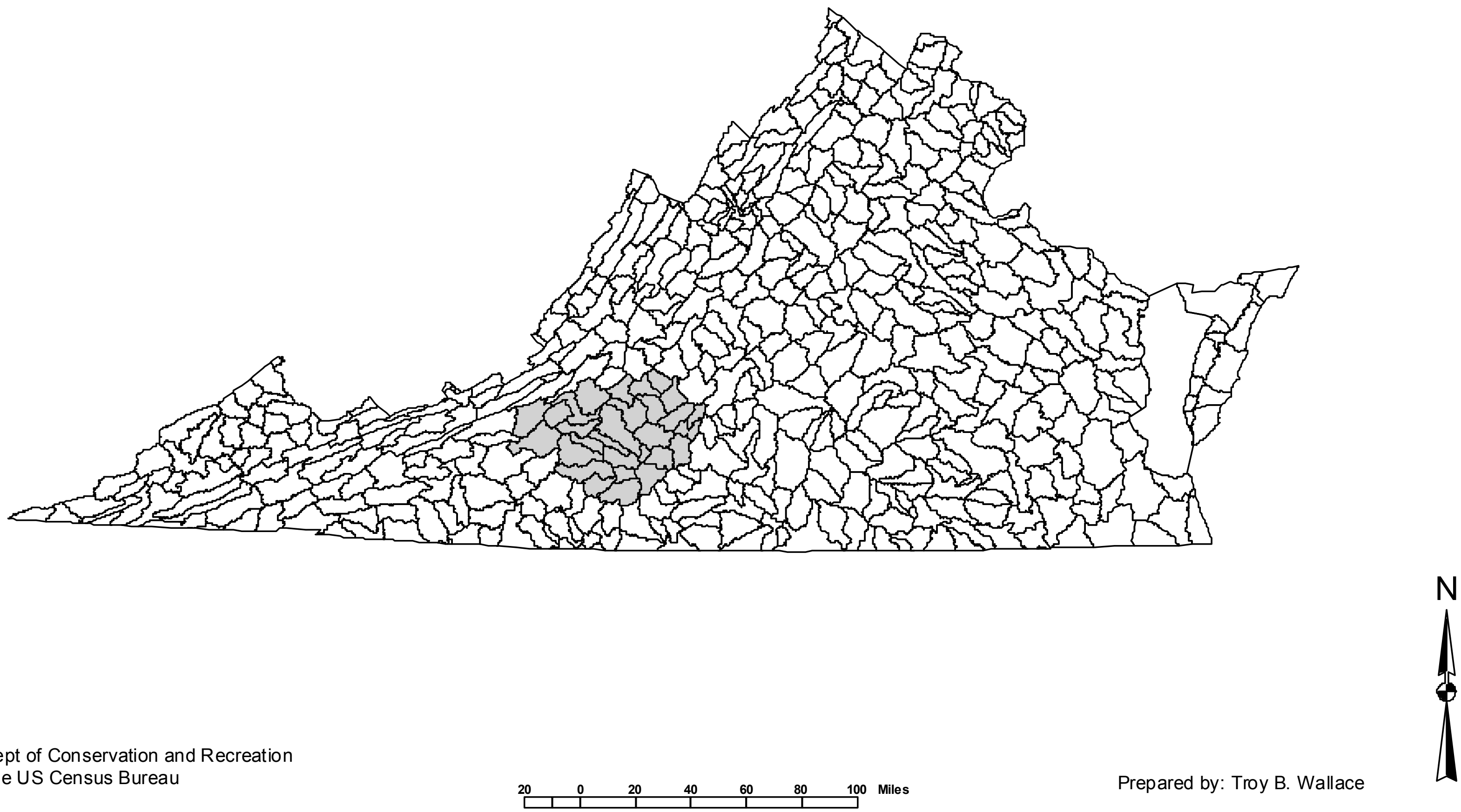


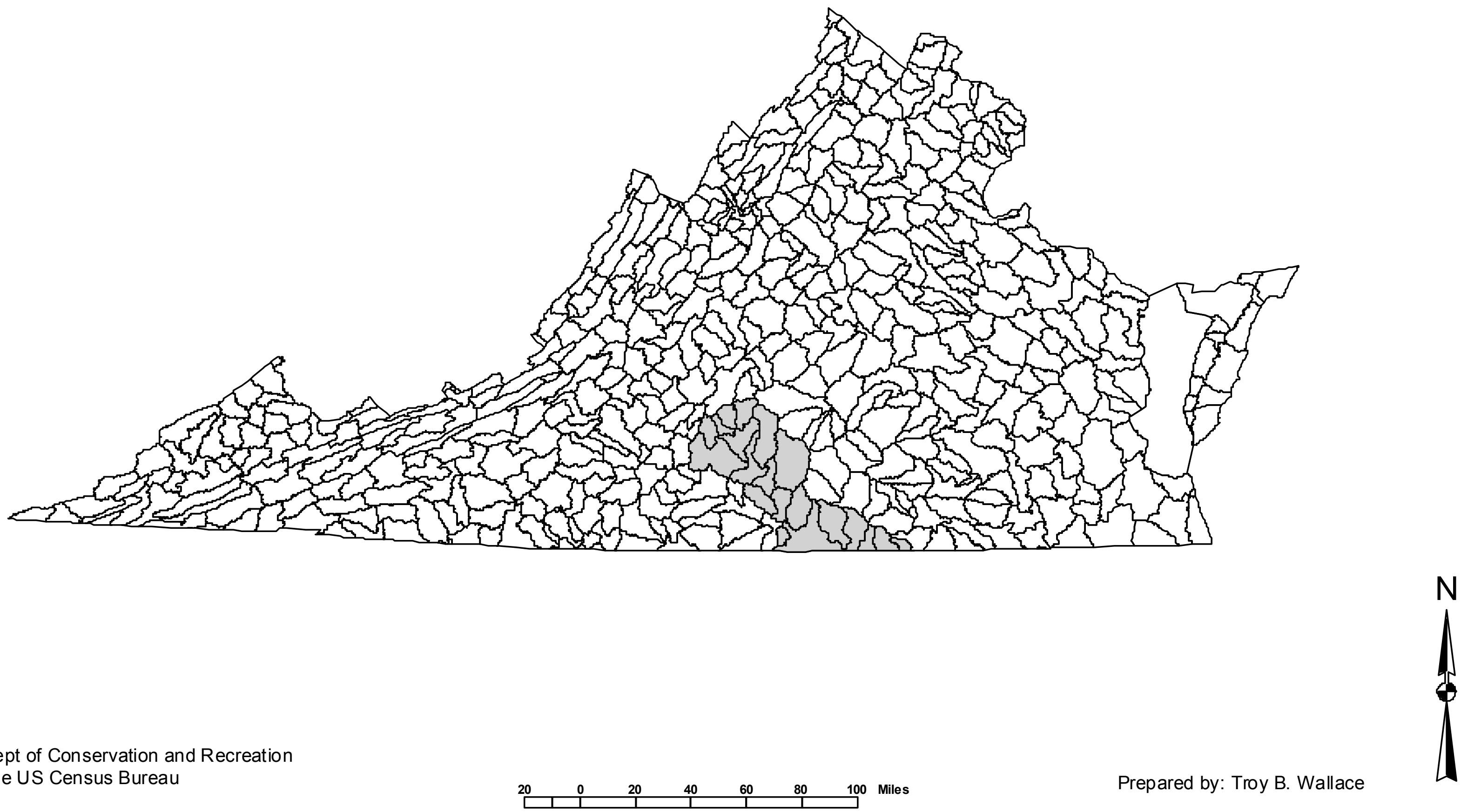
Plate XIX: Planning Area 19: Upper Roanoke



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

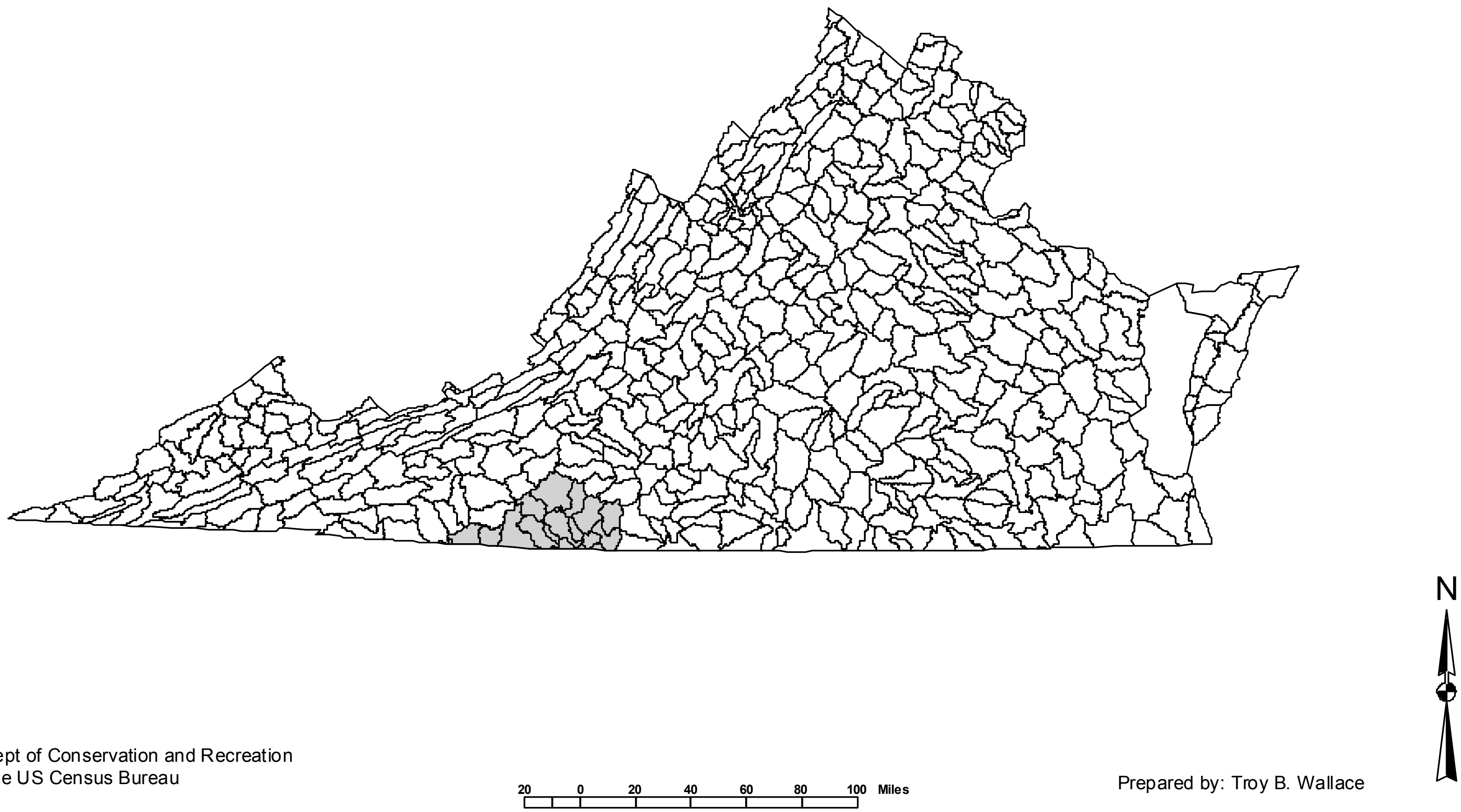
Plate XX: Planning Area 20: Lower Roanoke



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

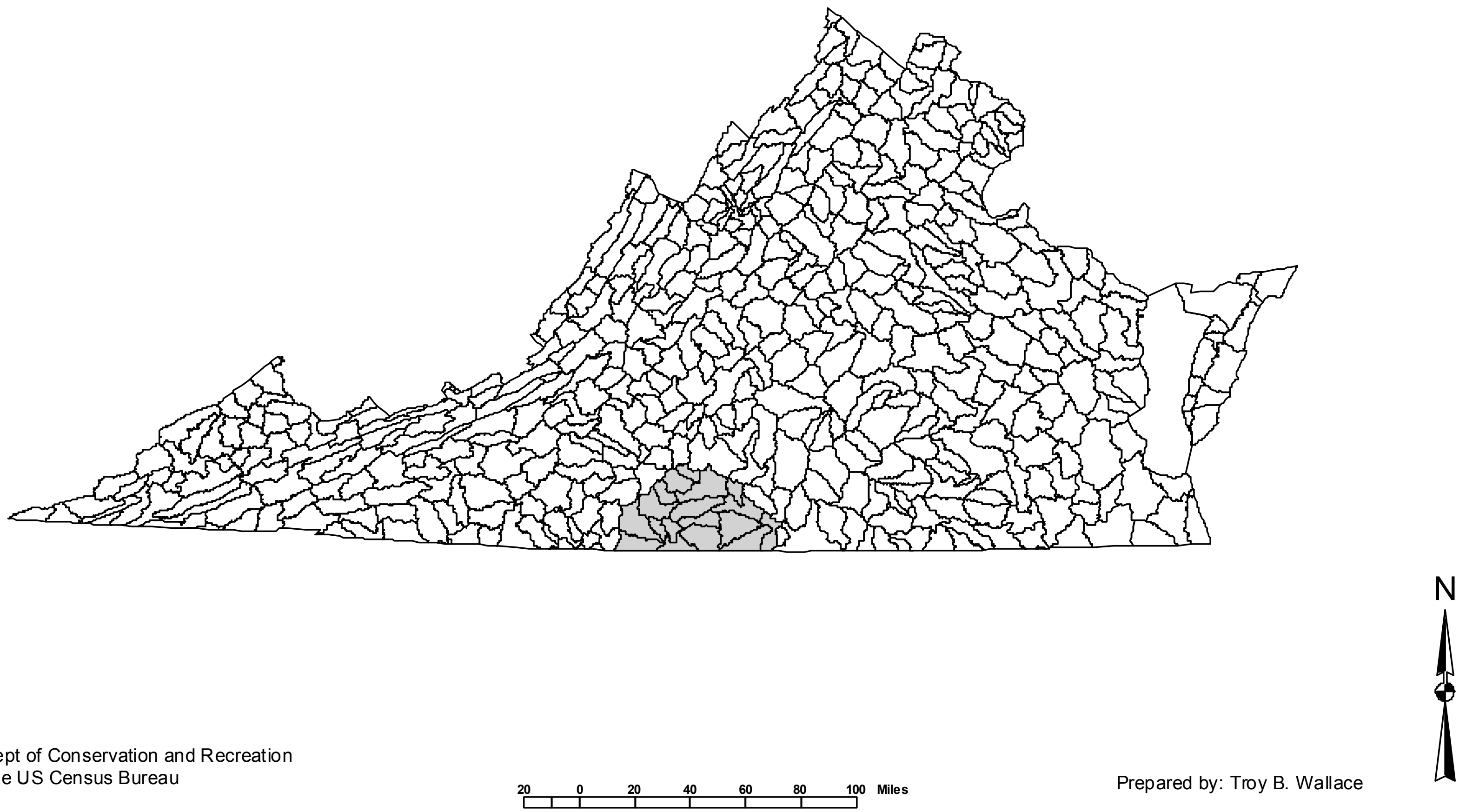
Plate XXI: Planning Area 21: Martinsville/Ararat



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

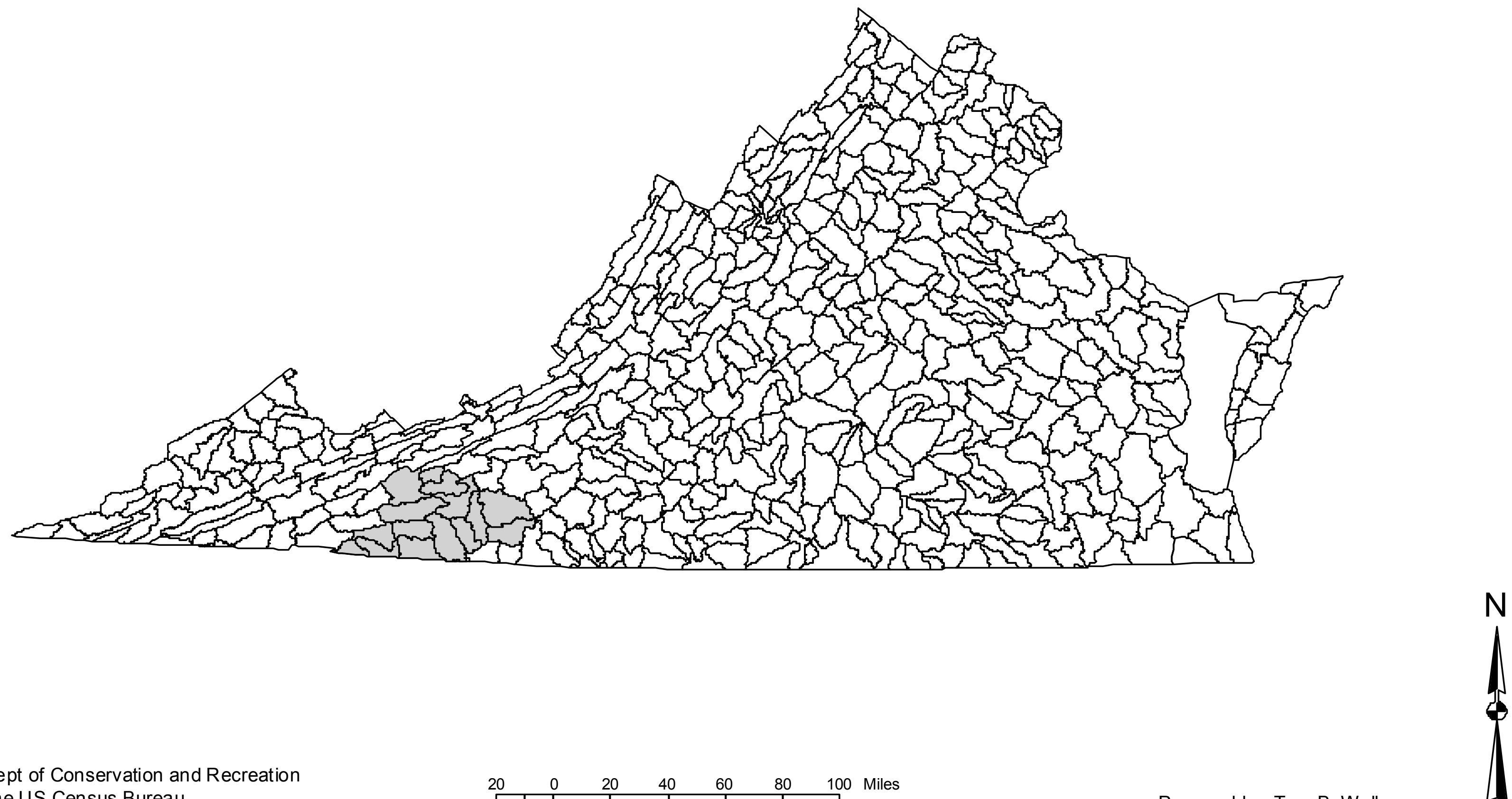
Plate XXII: Planning Area 22: Danville



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

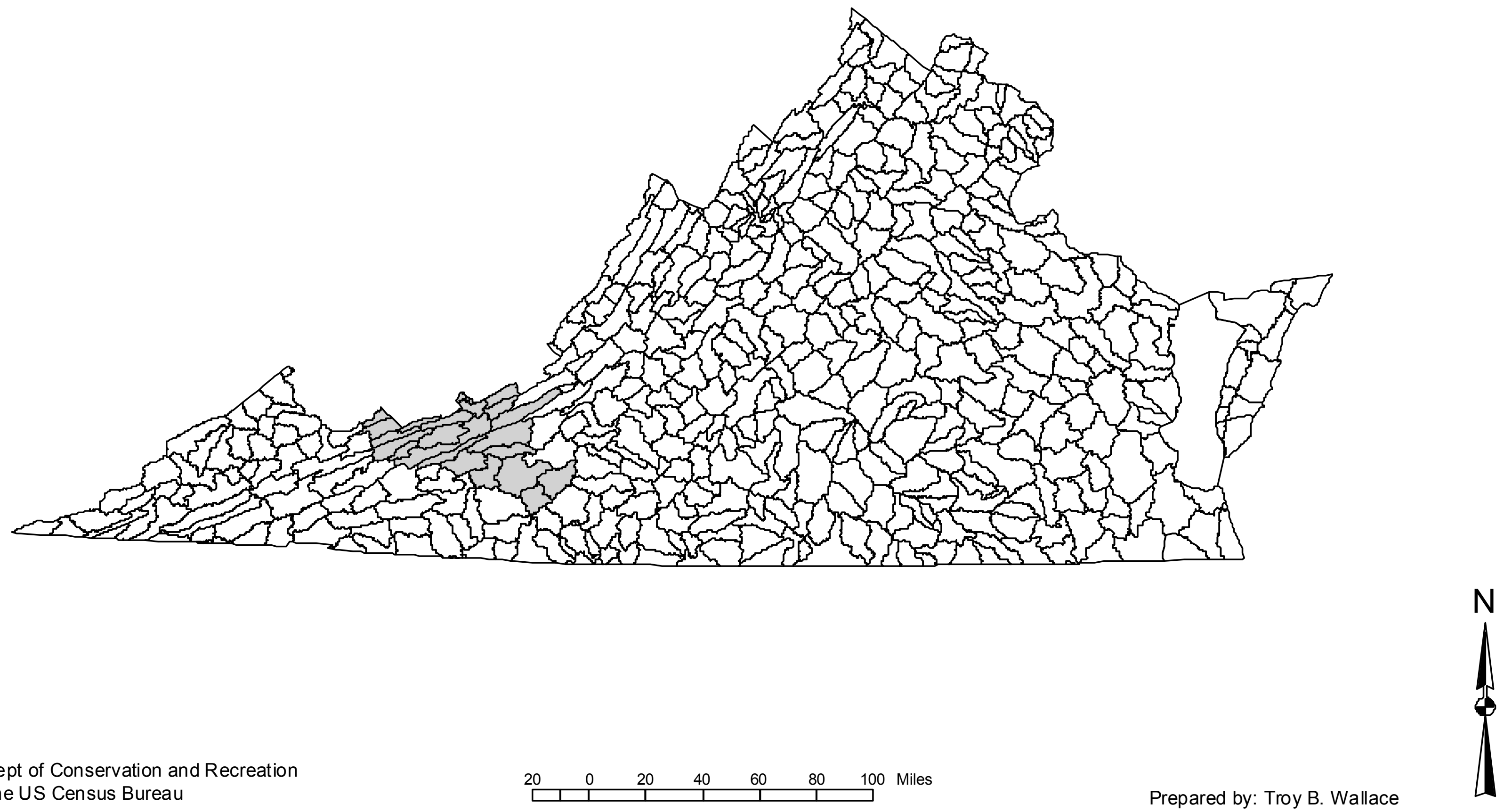
Plate XXIII: Planning Area 23: Upper New



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate XXIV: Planning Area 24: Lower New



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate XXV: Planning Area 25: Holston

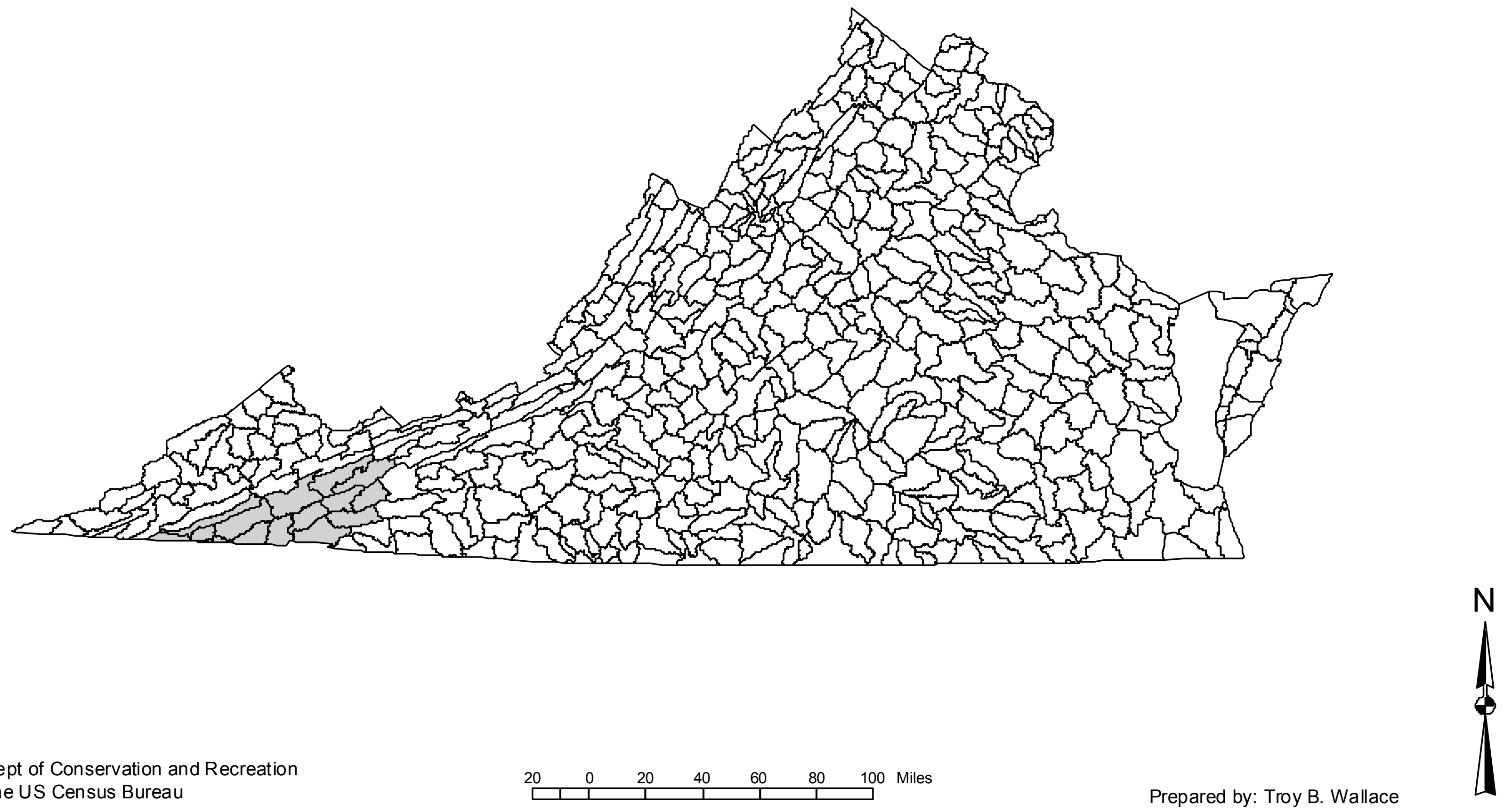
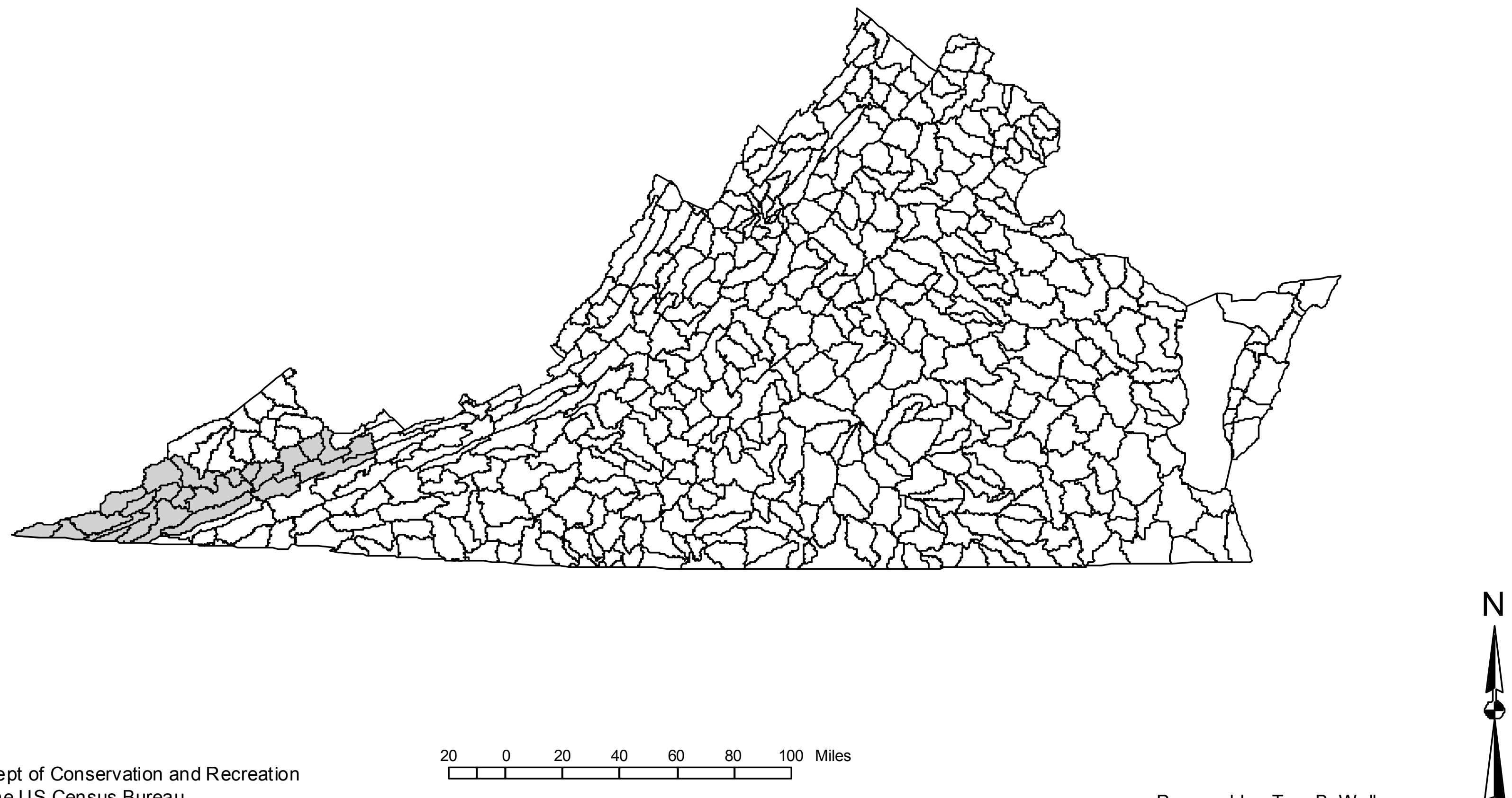


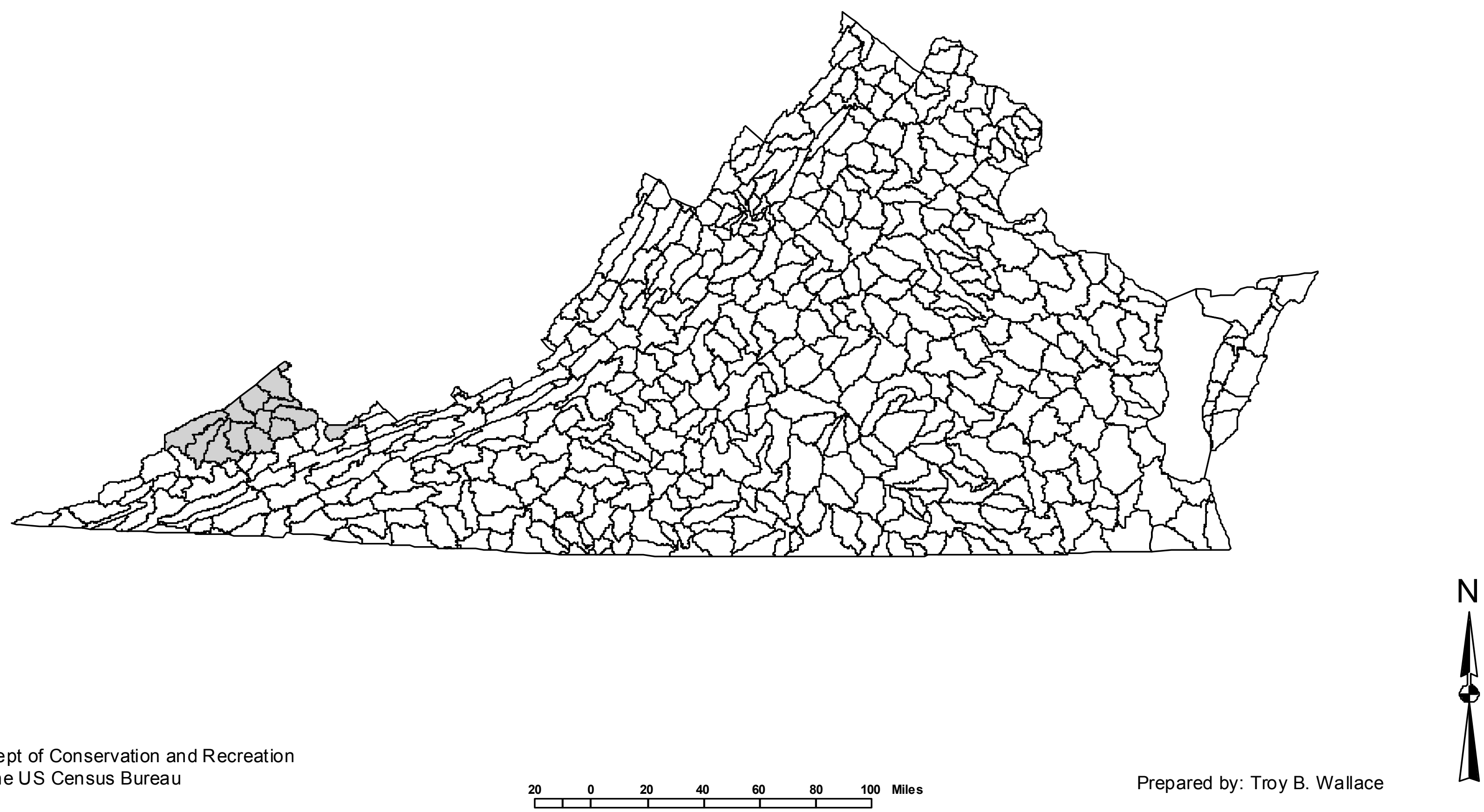
Plate XXVI: Planning Area 26: Clinch/Powell



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

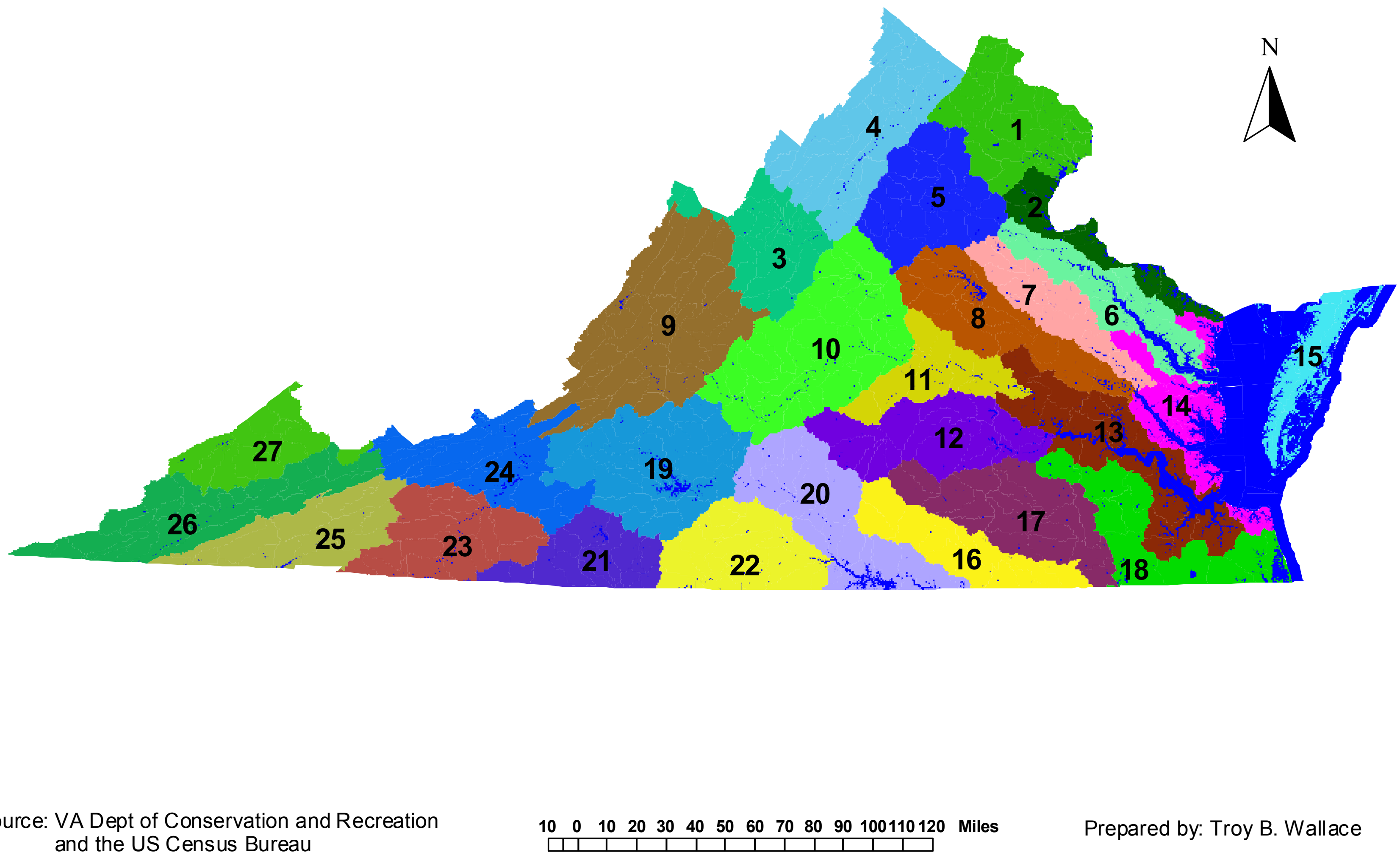
Plate XXVII: Planning Area 27: Big Sandy



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

Plate XXVIII: Virginia Water Supply Planning Areas



Source: VA Dept of Conservation and Recreation
and the US Census Bureau

Prepared by: Troy B. Wallace

APPENDIX C: FLOW PARAMETERS AT USGS GAGING STATIONS

WITHIN EACH PLANNING AREA

C.1 Annual Mean (Q_{am}), $7Q_{10}$ and $1Q_{30}$ at USGS gaging stations in Virginia

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am}(cfs)	$7Q_{10}$ period	$7Q_{10}$(cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
1	Upper Potomac	6385	Potomac(MD)	9651	1895-1997***	9520	1895-1977**	857	1895-77**	605.00
	1625.60 $mi.^2$	6440	Goose Cr.	332	1910,12,31-97***	322	1931-84*	2.5	1909-11,11-12,30-77**	0.85
	3.95%	6460	Difficult Run	57.9	1935-97***	61	1936-84*	3	1934-77**	0.70
		6550	Accotink Cr.	37	1950-77**	12.5	1950-56*	0.56	1950-77**	0.01
		6561	Cedar Run	155	1973-97***	181	1974-84*	.45(g)		
		6565	Broad Run	50.5	1950-77**	50.2	1952-84*	0.92	1950-77**	0.31
		6575	Occoquan	570	1913-16,20-23,37-55**	490	1914-56*	8.4	1913-16,20-23,37-55**	2.00
2	Lower Potomac	6584.80	Quantico Cr.	6.9			1983-84*	0.01		
	691.08 $mi.^2$	6585	S.F.Quantico Cr.	7.64	1951-97***	7.05	1953-84*	0.00	1951-77**	0.00
	1.68%	6590	N.B.Chopawamsic Cr.	5.79			1952-56*	0.00		
		6595	M.F.Chopawamsic Cr.	4.51			1952-56*	0.00		
		6600	S.B.Chopawamsic	2.56			1952-56*	0.00		
		6604	Aquia Cr.	34.9	1971-97***	36.4	1973-84*	.01(g)		
		6605	Beaverdam Cr.	12.7	1951-57****	10.4	1952-56*	0.00		
3	Up Shen/Laurel	6205	North River	17.2	1947-97***	27.4	1948-84*	0.21	1946-77**	0.10
	1233.23 $mi.^2$	6210	Dry River	72.6			1946-47*	0.12		
	3.00%	6220	North River	379	1926-73,76-97***	385	1928-84*	39	1925-72,75-77**	26.66
		6240	Bell Cr.	9.6			1949-56*	0.00		
		6248	Christians Cr.	70.1	1968-97***	72.6	1969-84*	11		
		6250	Middle River	375	1928-97***	321	1929-84*	52	1927-77**	36.77
		6260	South River	127	1953-97***	149	1954-84*	24	1952-77**	18.92
		6275	South River	212	1926-51,69-98****	266	1926-84*	48	1925-51,68-77**	30.62
		6285	S.F.Shenandoah	1084	1930-1998****	1048	1962-84*	147	1930-77**	121.00

* Nelms, D.L., G.E. Harlow, Jr. and D.C. Hayes. "Baseflow Characteristics of Streams in the Valley and Ridge, the Blue Ridge and the Piedmont Physiographic Provinces of Virginia." US Geological Survey Water Supply Paper 2457, 1997.

** Virginia State Water Control Board. ""Hydrologic Analysis of Virginia Streams." Basic Data Bulletins 56, 57 and 58, November, 1982.

*** White, R.K., D.C. Hayes, M.R. Eckenwiler, and P.E. Herman. "Water Resources Data, Virginia, Water Year 1997." US Geological Survey Water Data Report VA-97-1, 1998.

**** White, R.K., D.C. Hayes, M.R. Eckenwiler, and P.E. Herman. "Water Resources Data, Virginia, Water Year 1998." US Geological Survey Water Data Report VA-98-1, 1999.

^ Hayes, D.C. "Low-Flow Characteristics of Streams in Virginia." US Geological Survey Water Supply Paper 2374, 1991.

***** White, R.K., D.C. Hayes, M.R. Eckenwiler, and P.E. Herman. "Water Resources Data, Virginia, Water Year 1999." US Geological Survey Water Data Report VA-99-1, 2000.

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am}(cfs)	$7Q_{10}$ period	$7Q_{10}$(cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
4	L.Shenandoah/Opequon	6310	S.F.Shenandoah	1642	1931-97***	1595	1956-84*	235	1899-06,30-77**	146.00
	2151.87 mi.[2]	6320	N.F.Shenandoah	210	1925-97***	198	1926-84*	0.77	1925-77**	0.27
	5.23%	6329	Smith Cr.	93.2	1960-97***	77	1962-84*	8.0	1960-77**	6.24
		6330	N.F.Shenandoah	506	1944-97***	406	1945-84*	18	1943-77**	10.20
		6340	N.F.Shenandoah	768	1925-77**	570	1925-77**	66.6	1925-77**	46.50
		6335	Stony Cr.	79.4			1947-56*	3.3		
		6345	Cedar Cr.	103	1938-97***	98.3	1939-84*	4.3	1937-77**	2.78
		6355	Passage Cr.	87.8	1933-97***	72.3	1933-84*	1.3	1932-77**	0.47
		6362.10	Happy Cr.	14	1948-77**	14.0	1948-77**	0.17	1948-77**	0.06
		6365	Shenandoah(WVA)	3022	1895-1997***	2757	1895-09,28-77**	367	1895-09,28-77**	242.00
		6139	Hogue Cr.	15	1960-86,93-97***	32.2	1962-84*	0.37	1960-77**	0.08
		6150	Opequon Cr.	57.4	1944-88***	42.9	1945-84*	1.4	1943-77**	0.47
		6160	Abrams Cr.	16.5	1949-1960**	17.50	1951-84*	6.5	1949-60**	4.50
5	Upper Rappahannock	6620	Rappahannock	195	1942-77**	191	1944-84*	2.5	1942-77**	0.82
	1566.90 mi.[2]	6625	Rush River	14.7	1953-77**	16.4	1955-77**	0.00	1953-77**	0.00
	3.81%	6628	Battle Run	27.6	1958-95,97-98****	27.2	1960-84*	0.34	1958-77**	0.01
		6630	Thornton River	142			1945-56*	1.4(g)		
		6635	Hazel River	287	1942-77**	328	1944-84*	6.1	1942-77**	1.66
		6640	Rappahannock	620	1943-97***	698	1944-84*	11	1942-77**	3.92
		6645	Rappahannock	641			1929-52*	11		
		6655	Rapidan River	114	1942-77**	144	1944-84*	4.3	1942-77**	1.77
		6665	Robinson River	179	1944-97***	228	1945-84*	9.7	1943-77**	2.92
		6670	Rapidan River	446			1925-30*	14		
		6675	Rapidan River	472	1931-97***	543	1930-77**	19.43	1930-77**	4.27
6	Lower Rappahannock	6680	Rappahannock	1596	1907-98****	1697	1911-84*	48	1907-77**	14.70
	1157.13 mi.[2]	6685	Cat Point Cr.	45.6	1944-97***	45.4	1943-77**	0.07	1943-77**	0.00
	2.81%	6688	Hoskins Cr.	15.5	1964-69,70-77**	16	1964-69,70-77**	0.67	1964-69,70-77**	0.20
		6690	Piscataway Cr.	28	1952-97***	31.10	1951-77**	0.86	1951-77**	0.02

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am} (cfs)	$7Q_{10}$ period	$7Q_{10}$ (cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
7	Pamunkey	6710	N. Anna River	441	1926-77**	384	1926-77**	9.32	1926-77**	2.63
	1472.76 $mi.^2$	6711	Little River	107	1962-97	97.9	1963-84*	0.58	1961-77**	0.15
	3.58%	6715	Bunch Cr.	4.37	1948-77**	4.52	1950-79*	0.00	1948-77**	0.00
		6725	S. Anna River	394	1931-97	368	1932-84*	9.7	1930-77**	4.03
		6730	Pamunkey River	1081	1942-71****	915				
					1972-98****	1168	1941-77**	37.45	1941-77**	16.67
		6735	Totopotomay Cr.	5.89	1948-77**	5.69	1948-77**	0.06	1948-77**	0.00
		6735.50	Totopotomay Cr.	26.2	1978-97***	25.9		0.93^		
8	Mattaponi	6738	Po River	77.4	1963-97***	76.7	1964-84*	0.22	1962-77**	0.05
	911.40 $mi.^2$	6740	Mattaponi River	257	1943-97	240	1942-77**	0.46	1942-77**	0.02
	2.22%	6745	Mattaponi River	601	1942-87,89-97***	588	1941-77**	17.43	1941-77**	8.17
9	Upper James/Maury	0115	Back Creek	134	1952-97***	184.5	1953-84*	3.6	1951-77**	1.89
	2976.03 $mi.^2$	0118	Jackson River	345	1980-98****	459				
	7.24%	0125	Jackson River	411	1925-77**	486	1927-79*	64	1925-77**	54.95
		0130	Dunlap Cr.	164	1929-97***	170	1930-84*	11	1928-77**	8.46
		0131	Jackson River	614	1980-98****	741				
		0140	Potts Cr.	153	1929-97***	181	1930-84*	17	1928-56,65-77**	14.18
		0157	Bullpasture River	110	1960-97***	153	1962-84*	25	1960-77**	21.86
		0160	Cowpasture River	461	1926-97***	539	1927-84*	54	1925-77**	44.31
		0165	James River	1373	1980-98****	1758	1926-79*	185	1925-77**	162.50
		0170	Meadow Cr.	13.8	1929-52**	16.6	1931-52*	1.9	1929-52**	1.29
		0175	Johns Cr.	104	1927-97***	130	1928-84*	7.8	1926-77**	6.66
		0180	Craig Cr.	329	1925-97***	392	1926-84*	31	1925-77**	25.71
		0185	Catawba Cr.	34.3	1953-98****	35.7	1929-37*	7.5	1943-77**	1.31
		0195	James River	2075	1980-98****	2707	1912-79*	271	1898-77**	225.20
		0210	Calfpasture River	190	1925-38**	212	1926-38*	8.5	1925-38**	6.89
		0215	Maury River	329	1929-97***	386	1930-66*	14	1928-77**	8.52
		0225	Kerrs Cr.	35	1927-97***	36.8	1928-84*	4.9	1926-77**	3.94
		0230	Maury River	487	1925-60**	506	1928-60*	43	1925-60**	34.44
		0235	South River	910	1949-56,57-61**	126	1949-56,57-61**	13.93	1949-56,57-61**	11.51
		0240	Maury River	646	1939-97***	680	1940-66*	62	1938-77**	35.58

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am} (cfs)	$7Q_{10}$ period	$7Q_{10}$ (cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
10	Up Mid James/Rivanna	0250	Pedlar River	91			1942-56**	3.66	1942-56**	2.17
	2790.46 mi.^{2}	0255	James River	3259	1927-79***	3663				
	6.79%				1980-97***	3788	1928-79*	401	1926-77**	254.70
		0260	James River	3683	1925-1979***	4192				
					1980-97***	4406	1926-79*	449	1924-77**	259.20
		0265	Tye River	68	1927-38**	131	1927-38**	3.99	1927-38**	1.50
		0270	Tye River	92.8	1939-97***	159	1940-84*	5	1938-77**	1.86
		0275	Piney River	47.6	1950-97***	97.2	1951-84*	3.2	1949-77**	1.66
		0278	Buffalo River	147	1960-77**	164	1962-84*	7.9	1960-77**	2.79
		0280	Tye (Buffalo) River	360	1940-60**	474	1941-60*	37	140-60**	23.02
		0285	Rockfish River	94.6	1943-97***	145	1944-84*	4.1(g)	1943-77**	0.87
		0290	James River	4584	1925-79***	5149				
					1980-98****	5701	1926-79*	508	1924-77**	338.50
		0295	Hardware River	104	1925-38**	117	1927-38*	4.2	1925-38**	1.43
		0300	Hardware River	116	1939-95,97***	130	1940-84*	7.5(g)	1938-77**	1.13
		0305	Slate River	226	1926-77**	229	1927-84*	9.5	1926-77**	3.33
		0310	Meechums River	95.4	1942-51,79-97***	112	1944-84*	1.6(g)		
		0315	N.F. Moormans River	11.4	1951-63**	15.2	1953-84*	0.00	1951-63**	0.00
		0324	Buck Mountain Cr.	37	1980-97***	45.2	1981-84*	0.88		
		0325	S.F. Rivanna River	216	1951-66**	189	1951-66**	3.11	1951-66**	0.99
		0326.80	N.F. Rivanna River	176			1971-84*	8.17		
		0340	Rivanna	664	1935-98****	742	1933-77**	28.42	1933-77**	12.12
11	Lower Middle James	0345	Willis River	262	1926-77**	247	1927-84*	7.19	1926-77**	2.52
	945.49 mi.^{2}	0350	James River	6257	1899-98****	7191	1926-79*	584	1898-77**	367.80
	2.30%	0355	Lickinghole Cr.	70			1945-46*	4.7		
		0365	Fine Cr.	22.1	1945-97***	19.7	1946-84*	0.47	1944-77**	0.19
		0385	Falling Cr.	54	1942-56,57-63**	57	1942-56,57-63**	0.27	1942-56,57-63**	0.06
		0388.50	Holiday Cr.	8.53	1966-97***	8.89	1967-84	.52(g)		

#	Basin	Station	Description	Drainage (mi²)	Q_{am} period	Q_{am} (cfs)	$7Q_{10}$ period	$7Q_{10}$ (cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
12	Appomattox	0390	Buffalo Cr.	69.7	1947-97***	68.4	1948-84*	6.0	1946-77**	3.20
	1598.35 mi.^{2}	0395	Appomattox River	303	1926-97***	293	1927-84*	21	1926-77**	9.42
	3.89%	0400	Appomattox River	726	1926-97***	714	1927-84*	30(g)	1900-05,26-77**	17.00
		0410	Deep Cr.	158	1947-97***	148	1948-84*	1.4	1946-77**	0.14
		0415	Appomattox River	1334			1928-66*	58	1926-66**	32.21
		0416.50	Appomattox River	1344	1970-98****	1405				
		0420	Swift Cr.	143			1944-49	0.75		
		0405	*Flat Cr.*	73				0.3		
13	Lower James	0375	James River	6758	1937-98****	6946	1934-77**	623.05	1934-77**	319.10
	1925.85 mi.^{2}	0380	Falling Cr.	32.8	1955-77**	31.1	1957-84*	.64(g)	1955-77**	0.06
	4.68%	0425	Chickahominy River	252	1942-98****	260	1942-77**	5	1942-77**	1.93
14	Mainland Bay/York	6618	Bush Mill Stream	6.82	1963-69,69-77**	7.12	1963-69,69-77**	0.05	1963-69,69-77**	0.00
	1114.26 mi.^{2}	6695.20	Dragon Swamp	108	1982-98****	119		0.64^		
	2.71%	6700	Beaverdam Swamp	6.63	1949-77**	7.04	1949-77**	0.01	1949-77**	0.00
		6770	Ware Creek	6.29				.22^		
15	Eastern Shore	4848	Guy Cr.	1.72	1964-77**	1.13	1964-77**	0.04	1964-77**	0.00
	1105.30 mi.^{2}									
	2.69%									
16	Meherrin	0505	N.Meherrin River	9.2	1948-61**	9.62	1950-61*	0.21	1948-61**	0.15
	1115.53 mi.^{2}	0510	N.Meherrin River	55.6	1947-97***	50.7	1948-84*	0.49	1946-77**	0.02
	2.71%	0515	Meherrin River	552	1929-97***	499	1930-84*	16	1928-77**	5.98
		0516	Great Creek	30.7	1958-77**	28.9	1960-84*	.35(g)	1958-77**	0.11
		0520	Meherrin River	747	1952-98****	700	1967-84*	23	1951-77**	9.23
		0525	Fountaine Cr.	65.2	1953-77**	67.1	1955-84*	0.00	1953-77**	0.00

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am} (cfs)	$7Q_{10}$ period	$7Q_{10}$ (cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
17	Nottoway	0440	Nottoway River	38.7	1946-77**	36.7	1948-84*	0.11	1946-77**	0.01
	1722.63 mi.^{2}	0445	Nottoway River	309	1951-97***	305	1952-84*	4.0	1950-77**	0.71
	4.19%	0455	Nottoway River	579	1931-97***	556	1929-77**	13.8	1929-77**	5.84
		0460	Stony Cr.	112	1947-97	109	1948-84	0.25	1946-77**	0.15
		0470	Nottoway River	1421	1941-98****	1360	1941-77**	29.63	1941-77**	16.03
		0471	Assamoosick Swamp	86.4				0.00^		
18	Blackwater/SE Coastal	0475	Blackwater River	294	1942-86,89-97***	308	1941-77**	0.00	1941-77**	0.00
	1413.37 mi.^{2}	0480	Blackwater River	456	1942-77**	474	1942-77**	0.10	1942-77**	0.01
	3.44%	0485	Seacock Cr.	102				0.00^		
		0495	Blackwater River	617	1944-98****	628	1944-77**	1.98	1944-77**	0.58
		0435	Cypress Swamp	23.8				0.00^		
19	Upper Roanoke	0538	S.F.Roanoke River	110	1961-97***	115	1962-84*	11(g)	1960-77**	7.82
	2191.30 mi.^{2}	0545	Roanoke River	257	1944-97***	245	1945-84*	24	1943-77**	15.98
	5.33%	0550	Roanoke River	395	1899-97***	375	1951-84*	35	1899-77**	28.53
		0551	Tinker Cr.	11.7	1956-98****	12.4	1956-77**	1.16	1956-77**	0.84
		0566.50	Back Cr.	56.8	1974-97***	60.8	1976-84*	2.5		
		0569	Blackwater River	115	1977-97***	141	1978-84*	12		
		0570	Blackwater River	208	1924-63**	223	1927-63*	26(g)	1924-63**	16.92
		0575	Roanoke River	1020	1925-63**	1006	1927-62*	142	1925-63**	82.37
		0580	Snow Cr.	60			1935-43*	10		
		0584	Pigg River	350	1963-77**	356	1965-84*	47	1963-77**	41.02
		0585	Pigg River	394	1930-63**	400	1932-63*	66	1930-63**	38.52
		0595	Goose Cr.	188	1931-97***	184	1956-84*	23	1930-77**	11.87
		0605	Roanoke River		1931-62***	1940				
				1789	1963-98****	1723	1932-62*	266	1930-77**	48.57
		0610	Big Otter River	116	1943-60**	133	1945-60*	7.3	1943-60**	4.19
		0615	Big Otter River	320	1937-97***	343	1938-84*	28	1936-77**	14.46

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am}(cfs)	$7Q_{10}$ period	$7Q_{10}$(cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
20	Lower Roanoke	0625	Roanoke (Staunton) River	2415	1924-62***	2466				
	1181.01 mi.^{2}				1963-97***	2419	1925-62*	344	1923-77**	150.69
	2.87%	0630	Caldwells Cr.	5.1			1954-60*	0.40		
		0640	Falling River	173	1930-34,42-97***	157	1931-84*	15	1929-35,41-77**	7.00
		0650	Falling River	228			1935-41*	33		
		0655	Cub Cr.	98	1947-97***	101	1948-84*	8.2		
		0660	Roanoke (Staunton) River	2977	1928-30,51-62***	3357				
					1963-98****	3022	1902-62*	426	1900-06,27-30,50-77**	173.93
		0665	Roanoke Cr.	135	1946-72**	108	1948-72*	.80(g)	1946-72**	0.28
		0670	Roanoke River	3230	1929-52**	3355	1931-52*	433	1929-52**	181.55
		0790	Roanoke River	7320	1934-52**	8375	1936-52*	1423	1934-52**	1080.00
		0796.40	Allen Cr.	53.4	1961-77**	38.8	1963-84*	0.03	1961-77**	0.00
21	Martinsville/Ararat	0685	Dan River(NC)	129	1938-98****	198	1924-77**	42.82	1924-77**	27.33
	1028.37 mi.^{2}	0697	S.Mayo River	84.6	1963-98****	132	1964-84*	27	1962-77**	21.01
	2.50%	0700	N.Mayo River	108	1929-35,37-98****	131	1930-84*	25	1928-77**	17.78
		0725	Smith River	259	1940-97***	350	1940-50*	95	1939-77**	41.23
		0730	Smith River	380	1951-98****	487	1929-77**	110	1929-77**	18.95
		0735	Leatherwood Cr.	68			1925-34	7.5		
		1135.5	*Ararat River*	21.7				3.4^		
22	Danville	0745	Sandy River	112	1930-97***	111	1930-84*	15	1929-77**	8.76
	1361.23 mi.^{2}	0750	Dan River	2050	1934-77**	2302	1934-77**	440	1934-77**	195.81
	3.31%	0755	Dan River	2550	1951-97***	2794	1950-77**	415	1950-77**	137.33
		0765	Georges Cr.	9.24	1950-97***	10.1	1950-84*	1.6(g)	1949-77**	0.93
		0770	Banister River	547	1929-98****	516	1928-77**	39.86	1928-77**	11.07
		0780	Hyco River	338	1934-50**	403	1934-50**	3.45	1934-50**	1.48

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am}(cfs)	$7Q_{10}$ period	$7Q_{10}$(cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
23	Upper New	1610	New River(NC)	205	1925-97***	434	1924-77**	103.2	1924-77**	71.70
	1455.8 $mi.^2$	*1626.50*	*Wilson Cr.**	17.7				1.3		
	3.54%	1640	New River	1131	1930-97***	1929	1931-84*	400	1929-77**	287.30
		1650	Chestnut Cr.	39.4	1945-97***	69	1946-84*	17	1944-77**	12.86
		1655	New River	1340	1930-78,96-97***	2150	1931-78*	427	1929-77**	208.00
		1660	Cripple Cr.	148			1930-34*	27		
		1668	Glade Cr.	7.15			1978-84*	0.10		
		1670	Reed Cr.	247	1909-16,27-97***	270	1910-84*	52	1908-16,27-77**	31.97
		1675	Big Island Reed Cr.	278	1908-16, 39-77**	397	1910-84*	101	1908-16,39-77**	79.72
		1680	New River	2202	1930-98****	3252	1931-84*	725	1929-77**	509.40
24	Lower New	1685	Peak Cr.	60.9			1952-56*	2.5		
	1609.54 $mi.^2$	1700	Little River	300	1929-97***	366	1930-84*	69	1928-77**	51.13
	3.92%	1715	New River	2941	1914-76**	3942	1914-76**	885.64	1914-76**	616.30
		1730	Walker Cr.	305	1938-97***	328	1939-84*	33	1938-77**	24.77
		1755	Wolf Cr.	223	1908-16,38-97***	301	1910-84*	23	1908-16,38-77**	16.90
		1765	New River	3768	1939-98****	5082	1927-77**	1126	1927-77**	874.61
25	Holston	4715	S.F.Holston River	76.1	1921-32,42-97***	113	1922-84*	20	1920-31,42-77**	12.24
	1322.04 $mi.^2$	4725	Beaverdam Cr.	56	1947-59**	165	1949-59*	4.7	1947-59**	2.58
	3.22%	4730	S.F.Holston River	301	1932-98****	481	1933-84*	73	1931-77**	59.99
		4740	M.F.Holston River	132	1942-81,89,97***	164	1944-81*	27	1942-77**	18.74
		4745	M.F.Holston River	155			1907-09,20-31**	25	1907-09,20-31**	13.50
		4750	M.F.Holston River	211	1932-53,76-98****	247	1978-84*	50	1931-53,76-77**	6.62
		4775	Beaver Cr.	13.7	1945-57**	14.6	1947-56*	3.2	1945-57**	2.78
		4784	Beaver Cr.	27.7	1958-98****	34.9	1959-84*	8.5	1957-77**	7.26
		4878	Lick Cr.	25.5			1966-68*	0.39		
		4880	N.F.Holston River	222	1907-09,21-97***	300	1922-84*	24	1907-08,20-77**	89.45
		4884.50	Brumley Cr.	21.1			1980-81*	0.15		
		4895	N.F.Holston River	493	1920-31**	684	1922-31*	46	1920-31**	26.17
		4898.50	Cove Cr.	17.6			1966-68*	1.4		
		4899	Big Moccassin Cr.	79.6			1966-68*	6.7		
		4900	N.F.Holston River	672	1931-77**	897	1958-81*	56	1931-77**	44.50

#	Basin	Station	Description	Drainage (mi^2)	Q_{am} period	Q_{am}(cfs)	$7Q_{10}$ period	$7Q_{10}$(cfs)	$1Q_{30}$ period	$1Q_{30}$ (cfs)
26	Clinch/Powell	5215	Clinch River	137	1945-77**	191	1972-84*	19	1945-77**	9.49
	1810.81 $mi.^2$	5220	Little River	103			1950-52*	18		
	4.40%	5230	Big Cedar Cr.	51.5			1953-59*	3.2		
		5240	Clinch River	528	1921-97***	709	1922-84*	54		
		5245	Guest River	87.3	1996-97***	183		1.8^		
		5250	Stony Cr.	41.4			1950-52*	0.52		
		5260	Copper Cr.	106	1948-72,96-97***	142	1949-72*	18	1947-72**	12.90
		5270	Clinch River	1126	1920-76**	1591	1951-81*	100	1920-76**	80.48
		5300	S.F.Powell River	40				2.0		
		5305	N.F.Powell River	71.4				1.3		
		5310	Powell River	290	1920-31**	562	1920-31**	13.69	1920-31**	9.90
		5315	Powell River	319	1932-97***	545	1933-84*	24	1931-77**	17.83
		5315.05	Batie Cr.	17.4				1.9		
		5315.2	Wallen Cr.	47.4				7.3		
		5315.35	Dry Cr.	23.6				0.88		
		5320	Powell River (TN)	685	1920-99*****	1142	1919-77**	80.77	1919-77**	68.25
27	Big Sandy	2075	Levisa Fork	235	1941-74**	286	1941-74**	1.3	1941-74**	0.35500
	998.81 $mi.^2$	2078	Levisa Fork	297	1968-97***	381		8.3(g)^		
	2.43%	2080.34	Grissom Cr.	2.82				0.00^		
		2080.36	Barton Fork	1.23				0.00^		
		2081	Russell Fork	87.4				0.04^		
		2085	Russell Fork	286	1926-97***	336	1926-77**	1.22	1926-77**	0.37500
		2087	N.F.Pound River	18.5	1961-77**	29.6	1961-77**	0.11	1961-77**	0.01500
		2088	Pound River	36.7	1962-77**	59.3	1962-77**	1.81	1965-77**	0.55000
		2089	Pound River	82.5	1963-77**	126	1963-77**	2.8	1963-77**	1.44500
		2089.50	Cranes Nest River	66.5	1964-97***	80.5	1963-77**	1.57	1963-77**	0.70000
		2090	Pound River	221	1926-64***	265	1926-77**	0.81	1926-77**	0.24500
					1965-97***	292				
		2092	Russell Fork	526	1962-77**	683	1962-77**	11.47	1962-77**	4.22500
		2092.50	Grassy Cr.	15.5				0.31		
		2135.90	Knox Cr.	84.3				0.8		

C.2 95% Exceedance Flow (Q_{95}), 90% Exceedance Flow (Q_{90}), 50% Exceedance .Flow(Q_{50}), 10% Exceedance Flow (Q_{10}), and Mean Baseflow Estimates at USGS Gaging Stations in Virginia

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
1	Upper Potomac	6385	Potomac(MD)	9.00%	952			5430****		
	1625.60 mi.^{2}	6440	Goose Cr.	0.78%	32.2	10.2		161****	191	
	3.95%	6460	Difficult Run	4.92%	6.1	10		38****	37.1	
		6550	Accotink Cr.	4.48%	1.25	2.6		20.5*	20.9	
		6561	Cedar Run	0.25%	18.1	1.7		82****	56.7	
		6565	Broad Run	1.83%	5.02	2.2		25.5*	30.8	
		6575	Occoquan	1.71%	49	27.7		182*	182	
2	Lower Potomac	6584.80	Quantico Cr.			0.57		6.41*	5.02	
	691.08 mi.^{2}	6585	S.F.Quantico Cr.	0.00%	0.705	0.10		2.8****	3.15	
	1.68%	6590	N.B.Chopawamsic Cr.			0.10		1.7*	2.43	
		6595	M.F.Chopawamsic Cr.			0.10		1.6*	2.06	
		6600	S.B.Chopawamsic			0.10		1.00*	1.42	
		6604	Aquia Cr.	0.03%	3.64	0.51		19.7*	19.4	
		6605	Beaverdam Cr.	0.00%	1.04	0.10		5.0****		
3	Up Shen/Laurel	6205	North River	0.77%	2.74	0.54		12****	16.3	
	1233.23 mi.^{2}	6210	Dry River			0.72		25.2*	30.4	
	3.00%	6220	North River	10.13%	38.5	53		207****	246	
		6240	Bell Cr.			0.10		.72*		
		6248	Christians Cr.	15.15%	7.26	15		44.4*	52.8	
		6250	Middle River	16.20%	32.1	67		48****	216	
		6260	South River	16.11%	14.9	29		85****	105	
		6275	South River	18.05%	26.6	59		158****	186	
		6285	S.F.Shenandoah	14.03%	104.8	188	240****	608****	710	2140****

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^ Hayes, D.C. "Low-Flow Characteristics of Streams in Virginia." US Geological Survey Water Supply Paper 2374, 1991.

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#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
4	L.Shenandoah/Opequon	6310	S.F.Shenandoah	14.73%	159.5	318		960****	1064	
	2151.87 mi.^{2}	6320	N.F.Shenandoah	0.39%	19.8	2.2		62****	89	
	5.23%	6329	Smith Cr.	10.39%	7.7	11.4		44****	55.2	
		6330	N.F.Shenandoah	4.43%	40.6	32.1		191****	237	
		6340	N.F.Shenandoah	11.68%	57					
		6335	Stony Cr.			6.84		32.6*	42	
		6345	Cedar Cr.	4.37%	9.83	7.77		43****	56.6	
		6355	Passage Cr.	1.80%	7.23	2.4		26****	40.2	
		6362.10	Happy Cr.	1.21%	1.4					
		6365	Shenandoah(WVA)	13.31%	275.7		613****	1620****		5630****
		6139	Hogue Cr.	1.15%	3.22	0.77	1.2****	5.5****	8.46	35****
		6150	Opequon Cr.	3.26%	4.29	3.41	4.7****	16****	20.6	81****
		6160	Abrams Cr.	37.14%	1.75	8.25		17.1*	17.8	
5	Upper Rappahannock	6620	Rappahannock	1.31%	19.1	12.3		122*	132	
	1566.90 mi.^{2}	6625	Rush River	0.00%	1.64	0.28		10.1*	12.5	
	3.81%	6628	Battle Run	1.25%	2.72	1.4		16****	19.5	
		6630	Thornton River			14.4		99.2*	109	
		6635	Hazel River	1.86%	32.8	26.9		212*	231	
		6640	Rappahannock	1.58%	69.8	47.8	77****	424****	432	1420****
		6645	Rappahannock			45.4		421*	415	
		6655	Rapidan River	2.99%	14.4	13.1		99.8*	112	
		6665	Robinson River	4.25%	22.8	27.2		150****	154	
		6670	Rapidan River			38.7		297*	266	
		6675	Rapidan River	3.58%	54.3		86****	345****		1080****
6	Lower Rappahannock	6680	Rappahannock	2.85%	168.5	150	237****	1000****	932	3340****
	1157.13 mi.^{2}	6685	Cat Point Cr.	0.15%	4.54			30****		
	2.81%	6688	Hoskins Cr.	4.19%	1.6			23****		
		6690	Piscataway Cr.	2.77%	3.11					

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	10%Q_{am}	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
7	Pamunkey	6710	N. Anna River	2.43%	38.4					
	1472.76 mi.^{2}	6711	Little River	0.59%	9.79	2		53****	54	
	3.58%	6715	Bunch Cr.	0.00%	0.452	0.04		1.7*	2.29	
		6725	S. Anna River	2.64%	36.8	30.4		194*	193	
		6730	Pamunkey River		91.5		130****	511****		1960****
				3.21%	116.8		124****	630****		2730****
		6735	Totopotomay Cr.	1.05%	0.569					
		6735.50	Totopotomay Cr.	3.59%	2.59			17****		
8	Mattaponi	6738	Po River	0.29%	7.67	1.3		36****	39..1	
	911.40 mi.^{2}	6740	Mattaponi River	0.19%	24			127****		
	2.22%	6745	Mattaponi River	2.96%	58.8		65****	378****		1340****
9	Upper James/Maury	0115	Back Creek	1.95%	18.45	8.51		80.5*	101	
	2976.03 mi.^{2}	0118	Jackson River		45.9			266****		
	7.24%	0125	Jackson River	13.17%	48.6	78		268*	316	
		0130	Dunlap Cr.	6.47%	17	16		68****	90.9	
		0131	Jackson River		74.1			367****		
		0140	Potts Cr.	9.39%	18.1	23.4		87****	114	
		0157	Bullpasture River	16.34%	15.3	30.5		82****	98.7	
		0160	Cowpasture River	10.02%	53.9	73.3		261****	301	
		0165	James River	10.52%	175.8	230		860****	921	
		0170	Meadow Cr.	11.45%	1.66	3		10.3*	12.8	
		0175	Johns Cr.	6.00%	13	11		60****	82.3	
		0180	Craig Cr.	7.91%	39.2	41.7		183****	239	
		0185	Catawba Cr.	21.01%	3.57	7.94		14****	64.2	
		0195	James River	10.01%	270.7	355	557****	1340****	1412	5950****
		0210	Calfpasture River	4.01%	21.2	14		92.6*	114	
		0215	Maury River	3.63%	38.6	22.7		157****	193	
		0225	Kerrs Cr.	13.32%	3.68	6.26		18****	22.7	
		0230	Maury River	8.50%	50.6	61.1		252*	299	
		0235	South River	11.06%	12.6					
		0240	Maury River	9.12%	68	81.9	107****	350****	399	1520****

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
10	Up Mid James/Rivanna	0250	Pedlar River			8.51		57.7*	67.7	
	2790.46 mi.^{2}	0255	James River		366.3	547		2100****	2130	
	6.79%			0.00%	378.8			1980****		
		0260	James River		419.2	682		2500****	2497	
				10.19%	440.6			2590****		
		0265	Tye River	3.05%	13.1	7.49		73.3*	95.5	
		0270	Tye River	3.14%	15.9	14.8		104****	116	
		0275	Piney River	3.29%	9.72	6.6		61****	73.3	
		0278	Buffalo River	4.82%	16.4	22.3		113*	124	
		0280	Tye (Buffalo) River	7.81%	47.4	75.7		319*	349	
		0285	Rockfish River	2.83%	14.5	12.4		89****	104	
		0290	James River		514.9			3190****		
				8.91%	570.1	782	1190****	3320****	3122	12300****
		0295	Hardware River	3.59%	11.7	20.2		75.0*	80.8	
		0300	Hardware River	5.77%	13	17.7		82****	86.3	
		0305	Slate River	4.15%	22.9	28.6		128*	123	
		0310	Meechums River	1.43%	11.2	15.9		72****	75.8	
		0315	N.F. Moormans River	0.00%	1.52	0.12		5.89*	9.72	
		0324	Buck Mountain Cr.	1.95%	4.52	2.8		20.9*	26.8	
		0325	S.F. Rivanna River	1.65%	18.9					
		0326.80	N.F. Rivanna River			22		150*	152	
		0340	Rivanna	3.87%	73.5		112****	428****		1440****
11	Lower Middle James	0345	Willis River	2.91%	24.7	22.6		130*	136	
	945.49 mi.^{2}	0350	James River	8.12%	719.1	991	1450****	4490****	4028	15100****
	2.30%	0355	Lickinghole Cr.			13.1		41.6*	36.8	
		0365	Fine Cr.	2.39%	1.97	1.2		11****	12.3	
		0385	Falling Cr.	0.47%	5.7					
		0388.50	Holiday Cr.	5.85%	0.889	1.4		5.4****	5.69	

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
12	Appomattox	0390	Buffalo Cr.	8.77%	6.84	13.2		44****	44.9	
	1598.35 mi.^{2}	0395	Appomattox River	7.17%	29.3	45.4		168****	163	
	3.89%	0400	Appomattox River	4.20%	71.4	83		387****	367	
		0410	Deep Cr.	0.95%	14.8	11.3		75****	79.8	
		0415	Appomattox River	4.13%		133.5			614	
		0416.50	Appomattox River		140.5		161****	703****		3500****
		0420	Swift Cr.			8.44		82.4*	85.1	
		0405	*Flat Cr.*			2.8			*38.3*	
13	Lower James	0375	James River	8.97%	694.6		950****	4200****		15000****
	1925.85 mi.^{2}	0380	Falling Cr.	2.06%	3.11	1.1		18.1*	20.5	
	4.68%	0425	Chickahominy River	1.92%	26		22****	166****		600****
14	Mainland Bay/York	6618	Bush Mill Stream	0.70%	0.712					
	1114.26 mi.^{2}	6695.20	Dragon Swamp	0.54%			7.4****	83****		265****
	2.71%	6700	Beaverdam Swamp	0.14%	0.704					
		6770	Ware Creek							
15	Eastern Shore			3.54%	0.113					
	1105.30 mi.^{2}									
	2.69%									
16	Meherrin	0505	N.Meherrin River	2.18%	0.962	0.59		3.30*	4.81	
	1115.53 mi.^{2}	0510	N.Meherrin River	0.97%	5.07	2.59		20****	22.4	
	2.71%	0515	Meherrin River	3.21%	49.9	44.8		252****	242	
		0516	Great Creek	1.21%	2.89	2		17.0*	18.2	
		0520	Meherrin River	3.29%	70	62.8	71****	360****	372	1440****
		0525	Fountaine Cr.	0.00%	6.71	0.26		27.2*	32.4	

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
17	Nottoway	0440	Nottoway River	0.30%	3.67	1.1		15.4*	16.6	
	1722.63 mi.^{2}	0445	Nottoway River	1.31%	30.5	28.2		174****	177	
	4.19%	0455	Nottoway River	2.49%	55.6			303****		
		0460	Stony Cr.	0.23%	10.9	2.73		49****	58.9	
		0470	Nottoway River	2.18%	136		102****	742****		3380****
		0471	Assamoosick Swamp							
18	Blackwater/SE Coastal	0475	Blackwater River	0.00%	30.8			160****		
	1413.37 mi.^{2}	0480	Blackwater River	0.02%	47.4					
	3.44%	0485	Seacock Cr.							
		0495	Blackwater River	0.32%	62.8		8.2****	375****		1640****
		0435	Cypress Swamp							
19	Upper Roanoke	0538	S.F.Roanoke River	9.57%	11.5	22.4		70.2*	77.4	
	2191.30 mi.^{2}	0545	Roanoke River	9.80%	24.5	42.6		136****	160	
	5.33%	0550	Roanoke River	9.33%	37.5	56.9		212****	229	
		0551	Tinker Cr.	9.35%	1.24			7.0****		
		0566.50	Back Cr.	4.11%	6.08	6.2		34****	39.4	
		0569	Blackwater River	8.51%	14.1	24.3		92****	96.6	
		0570	Blackwater River	11.66%	22.3	55.4		165*	160	
		0575	Roanoke River	14.12%	100.6	223		667*	668	
		0580	Snow Cr.			22.2		46.8*	45.8	
		0584	Pigg River	13.20%	35.6	86.7		262****	241	
		0585	Pigg River	16.50%	40	116		286*	270	
		0595	Goose Cr.	12.50%	18.4	36.9		113****	116	
		0605	Roanoke River		194			1310****		
				15.44%	172.3	440		1030***	1031	3440****
		0610	Big Otter River	5.49%	13.3	19.3		91.1*	98.1	
		0615	Big Otter River	8.16%	34.3	58.3		220****	219	

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
20	Lower Roanoke	0625	Roanoke (Staunton) River		246.6			1720****		
	1181.01 mi.^{2}			14.22%	241.9	568		1430****	1574	
	2.87%	0630	Caldwells Cr.			0.86		2.30*	2.54	
		0640	Falling River	9.55%	15.7	27.5		95****	93.1	
		0650	Falling River			71.2		153*	154	
		0655	Cub Cr.	8.12%	10.1	18.3		65****	63.3	
		0660	Roanoke (Staunton) River		335.7			2230****		
				14.10%	302.2	773	865****	1810****	1950	5800****
		0665	Roanoke Cr.		10.8	8.18		55.5*	56	
		0670	Roanoke River	12.91%	335.5	799		2279*	2038	
		0790	Roanoke River	16.99%	837.5	2158		5558*	4558	
		0796.40	Allen Cr.	0.08%	3.88	0.64		15.2*	17.5	
21	Martinsville/Ararat	0685	Dan River(NC)	21.63%	19.8		85****	158****		321****
	1028.37 mi.^{2}	0697	S.Mayo River	20.45%	13.2	41.6	52****	100****	99.2	217****
	2.50%	0700	N.Mayo River	19.08%	13.1	40.2	52****	96****	93.7	202****
		0725	Smith River	27.14%	35	128		271*	268	
		0730	Smith River	22.59%	48.7		168****	364****	916****	
		0735	Leatherwood Cr.			6.96		32.3*	28.1	
		1135.5	*Ararat River*							
22	Danville	0745	Sandy River	13.51%	11.1	27.4		72****	70	
	1361.23 mi.^{2}	0750	Dan River	19.11%	230.2	748		1709*	1400	
	3.31%	755	Dan River	14.85%	279.4			1910****		
		0765	Georges Cr.	15.84%	1.01	2.6		7.10*	7.44	
		0770	Banister River	7.72%	51.6			307****		
		0780	Hyco River	0.86%	40.3	16.6		150*	148	

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
23	Upper New	1610	New River(NC)	23.78%	43.4			351****		
	1455.8 mi.^{2}	*1626.50*	*Wilson Cr.**			0.53		5.50*	*8.25*	
	3.54%	1640	New River	20.74%	192.9	569		1470****	1367	
		1650	Chestnut Cr.	24.64%	6.9	24.6		52****	52.6	
		1655	New River	19.86%	215	619		1710****	1403	
		1660	Cripple Cr.			28.5		64.0*	74.8	
		1668	Glade Cr.			0.08		.33*	0.46	
		1670	Reed Cr.	19.26%	27	65.2		160****	186	
		1675	Big Island Reed Cr.	25.44%	39.7	141		315*	293	
		1680	New River	22.29%	325.2	954	1110****	2440****	2156	5860****
24	Lower New	1685	Peak Cr.			2		12.5*	21.4	
	1609.54 mi.^{2}	1700	Little River	18.85%	36.6	104		270****	255	
	3.92%	1715	New River	22.47%	394.2	1070		2971*	2515	
		1730	Walker Cr.	10.06%	32.8	42.9		163****	207	
		1755	Wolf Cr.	7.64%	30.1	32.6		155****	196	
		1765	New River	22.16%	508.2	1234	1560****	3710****	3207	9760****
25	Holston	4715	S.F.Holston River	17.70%	11.3	24.6		71****	84	
	1322.04 mi.^{2}	4725	Beaverdam Cr.	2.85%	16.5	8.26		52.7*	65.4	
	3.22%	4730	S.F.Holston River	15.18%	48.1	95.3	112****	307****	333	1000****
		4740	M.F.Holston River	16.46%	16.4	33.4		93****	109	
		4745	M.F.Holston River			36.3		120*	131	
		4750	M.F.Holston River	20.24%	24.7	69.6	62****	147****	191	500****
		4775	Beaver Cr.	21.92%	1.46	3.8		10.3*	12.9	
		4784	Beaver Cr.	24.36%	3.49	10.4	12****	27****	30.9	63****
		4878	Lick Cr.			0.86		158****	18.5	
		4880	N.F.Holston River	8.00%	30	32.3		156*	178	
		4884.50	Brumley Cr.			0.88		17.9*	22.70	
		4895	N.F.Holston River	6.73%	68.4	70.6		376*	385	
		4898.50	Cove Cr.			1.9		12.0*	11.90	
		4899	Big Moccassin Cr.			17		68.8*	66.8	
		4900	N.F.Holston River	6.24%	89.7	102		532*	553	

#	Basin	Station	Description	$7Q_{10}/Q_{am}$ (%)	$10\%Q_{am}$	Q_{95}(cfs)*	Q_{90}(cfs)	Q_{50} (cfs)	M.B.F.(cfs)*	Q_{10} (cfs)
26	Clinch/Powell	5215	Clinch River	9.95%	19.1	27.2		124*	131	
	1810.81 mi.^{2}	5220	Little River			30		98.5*	118	
	4.40%	5230	Big Cedar Cr.			6.67		28.6*	42.9	
		5240	Clinch River	7.62%	70.9	78.4		375****	415	
		5245	Guest River	0.98%	18.3					
		5250	Stony Cr.			2		41.8*	49.1	
		5260	Copper Cr.	12.68%	14.2	24.1		75****	93.1	
		5270	Clinch River	6.29%	159.1	151		864*	911	
		5300	S.F.Powell River							
		5305	N.F.Powell River							
		5310	Powell River	2.44%	56.2					
		5315	Powell River	4.40%	54.5	38.1		256****	288	
		5315.05	Batie Cr.							
		5315.2	Wallen Cr.							
		5315.35	Dry Cr.							
		5320	Powell River (TN)	7.07%	114.7		138*****	590*****		2570*****
27	Big Sandy	2075	Levisa Fork	0.45%	28.6					
	998.81 mi.^{2}	2078	Levisa Fork		38.1			186****		
	2.43%	2080.34	Grissom Cr.							
		2080.36	Barton Fork							
		2081	Russell Fork							
		2085	Russell Fork	0.36%	33.6			132****		
		2087	N.F.Pound River	0.37%	2.96					
		2088	Pound River	3.05%	5.93					
		2089	Pound River	2.22%				39****		
		2089.50	Cranes Nest River	1.95%	8.05			94****		
		2090	Pound River	0.31%	26.5			145****		
				0.00%	29.2					
		2092	Russell Fork	1.68%						
		2092.50	Grassy Cr.							
		2135.90	Knox Cr.							

APPENDIX D: SUPPLY ESTIMATES FOR EACH VIRGINIA PLANNING AREA FROM USGS GAGE DATA MEASURED IN VIRGNIA

D.1 Upper Potomac Planning Area

ACCOTINK CREEK

USGS gage number 01655000
Gaged area (mi^2) 37
drainage basin area (mi^2) 57.12
Land area added to gage 54.38%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	12.5	0.337837838	19.30	100.00%	**12.5**
$7Q_{10}$	0.56	0.015135135	0.86	4.48%	**0.6**
$1Q_{30}$	0.01	0.00027027	0.02	0.08%	**0.0**
Q_{95}	2.6	0.07027027	4.01	20.80%	**2.6**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	20.5	0.554054054	31.65	164.00%	**20.5**
MBF_{est}	20.9	0.564864865	32.27	167.20%	**20.9**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

GOOSE CREEK

USGS gage number 01644000
Gaged area (mi^2) 332
drainage basin area (mi^2) 386.15
Land area added to gage 16.31%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	322	0.969879518	374.52	100.00%	**242.0**
$7Q_{10}$	2.5	0.00753012	2.91	0.78%	**1.9**
$1Q_{30}$	0.85	0.002560241	0.99	0.26%	**0.6**
Q_{95}	10.2	0.030722892	11.86	3.17%	**7.7**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	161	0.484939759	187.26	50.00%	**121.0**
MBF_{est}	191	0.575301205	222.15	59.32%	**143.6**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

OCCOQUAN RIVER

USGS gage number	01657500
Gaged area (mi^2)	570
drainage basin area (mi^2)	592.46
Land area added to gage	3.94%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	490	0.859649123	509.31	100.00%	**329.2**
$7Q_{10}$	8.4	0.014736842	8.73	1.71%	**5.6**
$1Q_{30}$	2	0.003508772	2.08	0.41%	**1.3**
Q_{95}	27.7	0.048596491	28.79	5.65%	**18.6**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	182	0.319298246	189.17	37.14%	**122.3**
MBF_{est}	182	0.319298246	189.17	37.14%	**122.3**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

UPPER POTOMAC*

Gaged area (mi^2)	939
Planning area (mi^2)	1625.6
Land area added to gage (mi^2)	686.6
Land area added to gage (%)	73.12%

Flow	Flow (MGD)	$\%Q_{AM}$
Q_{AM}	**922.5**	100.00%
$7Q_{10}$	**12.8**	1.39%
$1Q_{30}$	**3.2**	0.35%
Q_{95}	**45.3**	4.91%
Q_{90}	**n/a**	n/a
Q_{50}	**406.7**	44.09%
MBF_{est}	**440.7**	47.77%
Q_{10}	**n/a**	n/a

*the addition of adjusted data developed from USGS gages 01655000 on Accotink Creek, 01644000 on Goose Creek and 01657500 on the Occoquan River.

D.2 Lower Potomac Planning Area

LOWER POTOMAC*

Gaged area (mi^2)	939
planning area (mi^2)	691.08
TOTAL drainage basin area (mi^2)	2316.68
Land area added to gage (mi^2)	1377.68
Land area added to gage (%)	146.72%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	824.5	0.878061768	606.81	100.00%	**392.2**
$7Q_{10}$	11.46	0.012204473	8.43	1.39%	**5.5**
$1Q_{30}$	2.86	0.003045793	2.10	0.35%	**1.4**
Q_{95}	40.5	0.04313099	29.81	4.91%	**19.3**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	363.5	0.387113951	267.53	44.09%	**172.9**
MBF_{est}	393.9	0.419488818	289.90	47.77%	**187.4**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

*the addition of adjusted data developed from USGS gages 01655000 on Accotink Creek, 01644000 on Goose Creek and 01657500 on the Occoquan River in the Upper Potomac Planning Area and applied to the 691.08 mi^2 of Potomac tributaries in the Lower Potomac Planning Area.

D.3 Upper Shenandoah/Laurel Planning Area

UPPER SHENANDOAH

USGS gage number	01628500
Gaged area (mi^2)	1084
drainage basin area (mi^2)	1233.23
Land area added to gage	13.77%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	1048	0.966789668	1192.27	100.00%	**770.5**
$7Q_{10}$	147	0.135608856	167.24	14.03%	**108.1**
$1Q_{30}$	121	0.111623616	137.66	11.55%	**89.0**
Q_{95}	188	0.173431734	213.88	17.94%	**138.2**
Q_{90}	240	0.221402214	273.04	22.90%	**176.5**
Q_{50}	608	0.560885609	691.70	58.02%	**447.0**
MBF_{est}	710	0.65498155	807.74	67.75%	**522.0**
Q_{10}	2140	1.974169742	2434.61	204.20%	**1573.4**

D.4 Lower Shenandoah/Opequon Planning Area

OPEQUON

USGS gage number	01615000
Gaged area (mi^2)	57.4
Total upstream drainage area (mi^2)	339.41
Land area added to gage (mi^2)	282.01
Land area added to gage (%)	491.31%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	42.9	0.74738676	253.67	100.00%	**163.9**
$7Q_{10}$	1.4	0.024390244	8.28	3.26%	**5.4**
$1Q_{30}$	0.47	0.008188153	2.78	1.10%	**1.8**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	4.7	0.081881533	27.79	10.96%	**18.0**
Q_{50}	16	0.278745645	94.61	37.30%	**61.1**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	81	1.411149826	478.96	188.81%	**309.5**

LOWER SHENANDOAH

USGS gage number	01636500
Gaged area (mi^2)	3022
Total upstream drainage area (mi^2)	2937.76
Land area added to gage (mi^2)	0
Land area added to gage (%)	0.00%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	2786	0.921906023	2708.34	100.00%	**1750.3**
$7Q_{10}$	367	0.121442753	356.77	13.17%	**230.6**
$1Q_{30}$	242	0.080079418	235.25	8.69%	**152.0**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	613	0.202845797	595.91	22.00%	**385.1**
Q_{50}	1620	0.536068829	1574.84	58.15%	**1017.8**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	5630	1.863004633	5473.06	202.08%	**3537.1**

LOWER SHENANDOAH/OPEQUON*

Gaged area (mi^2)	3079.4
Drainage area considered (mi^2)	3277.17
Land area added to gage (mi^2)	197.77
Land area added to gage (%)	6.42%

Flow	flow (cfs)	$\%Q_{AM}$	flow (MGD)
Q_{AM}	2962.01	100.00%	**1914.3**
$7Q_{10}$	365.05	12.32%	**235.9**
$1Q_{30}$	238.03	8.04%	**153.8**
Q_{95}	n/a	n/a	**n/a**
Q_{90}	623.70	21.06%	**403.1**
Q_{50}	1669.45	56.36%	**1078.9**
MBF_{est}	n/a	n/a	**n/a**
Q_{10}	5952.02	200.95%	**3846.6**

*the addition of adjusted data developed from USGS gages 01636500 on the Shenandoah and 01615000 on Opequon Creek.

D.5 Upper Rappahannock Planning Area

RAPPAHANNOCK

USGS gage number	01664000
Gaged area (mi^2)	620
Drainage basin area (mi^2)	861.71
Land area added to gage	38.99%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	698	1.125806452	970.12	100.00%	**627.0**
$7Q_{10}$	11	0.017741935	15.29	1.58%	**9.9**
$1Q_{30}$	3.92	0.006322581	5.45	0.56%	**3.5**
Q_{95}	47.8	0.077096774	66.44	6.85%	**42.9**
Q_{90}	77	0.124193548	107.02	11.03%	**69.2**
Q_{50}	424	0.683870968	589.30	60.74%	**380.8**
MBF_{est}	432	0.696774194	600.42	61.89%	**388.0**
Q_{10}	1420	2.290322581	1973.59	203.44%	**1275.5**

RAPIDAN

USGS gage number	01667500
Gaged area (mi^2)	472
drainage basin area (mi^2)	695.19
Land area added to gage	47.29%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**%Q_{AM}**	**Flow (MGD)**
Q_{AM}	543	1.150423729	799.76	100.00%	**516.9**
$7Q_{10}$	19.4	0.041165254	28.62	3.58%	**18.5**
$1Q_{30}$	4.27	0.00904661	6.29	0.79%	**4.1**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	86	0.18220339	126.67	15.84%	**81.9**
Q_{50}	345	0.730932203	508.14	63.54%	**328.4**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	1080	2.288135593	1590.69	198.90%	**1028.0**

UPPER RAPPAHANNOCK*

Gaged area (mi^2)	1092
planning area (mi^2)	1556.9
Land area added to gage	42.57%

Flow	**Flow (MGD)**	**%Q_{AM}**
Q_{AM}	**1144.0**	100.00%
$7Q_{10}$	**28.4**	2.48%
$1Q_{30}$	**7.6**	0.66%
Q_{95}	**n/a**	n/a
Q_{90}	**151.0**	13.20%
Q_{50}	**709.0**	61.98%
MBF_{est}	**n/a**	n/a
Q_{10}	**2303.0**	201.31%

*the addition of adjusted data developed from USGS gages 01664000 on the Rappahannock and 01667300 on the Rapidan.

D.6 Lower Rappahannock Planning Area

LOWER RAPPAHANNOCK

USGS gage number	01668000
Gaged area (mi^2)	1596
Drainage basin considered (mi^2)	2714.03
Land area added to gage (mi^2)	1118.03
Land area added to gage (%)	70.05%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**%MAF**	**Flow (MGD)**
Q_{AM}	1697	1.063283208	2885.78	100.00%	**1865.0**
$7Q_{10}$	48	0.030075188	81.62	2.83%	**52.8**
$1Q_{30}$	14.7	0.009210526	25.00	0.87%	**16.2**
Q_{95}	150	0.093984962	255.08	8.84%	**164.8**
Q_{90}	237	0.148496241	403.02	13.97%	**260.5**
Q_{50}	1000	0.626566416	1700.52	58.93%	**1099.0**
MBF_{est}	932	0.5839599	1584.88	54.92%	**1024.3**
Q_{10}	3340	2.09273183	5679.74	196.82%	**3670.7**

D.7 Pamunkey Planning Area

PAMUNKEY

USGS gage number	01673000
Gaged area (mi^2)	1081
planning area (mi^2)	1472.76
Land area added to gage (mi^2)	391.76
Land area added to gage (%)	36.24%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**%Q_{AM}**	**Flow (MGD)**
Q_{AM}	1168	1.080481036	1591.29	100.00%	**1028.4**
$7Q_{10}$	37.5	0.034643848	51.02	3.21%	**33.0**
$1Q_{30}$	16.7	0.015420907	22.71	1.43%	**14.7**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	124	0.114708603	168.94	10.62%	**109.2**
Q_{50}	630	0.58279371	858.32	53.94%	**554.7**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	2730	2.525439408	3719.37	233.73%	**2403.7**

D.8 Mattaponi Planning Area

MATTAPONI

USGS gage number	01674500
Gaged area (mi^2)	601
planning area (mi^2)	911.4
Land area added to gage (mi^2)	310.4
Land area added to gage (%)	51.65%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	588	0.978369384	891.69	100.00%	**576.3**
$7Q_{10}$	17.43	0.029001664	26.43	2.96%	**17.1**
$1Q_{30}$	8.17	0.01359401	12.39	1.39%	**8.0**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	65	0.108153078	98.57	11.05%	**63.7**
Q_{50}	378	0.628951747	573.23	64.29%	**370.5**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	1340	2.229617304	2032.07	227.89%	**1313.3**

D.9 Upper James/Maury Planning Area

JAMES

USGS gage number	02019500
Gaged area (mi^2)	2075
drainage area (mi^2)	2138.06
Land area added to gage (mi^2)	63.06
Land area added to gage (%)	3.04%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	2707	1.304578313	2789.27	100.00%	**1802.6**
$7Q_{10}$	271	0.13060241	279.24	10.01%	**180.5**
$1Q_{30}$	225.2	0.10853012	232.04	8.32%	**150.0**
Q_{95}	355	0.171084337	365.79	13.11%	**236.4**
Q_{90}	557	0.268433735	573.93	20.58%	**370.9**
Q_{50}	1340	0.645783133	1380.72	49.50%	**892.3**
MBF_{est}	1412	0.680481928	1454.91	52.16%	**940.3**
Q_{10}	5950	2.86746988	6130.82	219.80%	**3962.2**

MAURY

USGS gage number 02024000
Gaged area (mi^2) 646
drainage area (mi^2) 837.97
Land area added to gage (mi^2) 191.97
Land area added to gage (%) 29.72%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	680	1.052631579	882.07	100.00%	**570.1**
$7Q_{10}$	62	0.095975232	80.42	9.12%	**52.0**
$1Q_{30}$	35.58	0.055077399	46.15	5.23%	**29.8**
Q_{95}	81.9	0.126780186	106.24	12.04%	**68.7**
Q_{90}	107	0.165634675	138.80	15.74%	**89.7**
Q_{50}	350	0.541795666	454.01	51.47%	**293.4**
MBF_{est}	399	0.617647059	517.57	58.68%	**334.5**
Q_{10}	1520	2.352941176	1971.69	223.53%	**1274.3**

UPPER JAMES/MAURY*

USGS gage number n/a
Gaged area (mi^2) 2721
planning area (mi^2) 2976.03
Land area added to gage (mi^2) 255.03
Land area added to gage (%) 9.37%

Flow	Flow (MGD)	%Q_{AM}
Q_{AM}	**2372.7**	100.00%
$7Q_{10}$	**232.5**	9.80%
$1Q_{30}$	**179.8**	7.58%
Q_{95}	**305.1**	12.86%
Q_{90}	**460.6**	19.41%
Q_{50}	**1185.7**	49.97%
MBF_{est}	**1274.8**	53.73%
Q_{10}	**5236.5**	220.70%

*the addition of adjusted data developed from USGS gages 02019500 on the James and 02024000 on the Maury.

D.10 Upper Middle James/Rivanna Planning Area

JAMES

USGS gage number	02029000
Gaged area (mi^2)	4584
Drainage basin considered (mi^2)	4998.69
Land area added to gage (mi^2)	414.69
Land area added to gage (%)	9.05%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	5701	1.243673647	6216.74	100.00%	**4017.7**
$7Q_{10}$	508	0.110820244	553.96	8.91%	**358.0**
$1Q_{30}$	338.5	0.073843805	369.12	5.94%	**238.6**
Q_{95}	782	0.170593368	852.74	13.72%	**551.1**
Q_{90}	1190	0.259598604	1297.65	20.87%	**838.6**
Q_{50}	3320	0.72425829	3620.34	58.24%	**2339.7**
MBF_{est}	3122	0.681064572	3404.43	54.76%	**2200.2**
Q_{10}	12300	2.683246073	13412.72	215.75%	**8668.3**

RIVANNA

USGS gage number	02034000
Gaged area (mi^2)	664
planning area (mi^2)	767.66
Land area added to gage (mi^2)	103.66
Land area added to gage (%)	15.61%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	742	1.11746988	857.84	100.00%	**554.4**
$7Q_{10}$	28.42	0.042801205	32.86	3.83%	**21.2**
$1Q_{30}$	12.12	0.018253012	14.01	1.63%	**9.1**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	112	0.168674699	129.48	15.09%	**83.7**
Q_{50}	428	0.644578313	494.82	57.68%	**319.8**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	1440	2.168674699	1664.80	194.07%	**1075.9**

UPPER MIDDLE JAMES/RIVANNA*

Gaged area within planning area (mi^2)	5248
Drainage area considered (mi^2)	5766.35
Land area added to gage (mi^2)	518.35
Land area added to gage (%)	9.88%

Flow	flow (cfs)	flow (MGD)	$\%Q_{AM}$
Q_{AM}	7074.58	**4572.1**	100.00%
$7Q_{10}$	586.81	**379.2**	8.29%
$1Q_{30}$	383.13	**247.6**	5.42%
Q_{95}	n/a	**n/a**	n/a
Q_{90}	1427.14	**922.3**	20.17%
Q_{50}	4115.16	**2659.5**	58.17%
MBF_{est}	n/a	**n/a**	n/a
Q_{10}	15077.52	**9744.2**	213.12%

*the addition of adjusted data developed from USGS gages 02029000 on the James and 02034000 on the Rivanna.

D.11 Lower Middle James Planning Area

LOWER MIDDLE JAMES

USGS gage number	02035000
Gaged area (mi^2)	6257
Drainage area considered (mi^2)	6711.58
Land area added to gage (mi^2)	454.58
Land area added to gage (%)	7.27%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	7191	1.149272814	7713.44	100.00%	**4985.0**
$7Q_{10}$	584	0.093335464	626.43	8.12%	**404.8**
$1Q_{30}$	367.8	0.058782164	394.52	5.11%	**255.0**
Q_{95}	991	0.158382611	1063.00	13.78%	**687.0**
Q_{90}	1450	0.231740451	1555.34	20.16%	**1005.2**
Q_{50}	4490	0.717596292	4816.20	62.44%	**3112.6**
MBF_{est}	4028	0.64375899	4320.64	56.01%	**2792.3**
Q_{10}	15100	2.413297107	16197.04	209.98%	**10467.7**

D.12 Appomattox Planning Area

APPOMATTOX

PETERSBURG

USGS gage number	02041500
Gaged area (mi^2)	1334
planning area (mi^2)	1598.35
Land area added to gage (mi^2)	264.35
Land area added to gage (%)	19.82%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%MAF	Flow (MGD)
$7Q_{10}$	58	0.043478261	69.49	4.16%	**44.9**
$1Q_{30}$	32.21	0.024145427	38.59	2.31%	**24.9**
Q_{95}	133.5	0.100074963	159.95	9.57%	**103.4**
MBF_{est}	614	0.460269865	735.67	44.03%	**475.4**

MATOACA

USGS gage number	02041650
Gaged area (mi^2)	1344
planning area (mi^2)	1598.35
Land area added to gage (mi^2)	254.35
Land area added to gage (%)	18.92%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%MAF	Flow (MGD)
Q_{AM}	1405	1.045386905	1670.89	100.00%	**1079.9**
Q_{90}	161	0.119791667	191.47	11.46%	**123.7**
Q_{50}	703	0.523065476	836.04	50.04%	**540.3**
Q_{10}	3500	2.604166667	4162.37	249.11%	**2690.0**

D.13 Lower James Planning Area

JAMES

USGS gage number	02037500
Gaged area (mi^2)	6758
Drainage area considered (mi^2)	6758
Land area added to gage (mi^2)	0
Land area added to gage (%)	0.00%

Flow	gage (cfs)	$\%Q_{AM}$	gage (MGD)
Q_{AM}	6946	100.00%	**4489.0**
$7Q_{10}$	623.1	8.97%	**402.7**
$1Q_{30}$	319.1	4.59%	**206.2**
Q_{95}	n/a	n/a	**n/a**
Q_{90}	950	13.68%	**614.0**
Q_{50}	4200	60.47%	**2714.3**
MBF_{est}	n/a	n/a	**n/a**
Q_{10}	15000	215.95%	**9694.1**

APPOMATTOX

PETERSBURG

USGS gage number	02041500
Gaged area (mi^2)	1334
planning area (mi^2)	1598.35
Land area added to gage (mi^2)	264.35
Land area added to gage (%)	19.82%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%MAF	Flow (MGD)
$7Q_{10}$	58	0.043478261	69.49	4.16%	**44.9**
$1Q_{30}$	32.2	0.024145427	38.59	2.31%	**24.9**
Q_{95}	134	0.100074963	159.95	9.57%	**103.4**
MBF_{est}	614	0.460269865	735.67	44.03%	**475.4**

MATOACA

USGS gage number	02041650
Gaged area (mi^2)	1344
planning area (mi^2)	1598.35
Land area added to gage (mi^2)	254.35
Land area added to gage (%)	18.92%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%MAF	Flow (MGD)
Q_{AM}	1405	1.045386905	1670.89	100.00%	**1079.9**
Q_{90}	161	0.119791667	191.47	11.46%	**123.7**
Q_{50}	703	0.523065476	836.04	50.04%	**540.3**
Q_{10}	3500	2.604166667	4162.37	249.11%	**2690.0**

CHICKAHOMINY

USGS gage number	02042500
Gaged within planning area (mi^2)	252
planning area (mi^2)	469.22
Land area added to gage (mi^2)	217.22
Land area added to gage (%)	86.20%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	263	1.043650794	489.70	100.00%	**316.5**
$7Q_{10}$	5	0.01984127	9.31	1.90%	**6.0**
$1Q_{30}$	1.93	0.00765873	3.59	0.73%	**2.3**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	22	0.087301587	40.96	8.37%	**26.5**
Q_{50}	166	0.658730159	309.09	63.12%	**199.8**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	600	2.380952381	1117.19	228.14%	**722.0**

LOWER JAMES*

Gaged area within planning area (mi^2)	8344
Drainage area considered (mi^2)	8825.57
Land area added to gage (mi^2)	481.57
Land area added to gage (%)	5.77%
Land area considered negligible (mi^2)	>1300

Flow	flow (cfs)	%MAF	flow (MGD)
Q_{AM}	9106.60	100.00%	**5885.3**
$7Q_{10}$	701.85	7.71%	**453.6**
$1Q_{30}$	361.29	3.97%	**233.5**
Q_{95}	n/a	n/a	**n/a**
Q_{90}	1182.43	12.98%	**764.2**
Q_{50}	5345.13	58.70%	**3454.4**
MBF_{est}	n/a	n/a	**n/a**
Q_{10}	20279.56	222.69%	**13106.1**

*the addition of data developed from USGS gages 02037500 on the James, 02041500 and 02041650 on the Appomattox and 02042500 on the Chickahominy.

D.14 Mainland Chesapeake Bay/Lower York Planning Area

MAINLAND CHESAPEAKE BAY/YORK

USGS gage number	01669520
Gaged area (mi^2)	108
planning area (mi^2)	1114.26
Land area added to gage (mi^2)	1006.26
Land area added to gage (%)	931.72%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%MAF	Flow (MGD)
Q_{AM}	119	1.101851852	1227.75	100.00%	**793.5**
$7Q_{10}$	0.64	0.005925926	6.60	0.54%	**4.3**
$1Q_{30}$	n/a	n/a	n/a	n/a	**n/a**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	7.4	0.068518519	76.35	6.22%	**49.3**
Q_{50}	83	0.768518519	856.33	69.75%	**553.4**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	265	2.453703704	2734.06	222.69%	**1766.9**

D.15 Eastern Shore Planning Area

SCENARIO A	**Avg Rainfall (inches)**	**41**
	recharge (as % precip)	recharge (MGD)
	2	37.48
	3	56.22
	4	74.96
	6	112.44
	8	149.91
	10	187.39
	12	224.87
	14	262.35

SCENARIO B	**Avg Rainfall (inches)**	**42**
	recharge (as % precip)	recharge (MGD)
	2	38.39
	3	57.59
	4	76.78
	6	115.18
	8	153.57
	10	191.96
	12	230.35
	14	268.75

SCENARIO C	**Avg Rainfall (inches)**	**43**
	recharge (as % precip)	recharge (MGD)
	2	39.31
	3	58.96
	4	78.61
	6	117.92
	8	157.23
	10	196.53
	12	235.84
	14	275.15

D.16 Meherrin Planning Area

MEHERRIN

USGS gage number	02052000
Gaged area (mi^2)	747
planning area (mi^2)	1115.33
Land area added to gage (mi^2)	368.33
Land area added to gage (%)	49.31%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	700	0.93708166	1045.16	100.00%	**675.5**
$7Q_{10}$	23	0.030789826	34.34	3.29%	**22.2**
$1Q_{30}$	9.23	0.012356091	13.78	1.32%	**8.9**
Q_{95}	10.23	0.013694779	15.27	1.46%	**9.9**
Q_{90}	71	0.095046854	106.01	10.14%	**68.5**
Q_{50}	360	0.481927711	537.51	51.43%	**347.4**
MBF_{est}	372	0.497991968	555.43	53.14%	**359.0**
Q_{10}	1440	1.927710843	2150.03	205.71%	**1389.5**

D.17 Nottoway Planning Area

NOTTOWAY

USGS gage number	02047000
Gaged area (mi^2)	1421
planning area (mi^2)	1722.63
Land area added to gage (mi^2)	301.63
Land area added to gage (%)	21.23%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	1360	0.957072484	1648.68	100.00%	**1065.5**
$7Q_{10}$	29.63	0.020851513	35.92	2.18%	**23.2**
$1Q_{30}$	16.03	0.011280788	19.43	1.18%	**12.6**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	102	0.071780436	123.65	7.50%	**79.9**
Q_{50}	742	0.522167488	899.50	54.56%	**581.3**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	3380	2.378606615	4097.46	248.53%	**2648.1**

D.18 Blackwater/Southeast Coastal Planning Area

BLACKWATER/SE COASTAL

USGS gage number	02049500
Gaged area (mi^2)	617
planning area (mi^2)	1413.37
Land area added to gage (mi^2)	796.37
Land area added to gage (%)	129.07%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	628	1.017828201	1438.57	100.00%	**929.7**
$7Q_{10}$	1.98	0.003209076	4.54	0.32%	**2.9**
$1Q_{30}$	0.58	0.000940032	1.33	0.09%	**0.9**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	8.2	0.013290113	18.78	1.31%	**12.1**
Q_{50}	375	0.607779579	859.02	59.71%	**555.2**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	1640	2.65802269	3756.77	261.15%	**2427.9**

D.19 Upper Roanoke Planning Area

UPPER ROANOKE

USGS gage number	02060500
Gaged area (mi^2)	1789
planning area (mi^2)	2189.9
Land area added to gage (mi^2)	400.9
Land area added to gage (%)	22.41%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	1723	0.963107881	2109.11	100.00%	**1363.1**
$7Q_{10}$	266	0.148686417	325.61	15.44%	**210.4**
$1Q_{30}$	49	0.027389603	59.98	2.84%	**38.8**
Q_{95}	50	0.027948575	61.20	2.90%	**39.6**
Q_{90}	267	0.149245388	326.83	15.50%	**211.2**
Q_{50}	1030	0.575740637	1260.81	59.78%	**814.8**
MBF_{est}	1031	0.576299609	1262.04	59.84%	**815.6**
Q_{10}	3440	1.922861934	4210.88	199.65%	**2721.4**

D.20 Lower Roanoke Planning Area

DANVILLE*

Gaged area (mi^2)	3097
Drainage area considered (mi^2)	3266.92
Land area added to gage (mi^2)	169.92
Land area added to gage (%)	5.49%
Land area considered negligible (mi^2)**	151.71

Flow	flow (cfs)	%Q_{AM}	flow (MGD)
Q_{AM}	3505.31	100.00%	**2265.4**
$7Q_{10}$	478.02	13.64%	**308.9**
$1Q_{30}$	155.87	4.45%	**100.7**
Q_{95}	n/a	n/a	**n/a**
Q_{90}	1090.78	31.12%	**704.9**
Q_{50}	2334.88	66.61%	**1509.0**
MBF_{est}	n/a	n/a	**n/a**
Q_{10}	6308.83	179.98%	**4077.2**

*the addition of adjusted data developed from USGS gages 02075500 on the Dan and 02097000 on the Banister.

**151.71 mi^2 is the land area of hydrologic units L73, which drains Aarons Creek and a small portion of the Dan, and L74, which drains about 400 mi^2 of the Hyco River in VA and NC and is not included In the land area contributing to the Dan River flow.

ROANOKE

USGS gage number	02066000
Gaged area (mi^2)	2977
Drainage area considered (mi^2)	3341.66
Land area added to gage (mi^2)	364.66
Land area added to gage (%)	12.25%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	3022	1.015115888	3392.17	100.00%	**2192.3**
$7Q_{10}$	426	0.143097078	478.18	14.10%	**309.0**
$1Q_{30}$	173.93	0.058424589	195.24	5.76%	**126.2**
Q_{95}	773	0.259657373	867.69	25.58%	**560.8**
Q_{90}	865	0.290560967	970.96	28.62%	**627.5**
Q_{50}	1810	0.607994625	2031.71	59.89%	**1313.0**
MBF_{est}	1950	0.655021834	2188.86	64.53%	**1414.6**
Q_{10}	5800	1.948270071	6510.46	191.93%	**4207.5**

LOWER ROANOKE*

Gaged area (mi^2)	6074
Drainage area considered (mi^2)	7267.83
Land area added to gage (mi^2)	1193.83
Land area added to gage (%)	19.65%
VA area considered negligible (mi^2)**	151.71
Drainage considered negligible (mi^2)**	460.73
Drainage considered negligible (%)	5.96%
TOTAL area + negligible area (mi^2)	7728.56

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**%MAF**	**Flow (MGD)**
Q_{AM}	6527	1.074630746	7810.23	100.00%	**5047.5**
$7Q_{10}$	904	0.148833768	1081.70	13.85%	**699.1**
$1Q_{30}$	330	0.054296809	394.62	5.05%	**255.0**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	1956	0.321991472	2340.18	29.96%	**1512.4**
Q_{50}	4145	0.682396621	4959.54	63.50%	**3205.2**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	12109	1.993551752	14488.80	185.51%	**9363.7**

*the addition of adjusted data developed from USGS gages 02075500 on the Dan, 02097000 on the Banister and 02066000 on the Roanoke.

**151.71 mi^2 is the Virginia land area of hydrologic units L73 (60.73 mi^2), which drains Aarons Creek and a small portion of the Dan, and L74, which drains about 400 mi^2 of the Hyco River in VA and NC (see plate 36).

D.21 Martinsville/Ararat Planning Area

DAN RIVER

USGS gage number	02068500
Gaged within planning area (mi^2)	119.8
planning area (mi^2)*	238.13
Land area added to gage (mi^2)	118.33
Land area added to gage (%)	98.77%
TOTAL gaged area (mi^2)	129
Land area added to gaged area (%)	91.73%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	198	1.534883721	365.50	100.00%	**236.2**
$7Q_{10}$	42.82	0.331937984	79.04	21.63%	**51.1**
$1Q_{30}$	27.3	0.211627907	50.39	13.79%	**32.6**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	85	0.658914729	156.91	42.93%	**101.4**
Q_{50}	158	1.224806202	291.66	79.80%	**188.5**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	321	2.488372093	592.56	162.12%	**383.0**

*Includes the ungaged Ararat headwaters (M01-M03).

SMITH RIVER

USGS gage number	02073000
Gaged within planning area (mi^2)	380
planning area (mi^2)	541.29
Land area added to gage (mi^2)	161.29
Land area added to gage (%)	42.44%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	487	1.281578947	693.71	100.00%	**448.3**
$7Q_{10}$	110	0.289473684	156.69	22.59%	**101.3**
$1Q_{30}$	18.95	0.049868421	26.99	3.89%	**17.4**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	168	0.442105263	239.31	34.50%	**154.7**
Q_{50}	364	0.957894737	518.50	74.74%	**335.1**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	916	2.410526316	1304.79	188.09%	**843.3**

NORTH MAYO RIVER

USGS gage number	02070000
Gaged within planning area (mi^2)	108
planning area (mi^2)	123
Land area added to gage (mi^2)	15
Land area added to gage (%)	13.89%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	131	1.212962963	149.19	100.00%	**96.4**
$7Q_{10}$	25	0.231481481	28.47	19.08%	**18.4**
$1Q_{30}$	17.78	0.16462963	20.25	13.57%	**13.1**
Q_{95}	40.2	0.372222222	45.78	30.69%	**29.6**
Q_{90}	52	0.481481481	59.22	39.69%	**38.3**
Q_{50}	96	0.888888889	109.33	73.28%	**70.7**
MBF_{est}	93.7	0.867592593	106.71	71.53%	**69.0**
Q_{10}	202	1.87037037	230.06	154.20%	**148.7**

SOUTH MAYO RIVER

USGS gage number	02069700
Gaged within planning area (mi^2)	84.6
planning area (mi^2)	125.98
Land area added to gage (mi^2)	41.38
Land area added to gage (%)	48.91%

Flow	**gage (cfs)**	**yield (cfs/mi^2)**	**Adjusted (cfs)**	**$\%Q_{AM}$**	**Flow (MGD)**
Q_{AM}	132	1.560283688	196.56	100.00%	**127.0**
$7Q_{10}$	27	0.319148936	40.21	20.45%	**26.0**
$1Q_{30}$	21.01	0.248345154	31.29	15.92%	**20.2**
Q_{95}	41.6	0.491725768	61.95	31.52%	**40.0**
Q_{90}	52	0.61465721	77.43	39.39%	**50.0**
Q_{50}	100	1.182033097	148.91	75.76%	**96.2**
MBF_{est}	99.2	1.172576832	147.72	75.15%	**95.5**
Q_{10}	217	2.56501182	323.14	164.39%	**208.8**

MARTINSVILLE/ARARAT*

Gaged area within planning area (mi^2)	692.4
planning area (mi^2)	1028.37
Land area added to gage (mi^2)	335.97
Land area added to gage (%)	48.52%

Flow	Flow (MGD)	$\%Q_{AM}$
Q_{AM}	**907.6**	100.00%
$7Q_{10}$	**196.7**	21.67%
$1Q_{30}$	**83.3**	9.18%
Q_{95}	**n/a**	n/a
Q_{90}	**344.4**	37.95%
Q_{50}	**690.5**	76.08%
MBF_{est}	**n/a**	n/a
Q_{10}	**1583.8**	174.50%

*the addition of adjusted data developed from USGS gages 02068500 on the Dan, 02073000 on the Smith, 02070000 on the North Mayo and 02069700 on the South Mayo.

D.22 Danville Planning Area

DAN RIVER*

USGS gage number	02075500
Gaged area (mi^2)	2550
drainage area considered (mi^2)	2669.88
Land area added to gage (mi^2)	119.88
Land area added to gage (%)	4.70%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	2810	1.101960784	2942.10	100.00%	**1901.4**
$7Q_{10}$	415	0.162745098	434.51	14.77%	**280.8**
$1Q_{30}$	137.3	0.053854902	143.79	4.89%	**92.9**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	924	0.362352941	967.44	32.88%	**625.2**
Q_{50}	1910	0.749019608	1999.79	67.97%	**1292.4**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	5030	1.97254902	5266.47	179.00%	**3403.6**

*gage data is adjusted to the downstream point of hydrologic unit L64 (see plate 36).

BANISTER RIVER

USGS gage number	02077000
Gaged within planning area (mi^2)	547
planning area (mi^2)	597.04
Land area added to gage (mi^2)	50.04
Land area added to gage (%)	9.15%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	516	0.943327239	563.20	100.00%	**364.0**
$7Q_{10}$	39.86	0.072870201	43.51	7.72%	**28.1**
$1Q_{30}$	11.07	0.02023766	12.08	2.15%	**7.8**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	113	0.206581353	123.34	21.90%	**79.7**
Q_{50}	307	0.561243144	335.08	59.50%	**216.6**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	955	1.745886654	1042.36	185.08%	**673.7**

DANVILLE*

Gaged area (mi^2)	3097
Drainage area considered (mi^2)	3266.92
Land area added to gage (mi^2)	169.92
Land area added to gage (%)	5.49%
Land area considered negligible (mi^2)**	151.71

Flow	flow (cfs)	$\%Q_{AM}$	flow (MGD)
Q_{AM}	3505.31	100.00%	**2265.4**
$7Q_{10}$	478.02	13.64%	**308.9**
$1Q_{30}$	155.87	4.45%	**100.7**
Q_{95}	n/a	n/a	**n/a**
Q_{90}	1090.78	31.12%	**704.9**
Q_{50}	2334.88	66.61%	**1509.0**
MBF_{est}	n/a	n/a	**n/a**
Q_{10}	6308.83	179.98%	**4077.2**

*the addition of adjusted data developed from USGS gages 02075500 on the Dan and 02077000 on the Banister.

**151.71 mi^2 is the Virginia land area of hydrologic units L73 (60.73 mi^2), which drains Aarons Creek and a small portion of the Dan, and L74 (90.98 mi^2), which drains about 400 mi^2 of the Hyco River in VA and NC (see plate 36).

D.23 Upper New Planning Area

UPPER NEW

USGS gage number	03168000
Gaged area (mi^2)	2202
Drainage area considered (mi^2)	2202
Land area added to gage (mi^2)	0
Land area added to gage (%)	0.00%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	3252	1.476839237	3252.00	100.00%	**2101.7**
$7Q_{10}$	725	0.32924614	725.00	22.29%	**468.5**
$1Q_{30}$	509.4	0.23133515	509.40	15.66%	**329.2**
Q_{95}	954	0.433242507	954.00	29.34%	**616.5**
Q_{90}	1110	0.504087193	1110.00	34.13%	**717.4**
Q_{50}	2440	1.10808356	2440.00	75.03%	**1576.9**
MBF_{est}	2156	0.9791099	2156.00	66.30%	**1393.4**
Q_{10}	5860	2.661217075	5860.00	180.20%	**3787.2**

D.24 Lower New Planning Area

LOWER NEW

USGS gage number	03176500
Gaged area (mi^2)	3768
Drainage area considered (mi^2)	3811.54
Land area added to gage (mi^2)	43.54
Land area added to gage (%)	1.16%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	5082	1.348726115	5140.72	100.00%	**3322.3**
$7Q_{10}$	1126	0.298832272	1139.01	22.16%	**736.1**
$1Q_{30}$	874.6	0.23211518	884.72	17.21%	**571.8**
Q_{95}	1234	0.327494692	1248.26	24.28%	**806.7**
Q_{90}	1560	0.414012739	1578.03	30.70%	**1019.8**
Q_{50}	3710	0.984607219	3752.87	73.00%	**2425.4**
MBF_{est}	3207	0.85111465	3244.06	63.11%	**2096.5**
Q_{10}	9760	2.590233546	9872.78	192.05%	**6380.5**

D.25 Holston Planning Area

NORTH FORK HOLSTON RIVER

USGS gage number	03490000
Gaged area (mi^2)	672
planning area (mi^2)	715.25
Land area added to gage (mi^2)	43.25
Land area added to gage (%)	6.44%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	897	1.334821429	954.73	100.00%	**617.0**
$7Q_{10}$	56	0.083333333	59.60	6.24%	**38.5**
$1Q_{30}$	44.5	0.066220238	47.36	4.96%	**30.6**
Q_{95}	102	0.151785714	108.56	11.37%	**70.2**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	532	0.791666667	566.24	59.31%	**365.9**
MBF_{est}	553	0.822916667	588.59	61.65%	**380.4**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

SOUTH FORK HOLSTON

USGS gage number	03473000
TOTAL gaged area (mi^2)	301
planning area (mi^2)	217.95
gage VA land area (mi^2)*	200
Land area added to gage (mi^2)	17.95
Land area added to gage (%)	5.96%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	481	1.598006645	481.00	100.00%	**310.9**
$7Q_{10}$	73	0.242524917	73.00	15.18%	**47.2**
$1Q_{30}$	59.99	0.199302326	59.99	12.47%	**38.8**
Q_{95}	95.3	0.316611296	95.30	19.81%	**61.6**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	307	1.019933555	307.00	63.83%	**198.4**
MBF_{est}	333	1.106312292	333.00	69.23%	**215.2**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

*200 mi^2 is an approximation of the portion of the gage drainage area in Virginia.

MIDDLE FORK HOLSTON RIVER

USGS gage number	03475000
Gaged area (mi^2)	211
planning area (mi^2)	241.78
Land area added to gage (mi^2)	30.78
Land area added to gage (%)	14.59%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	247	1.170616114	283.03	100.00%	**182.9**
$7Q_{10}$	50	0.236966825	57.29	20.24%	**37.0**
$1Q_{30}$	6.62	0.031374408	7.59	2.68%	**4.9**
Q_{95}	69.6	0.32985782	79.75	28.18%	**51.5**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	147	0.696682464	168.44	59.51%	**108.9**
MBF_{est}	191	0.90521327	218.86	77.33%	**141.4**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

BEAVER CREEK

USGS gage number	03478400
Gaged area (mi^2)	27.7
planning area (mi^2)	147.07
Land area added to gage (mi^2)	119.37
Land area added to gage (%)	430.94%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	34.9	1.259927798	185.30	100.00%	**119.8**
$7Q_{10}$	8.5	0.306859206	45.13	24.36%	**29.2**
$1Q_{30}$	7.26	0.262093863	38.55	20.80%	**24.9**
Q_{95}	10.4	0.375451264	55.22	29.80%	**35.7**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	27	0.974729242	143.35	77.36%	**92.6**
MBF_{est}	30.9	1.115523466	164.06	88.54%	**106.0**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

HOLSTON*

TOTAL gaged area (mi^2)	1211.7
drainage area considered (mi^2)	1423.05
Land area added to gaged area (mi^2)	211.35
Land area added to gaged area (%)	17.44%

Flow	Flow (MGD)	%MAF
Q_{AM}	**1230.5**	100.00%
$7Q_{10}$	**151.9**	12.34%
$1Q_{30}$	**99.2**	8.06%
Q_{95}	**219.0**	17.80%
Q_{90}	**n/a**	n/a
Q_{50}	**765.9**	62.24%
MBF_{est}	**843.1**	68.51%
Q_{10}	**n/a**	n/a

*the addition of adjusted data developed from USGS gages 03490000 on the North Fork Holston, 03473000 on the South Fork Holston, 03475000 on the Middle Fork Holston and 03478400 on Beaver Creek.

D.26 Clinch/Powell Planning Area

CLINCH RIVER

USGS gage number	03527000
Gaged within planning area (mi^2)	1126
planning area (mi^2)	1148.24
Land area added to gage (mi^2)	22.24
Land area added to gage (%)	1.98%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	1591	1.412966252	1622.42	100.00%	**1048.5**
$7Q_{10}$	100	0.088809947	101.98	6.29%	**65.9**
$1Q_{30}$	80.5	0.071474245	82.07	5.06%	**53.0**
Q_{95}	151	0.13410302	153.98	9.49%	**99.5**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	864	0.76731794	881.07	54.31%	**569.4**
MBF_{est}	911	0.809058615	928.99	57.26%	**600.4**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

POWELL RIVER

USGS gage number 03532000
TOTAL gaged land area (mi^2)* 685
planning area (mi^2) 662.57
Land area added to gage (mi^2) 0
Land area added to gage (%) 0.00%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	%Q_{AM}	Flow (MGD)
Q_{AM}	1142	1.667153285	1104.61	100.00%	**713.9**
$7Q_{10}$	80.77	0.117912409	78.13	7.07%	**50.5**
$1Q_{30}$	68.25	0.099635036	66.02	5.98%	**42.7**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	138	0.201459854	133.48	12.08%	**86.3**
Q_{50}	590	0.861313869	570.68	51.66%	**368.8**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	2570	3.751824818	2485.85	225.04%	**1606.5**

*USGS gage 03532000 is located just over the Virginia border in Tennessee

CLINCH/POWELL*

Gaged area within planning area (mi^2) 1788.57
planning area (mi^2) 1810.81
Land area added to gage (mi^2) 22.24
Land area added to gage (%) 1.24%

Flow	Flow (MGD)	%Q_{AM}
Q_{AM}	**1762.4**	100.00%
$7Q_{10}$	**116.4**	6.60%
$1Q_{30}$	**95.7**	5.43%
Q_{95}	**n/a**	n/a
Q_{90}	**n/a**	n/a
Q_{50}	**938.2**	53.23%
MBF_{est}	**n/a**	n/a
Q_{10}	**n/a**	n/a

*the addition of adjusted data developed from USGS gages 03527000 on the Clinch and 03532000 on the Powell.

D.27 Big Sandy Planning Area

RUSSELL FORK

USGS gage number	03209200
Gaged within planning area (mi^2)	526
planning area (mi^2)	546.69
Land area added to gage (mi^2)	20.69
Land area added to gage (%)	3.93%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	683	1.298479087	709.87	100.00%	**458.8**
$7Q_{10}$	11.5	0.021806084	11.92	1.68%	**7.7**
$1Q_{30}$	4.23	0.008032319	4.39	0.62%	**2.8**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	n/a	n/a	n/a	n/a	**n/a**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

LEVISA/TUG FORKS

USGS gage number	03207500
Gaged within planning area (mi^2)	235
planning area (mi^2)	452.11
Land area added to gage (mi^2)	217.11
Land area added to gage (%)	92.39%

Flow	gage (cfs)	yield (cfs/mi^2)	Adjusted (cfs)	$\%Q_{AM}$	Flow (MGD)
Q_{AM}	286	1.217021277	550.23	100.00%	**355.6**
$7Q_{10}$	1.3	0.005531915	2.50	0.45%	**1.6**
$1Q_{30}$	0.355	0.001510638	0.68	0.12%	**0.4**
Q_{95}	n/a	n/a	n/a	n/a	**n/a**
Q_{90}	n/a	n/a	n/a	n/a	**n/a**
Q_{50}	n/a	n/a	n/a	n/a	**n/a**
MBF_{est}	n/a	n/a	n/a	n/a	**n/a**
Q_{10}	n/a	n/a	n/a	n/a	**n/a**

BIG SANDY*

Gaged area within planning area (mi^2)	761
planning area (mi^2)	998.8
Land area added to gage (mi^2)	237.8
Land area added to gage (%)	31.25%

Flow	Flow (MGD)	$\%Q_{AM}$
Q_{AM}	**814.4**	100.00%
$7Q_{10}$	**9.3**	1.14%
$1Q_{30}$	**3.2**	0.39%
Q_{95}	**n/a**	n/a
Q_{90}	**n/a**	n/a
Q_{50}	**n/a**	n/a
MBF_{est}	**n/a**	n/a
Q_{10}	**n/a**	n/a

*the addition of adjusted data developed from USGS gages 03209200 on the Russell Fork and 03207500 on the Levisa Fork.

APPENDIX E: SUPPLY PROJECTIONS FOR EACH PLANNING AREA ACCOUNTING FOR UPSTREAM CONSUMPTION

1 up

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	922.5	922.5	922.5	922.5	922.5
$7Q_{10}$	12.8	12.8	12.8	12.8	12.8
$1Q_{30}$	3.2	3.2	3.2	3.2	3.2
Q_{95}	45.3	45.3	45.3	45.3	45.3
Q_{90}	n/a	n/a	n/a	n/a	n/a
Q_{50}	406.7	406.7	406.7	406.7	406.7
MBF_{est}	440.7	440.7	440.7	440.7	440.7
Q_{10}	n/a	n/a	n/a	n/a	n/a

2 lp

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	392.2	392.2	392.2	392.2	392.2
$7Q_{10}$	5.5	5.5	5.5	5.5	5.5
$1Q_{30}$	1.4	1.4	1.4	1.4	1.4
Q_{95}	19.3	19.3	19.3	19.3	19.3
Q_{90}	n/a	n/a	n/a	n/a	n/a
Q_{50}	172.9	172.9	172.9	172.9	172.9
MBF_{est}	187.4	187.4	187.4	187.4	187.4
Q_{10}	n/a	n/a	n/a	n/a	n/a

3 us/l

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	770.5	770.5	770.5	770.5	770.5
$7Q_{10}$	108.1	108.1	108.1	108.1	108.1
$1Q_{30}$	89.0	89.0	89.0	89.0	89.0
Q_{95}	138.2	138.2	138.2	138.2	138.2
Q_{90}	176.5	176.5	176.5	176.5	176.5
Q_{50}	447.0	447.0	447.0	447.0	447.0
MBF_{est}	522.0	522.0	522.0	522.0	522.0
Q_{10}	1573.4	1573.4	1573.4	1573.4	1573.4

	consumed (MGD)
1998	6.21
2000	6.37
2005	6.67
2015	7.21
2025	7.70

4 ls/o

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1914.3	1908.1	1907.9	1907.6	1907.1	1906.6
$7Q_{10}$	235.9	229.7	229.5	229.3	228.7	228.2
$1Q_{30}$	153.8	147.6	147.5	147.2	146.6	146.1
Q_{95}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{90}	403.1	396.9	396.7	396.4	395.9	395.4
Q_{50}	1078.9	1072.7	1072.5	1072.3	1071.7	1071.2
MBF_{est}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{10}	3846.6	3840.4	3840.3	3840.0	3839.4	3838.9

	consumed upstream
1998	6.21
2000	6.37
2005	6.67
2015	7.21
2025	7.70

5 ura

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1144	1144	1144	1144	1144
$7Q_{10}$	28.4	28.4	28.4	28.4	28.4
$1Q_{30}$	7.6	7.6	7.6	7.6	7.6
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	151	151	151	151	151
Q_{50}	709	709	709	709	709
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	2303	2303	2303	2303	2303

	consumed (MGD)
1998	2.41
2000	2.47
2005	2.59
2015	2.80
2025	2.99

6 lra

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1865.0	1,862.6	1,862.5	1,862.4	1,862.2	1,862.0
$7Q_{10}$	52.8	50.3	50.3	50.2	50.0	49.8
$1Q_{30}$	16.2	13.7	13.7	13.6	13.4	13.2
Q_{95}	164.8	162.4	162.4	162.3	162.1	161.9
Q_{90}	260.5	258.1	258.0	257.9	257.7	257.5
Q_{50}	1099.0	1,096.6	1,096.5	1,096.4	1,096.2	1,096.0
MBF_{est}	1024.3	1,021.9	1,021.8	1,021.7	1,021.5	1,021.3
Q_{10}	3670.7	3,668.2	3,668.2	3,668.1	3,667.9	3,667.7

	consumed upstream
1998	2.41
2000	2.47
2005	2.59
2015	2.80
2025	2.99

7 pa

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1028.4	1028.4	1028.4	1028.4	1028.4
$7Q_{10}$	33.0	33.0	33.0	33.0	33.0
$1Q_{30}$	14.7	14.7	14.7	14.7	14.7
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	109.2	109.2	109.2	109.2	109.2
Q_{50}	554.7	554.7	554.7	554.7	554.7
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	2403.7	2403.7	2403.7	2403.7	2403.7

8 ma

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	576.3	576.3	576.3	576.3	576.3
$7Q_{10}$	17.1	17.1	17.1	17.1	17.1
$1Q_{30}$	8.0	8.0	8.0	8.0	8.0
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	63.7	63.7	63.7	63.7	63.7
Q_{50}	370.5	370.5	370.5	370.5	370.5
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	1313.3	1313.3	1313.3	1313.3	1313.3

9 uj/m

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	2372.7	2372.7	2372.7	2372.7	2372.7
$7Q_{10}$	232.5	232.5	232.5	232.5	232.5
$1Q_{30}$	179.8	179.8	179.8	179.8	179.8
Q_{95}	305.1	305.1	305.1	305.1	305.1
Q_{90}	460.6	460.6	460.6	460.6	460.6
Q_{50}	1185.7	1185.7	1185.7	1185.7	1185.7
MBF_{est}	1274.8	1274.8	1274.8	1274.8	1274.8
Q_{10}	5236.5	5236.5	5236.5	5236.5	5236.5

	consumed (MGD)
1998	15.19
2000	15.59
2005	16.32
2015	17.64
2025	18.85

10 umj/r

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	4572.1	4,556.9	4,556.5	4,555.8	4,554.5	4,553.2
$7Q_{10}$	379.2	364.0	363.7	362.9	361.6	360.4
$1Q_{30}$	247.6	232.4	232.0	231.3	230.0	228.8
Q_{95}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{90}	922.3	907.1	906.7	906.0	904.7	903.5
Q_{50}	2659.5	2,644.3	2,643.9	2,643.2	2,641.9	2,640.7
MBF_{est}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{10}	9744.2	9,729.0	9,728.6	9,727.9	9,726.5	9,725.3

	consumed (MGD)	consumed upstream
1998	9.40	15.19
2000	9.64	15.59
2005	10.09	16.32
2015	10.91	17.64
2025	11.66	18.85

11 lmj

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	4985.0	4,960.4	4,959.8	4,958.6	4,956.4	4,954.5
$7Q_{10}$	404.8	380.2	379.6	378.4	376.3	374.3
$1Q_{30}$	255.0	230.4	229.7	228.6	226.4	224.4
Q_{95}	687.0	662.4	661.8	660.6	658.4	656.5
Q_{90}	1005.2	980.6	979.9	978.8	976.6	974.7
Q_{50}	3112.6	3,088.0	3,087.4	3,086.2	3,084.0	3,082.1
MBF_{est}	2792.3	2,767.7	2,767.1	2,765.9	2,763.8	2,761.8
Q_{10}	10467.7	10,443.1	10,442.5	10,441.3	10,439.1	10,437.2

	consumed (MGD)	consumed upstream
1998	3.82	24.59
2000	3.92	25.23
2005	4.10	26.41
2015	4.44	28.56
2025	4.75	30.52

12 app

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1079.9	1079.9	1079.9	1079.9	1079.9
$7Q_{10}$	44.9	44.9	44.9	44.9	44.9
$1Q_{30}$	24.9	24.9	24.9	24.9	24.9
Q_{95}	103.4	103.4	103.4	103.4	103.4
Q_{90}	123.7	123.7	123.7	123.7	123.7
Q_{50}	540.3	540.3	540.3	540.3	540.3
MBF_{est}	475.4	475.4	475.4	475.4	475.4
Q_{10}	2690.0	2690.0	2690.0	2690.0	2690.0

	consumed (MGD)
1998	7.17
2000	7.36
2005	7.70
2015	8.33
2025	8.90

13 lj

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	5885.3	5849.7	5848.8	5,847.1	5,844.0	5,841.1
$7Q_{10}$	453.6	418.0	417.1	415.4	412.3	409.4
$1Q_{30}$	233.5	197.9	197.0	195.3	192.2	189.3
Q_{95}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{90}	764.2	728.6	727.7	726.0	722.9	720.0
Q_{50}	3454.4	3418.8	3417.9	3,416.2	3,413.1	3,410.2
MBF_{est}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{10}	13106.1	13070.5	13069.6	13,067.9	13,064.8	13,061.9

	consumed upstream
1998	35.59
2000	36.51
2005	38.22
2015	41.33
2025	44.17

14 mb/y

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	793.5	793.5	793.5	793.5	793.5
$7Q_{10}$	4.3	4.3	4.3	4.3	4.3
$1Q_{30}$	n/a	n/a	n/a	n/a	n/a
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	49.3	49.3	49.3	49.3	49.3
Q_{50}	553.4	553.4	553.4	553.4	553.4
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	1766.9	1767.9	1768.9	1769.9	1770.9

15 es*

rain (in)	41	rain (in)	42	rain (in)	43
rchg(%rain)	rchg(MGD)	rchg(%rain)	rchg(MGD)	rchg(%rain)	rchg(MGD)
2	37.48	2	38.39	2	39.31
3	56.22	3	57.59	3	58.96
4	74.96	4	76.78	4	78.61
6	112.44	6	115.18	6	117.92
8	149.91	8	153.57	8	157.23
10	187.39	10	191.96	10	196.53
12	224.87	12	230.35	12	235.84
14	262.35	14	268.75	14	275.15

*all years are assumed to be the same, because there is no upstream consumptive effect.

16 me

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	675.5	675.5	675.5	675.5	675.5
$7Q_{10}$	22.2	22.2	22.2	22.2	22.2
$1Q_{30}$	8.9	8.9	8.9	8.9	8.9
Q_{95}	9.9	9.9	9.9	9.9	9.9
Q_{90}	68.5	68.5	68.5	68.5	68.5
Q_{50}	347.4	347.4	347.4	347.4	347.4
MBF_{est}	359.0	359.0	359.0	359.0	359.0
Q_{10}	1389.5	1389.5	1389.5	1389.5	1389.5

17 no

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1065.5	1065.5	1065.5	1065.5	1065.5
$7Q_{10}$	23.2	23.2	23.2	23.2	23.2
$1Q_{30}$	12.6	12.6	12.6	12.6	12.6
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	79.9	79.9	79.9	79.9	79.9
Q_{50}	581.3	581.3	581.3	581.3	581.3
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	2648.1	2648.1	2648.1	2648.1	2648.1

18 b/sec

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	929.7	929.7	929.7	929.7	929.7
$7Q_{10}$	2.9	2.9	2.9	2.9	2.9
$1Q_{30}$	0.9	0.9	0.9	0.9	0.9
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	12.1	12.1	12.1	12.1	12.1
Q_{50}	555.2	555.2	555.2	555.2	555.2
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	2427.9	2427.9	2427.9	2427.9	2427.9

19 uro

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1363.1	1363.1	1363.1	1363.1	1363.1
$7Q_{10}$	210.4	210.4	210.4	210.4	210.4
$1Q_{30}$	38.8	38.8	38.8	38.8	38.8
Q_{95}	39.6	39.6	39.6	39.6	39.6
Q_{90}	211.2	211.2	211.2	211.2	211.2
Q_{50}	814.8	814.8	814.8	814.8	814.8
MBF_{est}	815.6	815.6	815.6	815.6	815.6
Q_{10}	2721.4	2721.4	2721.4	2721.4	2721.4

	consumed (MGD)
1998	12.79
2000	13.12
2005	13.74
2015	14.86
2025	15.88

20 lro

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	5047.5	4976.9	4974.8	4970.9	4965.0	4959.9
$7Q_{10}$	699.1	628.5	626.4	622.5	616.6	611.5
$1Q_{30}$	255.0	184.4	182.3	178.4	172.5	167.4
Q_{95}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{90}	1512.4	1441.8	1439.7	1435.8	1429.9	1424.8
Q_{50}	3205.2	3134.6	3132.5	3128.6	3122.7	3117.6
MBF_{est}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{10}	9363.7	9293.1	9291.0	9287.1	9281.2	9276.1

	consumed upstream
1998	70.63
2000	72.70
2005	76.64
2015	82.52
2025	87.57

21 m/a

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	907.6	907.6	907.6	907.6	907.6
$7Q_{10}$	196.7	196.7	196.7	196.7	196.7
$1Q_{30}$	83.3	83.3	83.3	83.3	83.3
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	344.4	344.4	344.4	344.4	344.4
Q_{50}	690.5	690.5	690.5	690.5	690.5
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	1583.8	1583.8	1583.8	1583.8	1583.8

	consumed (MGD)
1998	5.55
2000	5.70
2005	5.96
2015	6.45
2025	6.89

22a ud(nc)

	consumed (MGD)
1998	10.21
2000	10.53
2005	11.14
2015	11.97
2025	12.65

22b ld(nc)

	consumed (MGD)
1998	37.71
2000	38.87
2005	41.12
2015	44.19
2025	46.73

22 d

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	2265.4	2211.9	2210.3	2207.2	2202.8	2199.1
$7Q_{10}$	308.9	255.5	253.8	250.7	246.3	242.6
$1Q_{30}$	100.7	47.3	45.6	42.5	38.1	34.5
Q_{95}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{90}	704.9	651.5	649.8	646.7	642.3	638.7
Q_{50}	1509.0	1455.5	1453.9	1450.7	1446.4	1442.7
MBF_{est}	n/a	n/a	n/a	n/a	n/a	n/a
Q_{10}	4077.2	4023.7	4022.1	4019.0	4014.6	4010.9

	consumed (MGD)	consumed upstream
1998	4.36	53.48
2000	4.48	55.10
2005	4.68	58.22
2015	5.06	62.60
2025	5.41	66.28

23a un(nc)

	consumed (MGD)
1998	7.41
2000	7.65
2005	8.07
2015	8.67
2025	9.17

23 un

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	2101.7	2094.3	2094.0	2093.6	2093.0	2092.5
$7Q_{10}$	468.5	461.1	460.9	460.5	459.9	459.4
$1Q_{30}$	329.2	321.8	321.6	321.1	320.5	320.0
Q_{95}	616.5	609.1	608.9	608.5	607.9	607.4
Q_{90}	717.4	709.9	709.7	709.3	708.7	708.2
Q_{50}	1576.9	1569.5	1569.3	1568.8	1568.2	1567.7
MBF_{est}	1393.4	1386.0	1385.7	1385.3	1384.7	1384.2
Q_{10}	3787.2	3779.7	3779.5	3779.1	3778.5	3778.0

	consumed (MGD)	consumed upstream
1998	2.02	7.41
2000	2.08	7.65
2005	2.17	8.07
2015	2.35	8.67
2025	2.51	9.17

24 ln

Flow	flow (MGD)	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	3322.3	3312.9	3312.6	3312.1	3311.3	3310.6
$7Q_{10}$	736.1	726.7	726.4	725.9	725.1	724.4
$1Q_{30}$	571.8	562.3	562.0	561.5	560.7	560.1
Q_{95}	806.7	797.3	797.0	796.5	795.7	795.0
Q_{90}	1019.8	1010.4	1010.1	1009.6	1008.8	1008.1
Q_{50}	2425.4	2415.9	2415.7	2415.1	2414.4	2413.7
MBF_{est}	2096.5	2087.1	2086.8	2086.3	2085.5	2084.9
Q_{10}	6380.5	6371.1	6370.8	6370.3	6369.5	6368.8

	consumed upstream
1998	9.44
2000	9.72
2005	10.25
2015	11.02
2025	11.68

25 ho

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1230.5	1230.5	1230.5	1230.5	1230.5
$7Q_{10}$	151.9	151.9	151.9	151.9	151.9
$1Q_{30}$	99.2	99.2	99.2	99.2	99.2
Q_{95}	219.0	219.0	219.0	219.0	219.0
Q_{90}	n/a	n/a	n/a	n/a	n/a
Q_{50}	765.9	765.9	765.9	765.9	765.9
MBF_{est}	843.1	843.1	843.1	843.1	843.1
Q_{10}	n/a	n/a	n/a	n/a	n/a

26 c/p

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	1762.4	1762.4	1762.4	1762.4	1762.4
$7Q_{10}$	116.4	116.4	116.4	116.4	116.4
$1Q_{30}$	95.7	95.7	95.7	95.7	95.7
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	n/a	n/a	n/a	n/a	n/a
Q_{50}	938.2	939.2	940.2	941.2	942.2
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	n/a	n/a	n/a	n/a	n/a

27 bs

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{AM}	814.4	814.4	814.4	814.4	814.4
$7Q_{10}$	9.3	9.3	9.3	9.3	9.3
$1Q_{30}$	3.2	3.2	3.2	3.2	3.2
Q_{95}	n/a	n/a	n/a	n/a	n/a
Q_{90}	n/a	n/a	n/a	n/a	n/a
Q_{50}	n/a	n/a	n/a	n/a	n/a
MBF_{est}	n/a	n/a	n/a	n/a	n/a
Q_{10}	n/a	n/a	n/a	n/a	n/a

APPENDIX F: COUNTY POPULATION DENSITIES FROM U.S. CENSUS BUREAU 1998 COUNTY POPULATION ESTIMATES

	1998 population	Area (acre)	Area(mi.^{2})	pop.dens./acre	pop.dens./mi.^{2}
LENOWISCO	**89,174**	**888,717**	**1388.62**	**0.10034**	**64.22**
Norton City	4,155	4,905	7.66	0.84709	542.14
Lee County	23,815	280,034	437.55	0.08504	54.43
Wise County	38,599	259,215	405.02	0.14891	95.30
Scott County	22,605	344,563	538.38	0.06560	41.99
Cumberland Plateau	**121,638**	**1,173,054**	**1832.90**	**0.10369**	**66.36**
Buchanan County	28,929	322,250	503.52	0.08977	57.45
Dickenson County	16,894	213,366	333.38	0.07918	50.67
Russell County	29,049	304,904	476.41	0.09527	60.97
Tazewell County	46,766	332,534	519.58	0.14064	90.01
Mount Rogers	**183,282**	**1,781,936**	**2784.28**	**0.10286**	**65.83**
Bristol City	17,486	7,307	11.42	2.39305	1,531.55
Galax City	6,864	5,183	8.10	1.32433	847.57
Bland County	6,748	229,304	358.29	0.02943	18.83
Carroll County	27,873	305,416	477.21	0.09126	58.41
Grayson County	16,118	285,227	445.67	0.05651	36.17
Smyth County	32,757	289,236	451.93	0.11325	72.48
Washington County	49,168	363,032	567.24	0.13544	86.68
Wythe County	26,268	297,231	464.42	0.08838	56.56
New River Valley	**155,484**	**941,392**	**1470.93**	**0.16516**	**105.70**
Radford City	15,734	6,450	10.08	2.43938	1,561.20
Floyd County	13,091	244,012	381.27	0.05365	34.34
Giles County	16,242	231,242	361.32	0.07024	44.95
Montgomery County	75,878	248,607	388.45	0.30521	195.34
Pulaski County	34,539	211,081	329.81	0.16363	104.72
Fifth	**256,055**	**1,047,495**	**1636.71**	**0.24445**	**156.44**
Cilfton Forge City	4,342	1,953	3.05	2.22325	1,422.88
Covington City	6,857	2,827	4.42	2.42554	1,552.35
Roanoke City	93,749	27,142	42.41	3.45402	2,210.57
Salem City	24,679	9,201	14.38	2.68221	1,716.61
Alleghany County	12,146	285,254	445.71	0.04258	27.25
Botecourt County	28,561	349,144	545.54	0.08180	52.35
Craig County	4,882	210,996	329.68	0.02314	14.81
Roanoke County	80,839	160,978	251.53	0.50217	321.39
Central Shenandoah	**240,925**	**2,200,092**	**3437.64**	**0.10951**	**70.08**
Buena Vista City	6,288	4,163	6.50	1.51045	966.69
Harrisonburg City	33,434	11,158	17.43	2.99642	1,917.71
Lexington City	7,360	1,600	2.50	4.60000	2,944.00
Staunton City	23,346	12,324	19.26	1.89435	1,212.39
Waynesboro City	18,561	8,980	14.03	2.06693	1,322.83
Augusta County	61,775	622,595	972.80	0.09922	63.50
Bath County	4,891	342,833	535.68	0.01427	9.13
Highland County	2,499	266,069	415.73	0.00939	6.01
Rockbridge County	19,557	384,062	600.10	0.05092	32.59
Rockingham County	63,214	546,308	853.61	0.11571	74.06

	1998 population	Area (acre)	Area(mi.^{2})	pop.dens./acre	pop.dens./mi.^{2}
Lord Fairfax	**178,445**	**1,053,777**	**1,646.53**	**0.16934**	**108.38**
Winchester City	22,659	5,970	9.33	3.79548	2429.11
Clarke County	12,779	114,167	178.39	0.11193	71.64
Frederick County	55,229	266,031	415.67	0.20760	132.87
Page County	22,989	200,486	313.26	0.11467	73.39
Shenandoah County	34,663	327,514	511.74	0.10584	67.74
Warren County	30,126	139,609	218.14	0.21579	138.10
Northern Virginia	**1,703,367**	**857,401**	**1,339.69**	**1.98666**	**1271.46**
Alexandria City	118,300	9,816	15.34	12.05175	7713.12
Fairfax City	20,697	4,081	6.38	5.07155	3245.79
Falls Church City	10,042	1,260	1.97	7.96984	5100.70
Manassass City	35,336	6,516	10.18	5.42296	3470.69
Manassass Park City	8,711	1,126	1.76	7.73623	4951.19
Arlington City	177,275	16,685	26.07	10.62481	6799.88
Farifax County	929,239	260,128	406.45	3.57224	2286.23
Loudoun County	143,940	333,949	521.80	0.43102	275.86
Prince William County	259,827	223,840	349.75	1.16077	742.89
Rappahannock-Rapidan	**132,566**	**1,259,164**	**1,967.44**	**0.10528**	**67.38**
Culpeper County	33,083	245,205	383.13	0.13492	86.35
Fauquier County	54,109	417,065	651.66	0.12974	83.03
Madison County	12,697	206,099	322.03	0.06161	39.43
Orange County	25,408	219,859	343.53	0.11556	73.96
Rappahannock County	7,269	170,936	267.09	0.04252	27.22
Thomas Jefferson	**187,782**	**1,388,913**	**2,170.18**	**0.13520**	**86.53**
Charlottesville City	38,223	6,716	10.49	5.69133	3642.45
Albemarle County	78,401	464,676	726.06	0.16872	107.98
Fluvanna County	18,575	185,901	290.47	0.09992	63.95
Greene County	13,991	100,362	156.82	0.13941	89.22
Louisa County	24,675	327,782	512.16	0.07528	48.18
Nelson County	13,917	303,476	474.18	0.04586	29.35
Central Virginia	**221,173**	**1,373,525**	**2,146.13**	**0.16103**	**103.06**
Bedford City	6,317	4,328	6.76	1.45957	934.12
Lynchburg City	65,473	31,478	49.18	2.07996	1331.17
Amherst County	30,042	306,518	478.93	0.09801	62.73
Appomattox County	13,134	215,035	335.99	0.06108	39.09
Bedford County	55,872	492,356	769.31	0.11348	72.63
Campbell County	50,335	323,810	505.95	0.15545	99.49
West Piedmont	**242,346**	**1,672,567**	**2,613.39**	**0.14489**	**92.73**
Danville City	50,868	28,052	43.83	1.81335	1160.54
Martinsville City	15,668	6,986	10.92	2.24277	1435.37
Franklin County	44,358	455,186	711.23	0.09745	62.37
Henry County	55,627	245,577	383.71	0.22652	144.97
Patrick County	18,441	311,041	486.00	0.05929	37.94
Pittsylvania County	57,384	625,725	977.70	0.09171	58.69
Southside	**84,626**	**1,330,793**	**2,079.36**	**0.06359**	**40.70**
Brunswick County	16,716	364,762	569.94	0.04583	29.33
Halifax County	36,863	531,045	829.76	0.06942	44.43
Mecklenburg County	31,047	434,986	679.67	0.07137	45.68

	1998 population	Area (acre)	Area(mi.^{2})	pop.dens./acre	pop.dens./mi.^{2}
Piedmont	**91,186**	**1,807,317**	**2823.93**	**0.05045**	**32.29**
Amelia County	10,367	229,393	358.43	0.04519	28.92
Buckingham County	14,639	373,702	583.91	0.03917	25.07
Charlotte County	12,259	305,622	477.53	0.04011	25.67
Cumberland County	7,851	192,418	300.65	0.04080	26.11
Lunenburg County	12,043	276,983	432.79	0.04348	27.83
Nottoway County	14,999	202,716	316.74	0.07399	47.35
Prince Edward County	19,028	226,483	353.88	0.08402	53.77
Richmond Regional	**828,032**	**1,406,743**	**2198.04**	**0.58862**	**376.71**
Richmond City	194,173	40,017	62.53	4.85226	3,105.45
Charles City County	7,092	131,010	204.70	0.05413	34.65
Chesterfield County	245,915	281,071	439.17	0.87492	559.95
Goochland County	17,823	183,372	286.52	0.09720	62.21
Hanover County	81,975	303,309	473.92	0.27027	172.97
Henrico County	246,052	155,612	243.14	1.58119	1,011.96
New Kent County	13,052	143,056	223.53	0.09124	58.39
Powhatan County	21,950	169,296	264.53	0.12965	82.98
RADCO	**231,722**	**914,433**	**1428.80**	**0.25341**	**162.18**
Fredericksburg City	21,686	6,724	10.51	3.22516	2,064.10
Caroline County	22,053	345,469	539.80	0.06383	40.85
King George County	17,236	119,783	187.16	0.14389	92.09
Spotsylvania County	83,692	263,503	411.72	0.31761	203.27
Stafford County	87,055	178,954	279.62	0.48647	311.34
Northern Neck	**47,833**	**561,645**	**877.57**	**0.08517**	**54.51**
Lancaster County	11,373	121,023	189.10	0.09397	60.14
Northumberland County	11,513	140,267	219.17	0.08208	52.53
Richmond County	8,665	138,399	216.25	0.06261	40.07
Westmoreland County	16,282	161,956	253.06	0.10053	64.34
Middle Peninsula	**82,208**	**957,196**	**1495.62**	**0.08588**	**54.97**
Essex County	9,127	183,051	286.02	0.04986	31.91
Gloucester County	35,081	184,317	288.00	0.19033	121.81
King and Queen County	6,529	208,920	326.44	0.03125	20.00
King William County	12,768	182,729	285.51	0.06987	44.72
Mathews County	9,073	80,104	125.16	0.11327	72.49
Middlesex County	9,630	118,075	184.49	0.08156	52.20
Crater	**162,151**	**1,240,275**	**1937.93**	**0.13074**	**83.67**
Colonial Heights City	16,955	4,975	7.77	3.40804	2,181.15
Emporia City	5,474	4,402	6.88	1.24353	795.86
Hopewell City	22,529	6,937	10.84	3.24766	2,078.50
Petersburg City	34,724	14,765	23.07	2.35178	1,505.14
Dinwiddie County	24,657	324,861	507.60	0.07590	48.58
Greensville County	11,281	189,982	296.85	0.05938	38.00
Prince George County	30,135	180,217	281.59	0.16722	107.02
Surry County	6,471	198,396	309.99	0.03262	20.87
Sussex County	9,925	315,740	493.34	0.03143	20.12
Accomack-Northampton	**44,954**	**706,904**	**1104.54**	**0.06359**	**40.70**
Accomack County	32,245	478,390	747.48	0.06740	43.14
Northampton County	12,709	228,514	357.05	0.05562	35.59

	1998 population	Area (acre)	Area(mi.^{2})	pop.dens./acre	pop.dens./mi.^{2}
Hampton Roads	**1,506,216**	**1,728,673**	**2701.05**	**0.87131**	**557.64**
Chesapeake City	199,564	224,590	350.92	0.88857	568.68
Franklin City	8,685	4,945	7.73	1.75632	1,124.04
Hampton City	136,968	38,215	59.71	3.58414	2,293.85
Newport News City	178,615	76,606	119.70	2.33161	1,492.23
Norfolk City	215,215	42,227	65.98	5.09662	3,261.84
Poquoson City	11,455	15,545	24.29	0.73689	471.61
Portsmouth City	98,936	29,485	46.07	3.35547	2,147.50
Suffolk City	62,703	274,722	429.25	0.22824	146.07
Virginia Beach City	432,380	196,311	306.74	2.20253	1,409.62
Williamsburg City	11,971	5,738	8.97	2.08627	1,335.21
Isle of Wight County	29,252	231,976	362.46	0.12610	80.70
James City County	44,233	114,889	179.51	0.38501	246.40
Southampton County	17,450	385,695	602.65	0.04524	28.96
York County	58,789	87,729	137.08	0.67012	428.88
VIRGINIA	6,791,165	26,292,012	41,081.27	0.25830	165.31

APPENDIX G: 1998 PLANNING AREA POPULATION ESTIMATES FROM 1998 COUNTY POPULATION DENSITIES

G.1 Population per Planning Area

Planning Area	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
Upper Potomac	**1,040,803.30**	**1,626.26**	1.61107	1031.0824	**1,676,803**	**1,676,803**
Lower Potomac	**442,296.40**	**691.09**	0.33243	212.75611	**147,033**	**147,033**
Up Shen/Laurel	**789,192.60**	**1,233.11**	0.18521	118.5337	**146,166**	**146,166**
L Shen/Opequon	**1,377,756.90**	**2,152.75**	0.15798	101.10627	**217,656**	**217,656**
U. Rappahannock	**997,139.10**	**1,558.03**	0.10786	69.027824	**107,547**	**107,547**
L. Rappahannock	**740,504.10**	**1,157.04**	0.1412	90.368832	**104,560**	**104,560**
Pamunkey	**943,078.90**	**1,473.56**	0.15049	96.315791	**141,927**	**141,927**
Mattaponi	**583,419.80**	**911.59**	0.11534	73.818367	**67,292**	**67,292**
U James/Maury	**1,903,680.70**	**2,974.50**	0.08966	57.382584	**170,685**	**170,685**
UMJames/Rivanna	**1,786,253.10**	**2,791.02**	0.15623	99.984017	**279,057**	**279,057**
LMJames	**605,540.10**	**946.16**	0.28483	182.29061	**172,475**	**172,475**
Appomattox	**1,023,422.20**	**1,599.10**	0.26431	169.15559	**270,496**	**270,496**
Lower James	**1,222,622.50**	**1,910.35**	0.87369	559.15862	**1,068,187**	**1,068,187**
Mainland Ches/York	**712,863.90**	**1,113.85**	0.58139	372.0894	**414,452**	**414,452**
Eastern Shore	**706,904.70**	**1,104.54**	0.06359	40.69939	**44,954**	**44,954**
Meherrin	**714,383.00**	**1,116.22**	0.05683	36.368265	**40,595**	**40,595**
Nottoway	**1,103,153.30**	**1,723.68**	0.05738	36.720935	**63,295**	**63,295**
Blackwater/SE Coastal	**904,665.50**	**1,413.54**	0.58119	371.9602	**525,780**	**525,780**
U. Roanoke	**1,401,664.00**	**2,190.10**	0.25044	160.27937	**351,028**	**351,028**
L. Roanoke	**1,159,371.20**	**1,811.52**	0.07696	49.251322	**89,220**	**89,220**
Martinsville/Ararat	**657,838.50**	**1,027.87**	0.14605	93.470615	**96,076**	**96,076**
Danville	**871,049.20**	**1,361.01**	0.13941	89.224398	**121,436**	**121,436**
Upper New	**931,979.90**	**1,456.22**	0.0866	55.427014	**80,714**	**80,714**
Lower New	**1,029,754.60**	**1,608.99**	0.12287	78.634225	**126,522**	**126,522**
Holston	**845,579.90**	**1,321.22**	0.13378	85.619495	**113,122**	**113,122**
Clinch/Powell	**1,158,550.00**	**1,810.23**	0.10502	67.215756	**121,676**	**121,676**
Big Sandy	**638,907.80**	**998.29**	0.09576	61.286307	**61,182**	**61,182**
STATE TOTAL	**26,292,375.20**	**41,081.84**	0.25939	166.00857	**6,819,937**	**6,819,937**

G.2 Municipal contribution to each planning area

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
1 Upper Potomac	Fairfax County						
	Falls Church City	260,127.8	406.45	3.572238	2286.232	929,238	929,238
	Arlington County	1,260.2	1.97	7.969841	5100.698	10,044	10,044
	Fairfax City	16,685.3	26.07	10.62481	6799.88	177,278	177,278
	Alexandria City	4,081.5	6.38	5.071551	3245.793	20,700	20,700
	Fauquier County	9,815.8	15.34	12.05175	7713.121	118,298	118,298
	Loudoun County	232,234.3	362.87	0.129738	83.03205	30,130	30,130
	Prince William County	333,948.9	521.80	0.431024	275.8553	143,940	143,940
	Manassas City	6,516.2	10.18	5.422959	3470.694	35,337	35,337
	Manassas Park City	1,125.9	1.76	7.736234	4951.19	8,710	8,710
	Stafford County	21.4	0.03	0.486466	311.3381	10	10
Upper Potomac TOTAL		**1,040,803.3**	**1,626.26**	1.611066	1031.082	**1,676,803**	**1,676,803**
2 Lower Potomac	Prince William County	48,854.3	76.33	1.160771	742.8935	56,709	56,709
	Stafford County	126,394.8	197.49	0.486466	311.3381	61,487	61,487
	Westmoreland County	119,576.5	186.84	0.100533	64.34143	12,021	12,021
	Fauquier County	2,661.4	4.16	0.129738	83.03205	345	345
	King George County	74,186.8	115.92	0.143894	92.09187	10,675	10,675
	Northumberland County	70,593.9	110.30	0.082079	52.53067	5,794	5,794
	Richmond County	28.7	0.04	0.062609	40.06965	2	2
Lower Potomac TOTAL		**442,296.4**	**691.09**	0.332431	212.7561	**147,033**	**147,033**
3 Up Shen/Laurel	Staunton City	12,323.9	19.26	1.894352	1212.386	23,346	23,346
	Waynesboro City	8,979.6	14.03	2.066927	1322.833	18,560	18,560
	Harrisonburg City	10,560.4	16.50	2.996415	1917.706	31,643	31,643
	Augusta County	465,344.2	727.10	0.099222	63.50196	46,172	46,172
	Rockingham County	222,928.0	348.33	0.115711	74.05522	25,795	25,795
	Highland County	69,056.5	107.90	0.009392	6.011072	649	649
Up Shen/Laurel TOTAL		**789,192.6**	**1,233.11**	0.185209	118.5337	**146,166**	**146,166**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
4 Low Shen/Opequon							
	Shenandoah County	327,514.8	511.74	0.105837	67.73549	34,663	34,663
	Page County	200,486.0	313.26	0.114666	73.38647	22,989	22,989
	Rockingam County	323,380.7	505.28	0.115711	74.05522	37,419	37,419
	Harrisonburg City	597.3	0.93	2.996415	1917.706	1,790	1,790
	Warren County	139,609.5	218.14	0.215788	138.1046	30,126	30,126
	Frederick County	266,031.0	415.7	0.20760	132.8674	55,229	55,229
	Clarke County	114,167.0	178.38	0.111933	71.63681	12,779	12,779
	Winchester City	5,970.6	9.33	3.795477	2429.106	22,661	22,661
L Shen/Opequon TOTAL		**1,377,756.9**	**2,152.75**	0.157979	101.1063	**217,656**	**217,656**
5 Upper Rappahannock	Albemarle County	2,919.9	4.56	0.168722	107.982	493	493
	Culpeper County	245,205.1	383.13	0.13492	86.34865	33,083	33,083
	Fauquier County	182,169.4	284.64	0.129738	83.03205	23,634	23,634
	Greene County	40,808.3	63.76	0.139405	89.21943	5,689	5,689
	Madison County	206,098.9	322.03	0.061606	39.42804	12,697	12,697
	Orange County	122,733.5	191.77	0.115565	73.96158	14,184	14,184
	Rappahannock County	170,935.6	267.09	0.042525	27.2158	7,269	7,269
	Spotsylvania County	13,501.2	21.10	0.317613	203.2724	4,288	4,288
	Stafford County	12,767.2	19.95	0.486466	311.3381	6,211	6,211
Upper Rapp TOTAL		**997,139.1**	**1,558.03**	0.107856	69.02782	**107,547**	**107,547**
6 Lower Rappahannock	Stafford County	39,770.5	62.14	0.486466	311.3381	19,347	19,347
	Fredericksburg City	6,724.4	10.51	3.225164	2064.105	21,687	21,687
	Spotsylvania County	47,108.5	73.61	0.317613	203.2724	14,962	14,962
	Westmoreland County	42,379.7	66.22	0.100533	64.34143	4,261	4,261
	Richmond County	138,349.3	216.17	0.062609	40.06965	8,662	8,662
	Northumberland County	1,163.2	1.82	0.082079	52.53067	95	95
	Middlesex County	73,392.6	114.68	0.081558	52.19733	5,986	5,986
	Lancaster County	106,483.5	166.38	0.093974	60.14328	10,007	10,007
	King George County	45,595.9	71.24	0.143894	92.09187	6,561	6,561
	Essex County	164,481.8	257.00	0.04986	31.91067	8,201	8,201
	Caroline County	75,054.7	117.27	0.063835	40.85437	4,791	4,791
Lower Rapp TOTAL		**740,504.1**	**1,157.04**	0.141201	90.36883	**104,560**	**104,560**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
7 Pamunkey	Caroline County	34,624.6	54.10	0.063835	40.85437	2,210	2,210
	Hanover County	255,929.3	399.89	0.270269	172.9721	69,170	69,170
	King William County	109,376.2	170.90	0.069874	44.71934	7,643	7,643
	Louisa County	315,737.9	493.34	0.075279	48.17836	23,768	23,768
	New Kent County	55,876.9	87.31	0.091237	58.39168	5,098	5,098
	Orange County	89,301.2	139.53	0.115565	73.96158	10,320	10,320
	Albemarle County	6,444.0	10.07	0.168722	107.982	1,087	1,087
	Fluvanna County	421.5	0.66	0.099919	63.94802	42	42
	Goochland County	6,119.5	9.56	0.097196	62.20535	595	595
	Spotsylvania County	69,247.8	108.20	0.317613	203.2724	21,994	21,994
Pamunkey TOTAL		**943,078.9**	**1,473.6**	0.150493	96.31579	**141,927**	**141,927**
8 Mattaponi	Caroline County	235,789.3	368.42	0.063835	40.85437	15,052	15,052
	King and Queen County	137,317.6	214.56	0.031251	20.00077	4,291	4,291
	King William County	73,352.7	114.61	0.069874	44.71934	5,125	5,125
	Essex County	102.4	0.16	0.04986	31.91067	5	5
	Orange County	3,212.0	5.02	0.115565	73.96158	371	371
	Spotsylvania County	133,645.8	208.82	0.317613	203.2724	42,448	42,448
Mattaponi TOTAL		**583,419.8**	**911.6**	0.115341	73.81837	**67,292**	**67,292**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
9 Upper James/Maury	Clifton Forge City	1,953.0	3.05	2.223246	1422.878	4,342	4,342
	Covington City	2,827.0	4.42	2.425539	1552.345	6,857	6,857
	Alleghany County	285,254.4	445.71	0.04258	27.25094	12,146	12,146
	Bath County	342,832.7	535.68	0.014266	9.13051	4,891	4,891
	Botetourt County	305,125.3	476.75	0.081803	52.35387	24,960	24,960
	Craig County	182,455.8	285.09	0.023138	14.80824	4,222	4,222
	Giles County	8,144.5	12.73	0.070238	44.95239	572	572
	Highland County	197,012.8	307.83	0.009392	6.011072	1,850	1,850
	Montgomery County	14,302.8	22.35	0.305213	195.3361	4,365	4,365
	Roanoke County	16,697.2	26.09	3.45402	2210.573	57,672	57,672
	Rockbridge County	384,061.7	600.10	0.050921	32.58974	19,557	19,557
	Augusta County	157,250.7	245.70	0.099222	63.50196	15,603	15,603
	Buena Vista City	4,163.1	6.50	1.510449	966.6875	6,288	6,288
	Lexington City	1,599.7	2.50	4.6	2944	7,359	7,359
	Nelson County	52.7	0.08	0.045859	29.34954	2	2
U James/Maury TOTAL		**1,903,733.4**	**2,974.58**	0.08966	57.38258	**170,685**	**170,685**
10 U Mid James/Rivanna	Amherst County	306,518.1	478.93	0.098011	62.72676	30,042	30,042
	Albemarle County	455,312.5	711.43	0.168722	107.982	76,821	76,821
	Appomattox County	88,529.7	138.33	0.061078	39.09019	5,407	5,407
	Bedford County	68,461.8	106.97	0.113479	72.62647	7,769	7,769
	Buckingham County	252,816.7	395.03	0.039173	25.07067	9,904	9,904
	Campbell County	43,616.6	68.15	0.155446	99.4855	6,780	6,780
	Cumberland County	6,660.1	10.41	0.040802	26.11315	272	272
	Fluvanna County	152,473.8	233.55	0.099919	63.94802	14,935	14,935
	Lynchburg City	31,478.5	49.19	2.079961	1331.175	65,474	65,474
	Nelson County	303,423.8	474.10	0.045859	29.34954	13,915	13,915
	Charlottesville City	6,715.5	10.49	5.691334	3642.454	38,220	38,220
	Greene County	59,553.8	93.05	0.139405	89.21943	8,302	8,302
	Louisa County	9,080.2	14.19	0.075279	48.17836	684	684
	Orange County	4,612.0	7.21	0.115565	73.96158	533	533
UMJames/Riv TOTAL		**1,786,253.1**	**2,791.02**	0.156225	99.98402	**279,057**	**279,057**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
11 Lower Middle James	Louisa County	2,963.9	4.63	0.075279	48.17836	223	223
	Powhatan County	119,016.6	185.96	0.129655	82.97892	15,431	15,431
	Henrico County	23,979.3	37.47	1.581189	1011.961	37,916	37,916
	Richmond City	15,832.4	24.74	4.852263	3105.448	76,823	76,823
	Goochland County	177,252.6	276.96	0.097196	62.20535	17,228	17,228
	Fluvanna County	36,005.2	56.26	0.099919	63.94802	3,598	3,598
	Cumberland County	117,276.1	183.24	0.040802	26.11315	4,785	4,785
	Chesterfield County	14,131.9	22.08	0.874921	559.9496	12,364	12,364
	Buckingham County	98,104.3	153.29	0.039173	25.07067	3,843	3,843
	Hanover County	977.8	1.53	0.270269	172.9721	264	264
LMJames TOTAL		**605,540.1**	**946.16**	0.284829	182.2906	**172,475**	**172,475**
12 Appomattox	Buckingham County	22,780.9	35.60	0.039173	25.07067	892	892
	Appomattox County	63,736.6	99.59	0.061078	39.09019	3,893	3,893
	Amelia County	229,393.3	358.43	0.045193	28.92364	10,367	10,367
	Cumberland County	68,481.8	107.00	0.040802	26.11315	2,794	2,794
	Chesterfield County	191,185.1	298.73	0.874921	559.9496	167,272	167,272
	Colonial Heights City	4,975.0	7.77	3.40804	2181.146	16,955	16,955
	Dinwiddie County	50,624.6	79.10	0.0759	48.5761	3,842	3,842
	Nottoway County	106,887.8	167.01	0.07399	47.35374	7,909	7,909
	Prince Edward County	216,548.7	338.36	0.084015	53.76969	18,193	18,193
	Prince George County	6,274.2	9.80	0.167215	107.0177	1,049	1,049
	Hopewell City	2,433.1	3.80	3.247657	2078.501	7,902	7,902
	Petersburg City	9,739.4	15.22	2.351778	1505.138	22,905	22,905
	Lunenburg County	43.4	0.07	0.043479	27.82669	2	2
	Charlotte County	38.5	0.06	0.040112	25.67145	2	2
	Powhatan County	50,279.8	78.56	0.129655	82.97892	6,519	6,519
Appomattox TOTAL		**1,023,422.2**	**1,599.10**	0.264306	169.1556	**270,496**	**270,496**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
13 Lower James							
	Charles City County	131,010.2	204.70	0.054133	34.64529	7,092	7,092
	Chesapeake City	58,623.9	91.60	0.88857	568.685	52,091	52,091
	Norfolk City	34,121.0	53.31	5.096621	3261.837	173,902	173,902
	Portsmouth City	29,484.7	46.07	3.355469	2147.5	98,935	98,935
	Chesterfield County	75,754.2	118.37	0.874921	559.9496	66,279	66,279
	Hampton City	9,827.4	15.36	3.584142	2293.851	35,223	35,223
	Newport News City	71,226.3	111.29	2.331606	1492.228	166,072	166,072
	Hanover County	46,402.2	72.50	0.270269	172.9721	12,541	12,541
	Henrico County	131,633.1	205.68	1.581189	1011.961	208,137	208,137
	Hopewell City	4,504.1	7.04	3.247657	2078.501	14,628	14,628
	Prince George County	81,238.6	126.94	0.167215	107.0177	13,584	13,584
	Isle of Wight County	129,972.9	203.08	0.126099	80.70352	16,389	16,389
	James City County	90,030.8	140.67	0.385006	246.4041	34,662	34,662
	Williamsburg City	4,362.3	6.82	2.086267	1335.211	9,101	9,101
	New Kent County	75,675.2	118.24	0.091237	58.39168	6,904	6,904
	Suffolk City	117,601.6	183.75	0.228242	146.0747	26,842	26,842
	Surry County	89,573.7	139.96	0.032617	20.87461	2,922	2,922
	Virginia Beach City	9,608.1	15.01	0.032617	20.87461	313	313
	York County	7,787.3	12.17	0.67012	428.8771	5,218	5,218
	Richmond City	24,184.9	37.79	4.852263	3105.448	117,351	117,351
Lower James TOTAL		**1,222,622.5**	**1,910.35**	0.873685	559.1586	**1,068,187**	**1,068,187**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
14 Mainland Ches/York	James City County	24,858.5	38.84	0.385006	246.4041	9,571	9,571
	Williamsburg City	1,375.9	2.15	2.086267	1335.211	2,870	2,870
	King and Queen County	71,602.7	111.88	0.031251	20.00077	2,238	2,238
	Gloucester County	66,348.8	103.67	0.19033	121.811	12,628	12,628
	New Kent County	11,504.2	17.98	0.091237	58.39168	1,050	1,050
	York County	79,941.4	124.91	0.67012	428.8771	53,570	53,570
	Essex County	18,466.6	28.85	0.04986	31.91067	921	921
	Gloucester County	117,968.5	184.33	0.19033	121.811	22,453	22,453
	Hampton City	28,387.3	44.36	3.584142	2293.851	101,744	101,744
	Newport News City	5,380.1	8.41	2.331606	1492.228	12,544	12,544
	Poqouson City	15,545.5	24.29	0.736893	471.6115	11,455	11,455
	Lancaster County	14,539.4	22.72	0.093974	60.14328	1,366	1,366
	Mathews County	80,104.1	125.16	0.113265	72.48976	9,073	9,073
	Middlesex County	44,682.3	69.82	0.081558	52.19733	3,644	3,644
	Northumberland County	68,510.3	107.05	0.082079	52.53067	5,623	5,623
	Virginia Beach City	55,521.9	86.75	2.202526	1409.616	122,288	122,288
	Norfolk City	8,105.6	12.67	5.096621	3261.837	41,311	41,311
	Richmond County	20.8	0.03	4.852263	3105.448	101	101
Mainland Ches/York TOTAL		**712,863.9**	**1,113.85**	0.58139	372.0894	**414,452**	**414,452**
15 Eastern Shore	Accomack County	478,390.7	747.49	0.067403	43.13803	32,245	32,245
	Northampton County	228,514.0	357.05	0.055616	35.59414	12,709	12,709
Eastern Shore TOTAL		**706,904.7**	**1,104.5**	0.06359	40.6994	**44,954**	**44,954**
16 Meherrin	Brunswick County	210,517.3	328.93	0.045827	29.32937	9,647	9,647
	Charlotte County	12,338.9	19.28	0.040112	25.67145	495	495
	Emporia City	4,207.1	6.57	1.243526	795.8564	5,232	5,232
	Greensville County	124,776.4	194.96	0.059379	38.00276	7,409	7,409
	Lunenburg County	212,380.8	331.85	0.043479	27.82669	9,234	9,234
	Mecklenburg County	68,111.7	106.42	0.071375	45.67981	4,861	4,861
	Southampton County	81,943.2	128.04	0.045243	28.95552	3,707	3,707
	Prince Edward County	107.6	0.17	0.084015	53.76969	9	9
Meherrin TOTAL		**714,383.0**	**1,116.22**	0.056825	36.36827	**40,595**	**40,595**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
17 Nottoway	Brunswick County	110,717.7	173.00	0.045827	29.32937	5,074	5,074
	Dinwiddie County	271,979.0	424.97	0.0759	48.5761	20,643	20,643
	Greensville County	65,205.6	101.88	0.059379	38.00276	3,872	3,872
	Emporia City	195.4	0.31	1.243526	795.8564	243	243
	Lunenburg County	64,558.5	100.87	0.043479	27.82669	2,807	2,807
	Nottoway County	95,827.9	149.73	0.07399	47.35374	7,090	7,090
	Prince Edward County	9,502.9	14.85	0.084015	53.76969	798	798
	Prince George County	24,801.7	38.75	0.167215	107.0177	4,147	4,147
	Petersburg City	164.0	0.26	2.351778	1505.138	386	386
	Southampton County	199,680.4	312.00	0.045243	28.95552	9,034	9,034
	Sussex County	259,934.0	406.15	0.031434	20.11782	8,171	8,171
	Franklin City	586.2	0.92	1.75632	1124.044	1,030	1,030
Nottoway TOTAL		**1,103,153.3**	**1,723.68**	0.057376	36.72094	**63,295**	**63,295**
18 Bwater/SE Coastal	Dinwiddie County	2,256.8	3.53	0.0759	48.5761	171	171
	Isle of Wight County	101,994.2	159.37	0.126099	80.70352	12,861	12,861
	Prince Edward County	323.6	0.51	0.084015	53.76969	27	27
	Prince George County	67,902.1	106.10	0.167215	107.0177	11,354	11,354
	Petersburg City	4,861.6	7.60	2.351778	1505.138	11,433	11,433
	Southampton County	104,071.8	162.61	0.045243	28.95552	4,709	4,709
	Franklin City	4,359.0	6.81	1.75632	1124.044	7,656	7,656
	Surry County	108,822.3	170.03	0.032617	20.87461	3,549	3,549
	Sussex County	55,805.6	87.20	0.031434	20.11782	1,754	1,754
	Virginia Beach City	131,181.4	204.97	2.202526	1409.616	288,930	288,930
	Chesapeake City	165,966.5	259.32	0.88857	568.685	147,473	147,473
	Sufflok City	157,120.6	245.50	0.228242	146.0747	35,861	35,861
BW/SECoastal TOTAL		**904,665.5**	**1,413.54**	0.581187	371.9602	**525,780**	**525,780**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
19 Upper Roanoke	Bedford County	423,894.2	662.33	0.113479	72.62647	48,103	48,103
	Bedford City	4,327.9	6.76	1.459566	934.122	6,317	6,317
	Roanoke City	27,141.9	42.41	3.45402	2210.573	93,749	93,749
	Salem City	9,201.5	14.38	2.682208	1716.613	24,680	24,680
	Botetourt County	44,018.3	68.78	0.081803	52.35387	3,601	3,601
	Campbell County	79,648.2	124.45	0.155446	99.4855	12,381	12,381
	Floyd County	19,129.2	29.89	0.053649	34.33536	1,026	1,026
	Franklin County	386,867.9	604.48	0.09745	62.36817	37,700	37,700
	Henry County	7,549.4	11.80	0.226516	144.9699	1,710	1,710
	Montgomery County	121,146.7	189.29	0.305213	195.3361	36,976	36,976
	Pittsylvania County	134,458.1	210.09	0.091708	58.69313	12,331	12,331
	Roanoke County	144,280.7	225.44	0.502174	321.3915	72,454	72,454
U. Roanoke TOTAL		**1,401,664.0**	**2,190.10**	0.250437	160.2794	**351,028**	**351,028**
20 Lower Roanoke	Appomattox County	62,768.6	98.08	0.061078	39.09019	3,834	3,834
	Brunswick County	43,527.5	68.01	0.045827	29.32937	1,995	1,995
	Campbell County	200,545.7	313.35	0.155446	99.4855	31,174	31,174
	Charlotte County	293,244.6	458.19	0.040112	25.67145	11,763	11,763
	Halifax County	159,486.2	249.20	0.069416	44.42622	11,071	11,071
	Mecklenburg County	357,965.4	559.32	0.071375	45.67981	25,550	25,550
	Pittsylvania County	41,509.6	64.86	0.091708	58.69313	3,807	3,807
	Prince Edward County	323.6	0.51	0.084015	53.76969	27	27
L. Roanoke TOTAL		**1,159,371.2**	**1,811.52**	0.076955	49.25132	**89,220**	**89,220**
21 Martinsville/Ararat	Franklin County	68,319.3	106.75	0.09745	62.36817	6,658	6,658
	Floyd County	2,672.8	4.18	0.053649	34.33536	143	143
	Henry County	225,257.0	351.96	0.226516	144.9699	51,024	51,024
	Martinsville City	7,075.6	11.06	2.242771	1435.374	15,869	15,869
	Patrick County	278,842.7	435.69	0.059288	37.94432	16,532	16,532
	Grayson County	874.0	1.37	0.056509	36.166	49	49
	Carroll County	42,709.7	66.73	0.091262	58.40794	3,898	3,898
	Patrick County	32,087.4	50.14	0.059288	37.94432	1,902	1,902
Mville/Ararat TOTAL		**657,838.5**	**1,027.87**	0.146048	93.47061	**96,076**	**96,076**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
22 Danville	Halifax County	371,558.7	580.56	0.069416	44.42622	25,792	25,792
	Henry County	12,771.6	19.96	0.226516	144.9699	2,893	2,893
	Mecklenburg County	8,909.5	13.92	0.071375	45.67981	636	636
	Pittsylvania County	449,757.2	702.75	0.091708	58.69313	41,246	41,246
	Danville City	28,052.2	43.83	1.813347	1160.542	50,868	50,868
Danville TOTAL		**871,049.2**	**1,361.01**	0.139413	89.2244	**121,436**	**121,436**
23 Upper New	Bland County	15.7	0.02	0.029428	18.83402	0	0
	Carroll County	262,706.7	410.48	0.091262	58.40794	23,975	23,975
	Floyd County	55,391.1	86.55	0.053649	34.33536	2,972	2,972
	Grayson County	281,118.2	439.25	0.056509	36.166	15,886	15,886
	Galax City	5,183.4	8.10	1.32433	847.5709	6,865	6,865
	Patrick County	110.7	0.17	0.059288	37.94432	7	7
	Pulaski County	20,356.2	31.81	0.163629	104.7226	3,331	3,331
	Smyth County	21,653.6	33.83	0.113254	72.48226	2,452	2,452
	Wythe County	285,444.3	446.01	0.088376	56.56045	25,226	25,226
Upper New TOTAL		**931,979.9**	**1,456.22**	0.086605	55.42701	**80,714**	**80,714**
24 Lower New	Bland County	198,756.7	310.56	0.029428	18.83402	5,849	5,849
	Craig County	28,540.8	44.60	0.023138	14.80824	660	660
	Floyd County	166,819.2	260.66	0.053649	34.33536	8,950	8,950
	Giles County	223,095.6	348.59	0.070238	44.95239	15,670	15,670
	Montgomery County	113,157.3	176.81	0.305213	195.3361	34,537	34,537
	Radford City	6,450.3	10.08	2.43938	1561.203	15,735	15,735
	Pulaski County	190,724.8	298.01	0.163629	104.7226	31,208	31,208
	Tazewell County	93,382.3	145.91	0.140635	90.00656	13,133	13,133
	Wythe County	8,827.6	13.79	0.088376	56.56045	780	780
Lower New TOTAL		**1,029,754.6**	**1,608.99**	0.122866	78.63422	**126,522**	**126,522**

Planning Area	Jurisdiction	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
25 Holston	Grayson County	3,234.8	5.05	0.056509	36.166	183	183
	Bristol City	7,306.6	11.42	2.393048	1531.551	17,485	17,485
	Wythe County	2,958.8	4.62	0.088376	56.56045	261	261
	Bland County	30,531.8	47.71	0.029428	18.83402	898	898
	Russell County	36,332.3	56.77	0.095273	60.97447	3,461	3,461
	Scott County	100,886.3	157.63	0.065605	41.9871	6,619	6,619
	Smyth County	267,582.8	418.09	0.113254	72.48226	30,305	30,305
	Tazewell County	33,714.7	52.68	0.140635	90.00656	4,741	4,741
	Washington County	363,031.8	567.23	0.135437	86.67974	49,168	49,168
Holston TOTAL		**845,579.9**	**1,321.22**	0.13378	85.6195	**113,122**	**113,122**
26 Clinch/Powell	Dickenson County	3,212.4	5.02	0.079179	50.67424	254	254
	Russell County	268,571.6	419.64	0.095273	60.97447	25,588	25,588
	Tazewell County	175,687.0	274.51	0.140635	90.00656	24,708	24,708
	Lee County	280,034.1	437.55	0.085043	54.42768	23,815	23,815
	Scott County	243,676.7	380.74	0.065605	41.9871	15,986	15,986
	Wise County	182,463.0	285.10	0.148907	95.30066	27,170	27,170
	Norton City	4,905.2	7.66	0.847095	542.1407	4,155	4,155
Clinch/Powell TOTAL		**1,158,550.0**	**1,810.23**	0.105025	67.21576	**121,676**	**121,676**
27 Big Sandy	Buchanan County	322,250.8	503.52	0.089772	57.45403	28,929	28,929
	Dickenson County	210,154.1	328.37	0.079179	50.67424	16,640	16,640
	Tazewell County	29,750.5	46.49	0.140635	90.00656	4,184	4,184
	Wise County	76,752.4	119.93	0.148907	95.30066	11,429	11,429
Big Sandy TOTAL		**638,907.8**	**998.29**	0.09576	61.28631	**61,182**	**61,182**
STATE TOTAL		**26,292,375.2**	**41,081.8**	0.259388	166.0086	**6,819,937**	**6,819,937**

G.3 The Upper Potomac Planning Area as an example of the 1998 population estimate methodology

Basin	Jurisdiction	Sub	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
Upper Potomac	Fairfax County	A09	6,415.7	10.02	3.572238	2286.232	22,918.40	22,918.40
		A10	8,721.3	13.63	3.572238	2286.232	31,154.56	31,154.56
		A11	56,566.0	88.38	3.572238	2286.232	202,067.19	202,067.19
		A12	7,661.2	11.97	3.572238	2286.232	27,367.63	27,367.63
		A13	21,145.5	33.04	3.572238	2286.232	75,536.75	75,536.75
		A14	21,516.5	33.62	3.572238	2286.232	76,862.05	76,862.05
		A15	32,964.8	51.51	3.572238	2286.232	117,758.10	117,758.10
		A16	23,163.7	36.19	3.572238	2286.232	82,746.24	82,746.24
		A21	4,119.3	6.44	3.572238	2286.232	14,715.12	14,715.12
		A22	24,932.7	38.96	3.572238	2286.232	89,065.53	89,065.53
		A23	23,709.2	37.05	3.572238	2286.232	84,694.89	84,694.89
		A24	12,821.2	20.03	3.572238	2286.232	45,800.37	45,800.37
		A25	16,390.7	25.61	3.572238	2286.232	58,551.47	58,551.47
			260,127.8	**406.45**	**3.572238**	**2286.232**	**929,238.29**	**929,238.29**
	Falls Church City	A12	409.8	0.64	7.969841	5100.698	3,266.04	3,266.04
		A13	850.4	1.33	7.969841	5100.698	6,777.55	6,777.55
			1,260.2	**1.97**	**7.969841**	**5100.698**	**10,043.59**	**10,043.59**
	Arlington County	A11	23.2	0.04	10.62481	6799.88	246.50	246.50
		A12	16,656.3	26.03	10.62481	6799.88	176,970.07	176,970.07
		A13	5.8	0.01	10.62481	6799.88	61.62	61.62
			16,685.3	**26.07**	**10.62481**	**6799.88**	**177,278.19**	**177,278.19**
	Fairfax City	A11	138.2	0.22	5.071551	3245.793	700.89	700.89
		A15	3,594.6	5.62	5.071551	3245.793	18,230.20	18,230.20
		A16	155.6	0.24	5.071551	3245.793	789.13	789.13
		A23	193.1	0.30	5.071551	3245.793	979.32	979.32
			4,081.5	**6.38**	**5.071551**	**3245.793**	**20,699.54**	**20,699.54**

Basin	Jurisdiction	Sub	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
Upper Potomac (cont.)	Alexandria City	A12	2,768.0	4.33	12.05175	7713.121	33,359.25	33,359.25
		A13	6,517.9	10.18	12.05175	7713.121	78,552.12	78,552.12
		A14	529.9	0.83	12.05175	7713.121	6,386.22	6,386.22
			9,815.8	**15.34**	**12.05175**	**7713.121**	**118,297.59**	**118,297.59**
	Fauquier County	A04	50,254.0	78.52	0.129738	83.03205	6,519.83	6,519.83
		A05	26,476.7	41.37	0.129738	83.03205	3,435.02	3,435.02
		A08	19,616.2	30.65	0.129738	83.03205	2,544.96	2,544.96
		A17	65,034.0	101.62	0.129738	83.03205	8,437.35	8,437.35
		A18	30,363.7	47.44	0.129738	83.03205	3,939.31	3,939.31
		A19	39,954.2	62.43	0.129738	83.03205	5,183.56	5,183.56
		A21	535.5	0.84	0.129738	83.03205	69.47	69.47
			232,234.3	**362.87**	**0.129738**	**83.03205**	**30,129.51**	**30,129.51**
	Loudoun County	A01	23,813.7	37.21	0.431024	275.8553	10,264.27	10,264.27
		A02	59,239.6	92.56	0.431024	275.8553	25,533.68	25,533.68
		A03	27,368.0	42.76	0.431024	275.8553	11,796.26	11,796.26
		A04	642.9	1.00	0.431024	275.8553	277.11	277.11
		A05	30,583.5	47.79	0.431024	275.8553	13,182.22	13,182.22
		A06	28,499.1	44.53	0.431024	275.8553	12,283.79	12,283.79
		A07	34,197.0	53.43	0.431024	275.8553	14,739.72	14,739.72
		A08	57,021.8	89.10	0.431024	275.8553	24,577.76	24,577.76
		A09	48,577.4	75.90	0.431024	275.8553	20,938.02	20,938.02
		A10	5,769.0	9.01	0.431024	275.8553	2,486.58	2,486.58
		A11	41.0	0.06	0.431024	275.8553	17.67	17.67
		A21	9,304.5	14.54	0.431024	275.8553	4,010.46	4,010.46
		A22	8,891.4	13.89	0.431024	275.8553	3,832.41	3,832.41
			333,948.9	**521.80**	**0.431024**	**275.8553**	**143,939.96**	**143,939.96**

Basin	Jurisdiction	Sub	Acres	Sq. miles	pop./ac	pop./mi^2	pop (f(ac))	pop(f(mi^2))
Upper Potomac (cont.)	Prince William County	A17	286.1	0.45	1.160771	742.8935	332.10	332.10
		A18	29,778.3	46.53	1.160771	742.8935	34,565.79	34,565.79
		A19	45,019.0	70.34	1.160771	742.8935	52,256.75	52,256.75
		A20	18,113.7	28.30	1.160771	742.8935	21,025.86	21,025.86
		A21	43,331.1	67.70	1.160771	742.8935	50,297.49	50,297.49
		A23	5,646.2	8.82	1.160771	742.8935	6,553.95	6,553.95
		A24	9,648.7	15.08	1.160771	742.8935	11,199.93	11,199.93
		A25	23,162.9	36.19	1.160771	742.8935	26,886.82	26,886.82
			174,986.0	**273.42**	**1.160771**	**742.8935**	**203,118.69**	**203,118.69**
	Manassas City	A19	3,473.1	5.43	5.422959	3470.694	18,834.48	18,834.48
		A20	283.3	0.44	5.422959	3470.694	1,536.32	1,536.32
		A21	2,082.0	3.25	5.422959	3470.694	11,290.60	11,290.60
		A23	677.8	1.06	5.422959	3470.694	3,675.68	3,675.68
			6,516.2	**10.18**	**5.422959**	**3470.694**	**35,337.08**	**35,337.08**
	Manassas Park City	A21	445.0	0.70	7.736234	4951.19	3,442.62	3,442.62
		A23	680.9	1.06	7.736234	4951.19	5,267.60	5,267.60
			1,125.9	**1.76**	**7.736234**	**4951.19**	**8,710.23**	**8,710.23**
	Stafford County	A18	21.4	0.03	0.486466	311.3381	10.41	10.41
			21.4	**0.03**	**0.486466**	**311.3381**	**10.41**	**10.41**
	Upper Potomac TOTAL		**1,040,803.3**	**1,626.26**	1.611066	1031.082	**1,676,803.1**	**1,676,803.1**

APPENDIX H: PLANNING AREA POPULATION PROJECTIONS

USING 1998 AS THE BASE YEAR FOR THE POPULATION

RATIO AND SHOWING THE 1995 POPULATION RATIO

	Planning Area	1995 pop***	%pop	1998 pop	%pop	2000 projection	2005 projection	2015 projection	2025 projection
1	**Upper Potomac**	**1,585,940**	24.26%	**1,676,803**	24.59%	**1,720,337**	**1,800,736**	**1,947,519**	**2,081,517**
2	**Lower Potomac**	**136,000**	2.08%	**147,033**	2.16%	**150,851**	**157,900**	**170,771**	**182,521**
3	**Up Shen/Laurel****	**120,770**	1.85%	**146,166**	2.14%	**149,960**	**156,969**	**169,764**	**181,444**
4	**L Shen/Opequon****	**235,890**	3.61%	**217,656**	3.19%	**223,307**	**233,743**	**252,796**	**270,190**
5	**U. Rappahannock**	**102,250**	1.56%	**107,547**	1.58%	**110,340**	**115,496**	**124,911**	**133,505**
6	**L. Rappahannock**	**100,610**	1.54%	**104,560**	1.53%	**107,275**	**112,288**	**121,441**	**129,797**
7	**Pamunkey**	**126,690**	1.94%	**141,927**	2.08%	**145,612**	**152,417**	**164,841**	**176,183**
8	**Mattaponi**	**61,010**	0.93%	**67,292**	0.99%	**69,039**	**72,266**	**78,157**	**83,534**
9	**U James/Maury**	**119,430**	1.83%	**170,685**	2.50%	**175,116**	**183,300**	**198,241**	**211,881**
10	**UMJames/Rivanna**	**270,910**	4.14%	**279,057**	4.09%	**286,302**	**299,683**	**324,111**	**346,411**
11	**LMJames**	**249,150**	3.81%	**172,475**	2.53%	**176,953**	**185,223**	**200,321**	**214,104**
12	**Appomattox**	**286,160**	4.38%	**270,496**	3.97%	**277,519**	**290,489**	**314,167**	**335,783**
13	**Lower James**	**988,900**	15.13%	**1,068,187**	15.66%	**1,095,920**	**1,147,137**	**1,240,644**	**1,326,006**
14	**Mainland Ches/York**	**417,550**	6.39%	**414,452**	6.08%	**425,212**	**445,084**	**481,364**	**514,484**
15	**Eastern Shore**	**45,130**	0.69%	**44,954**	0.66%	**46,121**	**48,277**	**52,212**	**55,804**
16	**Meherrin**	**40,090**	0.61%	**40,595**	0.60%	**41,649**	**43,596**	**47,149**	**50,393**
17	**Nottoway**	**58,280**	0.89%	**63,295**	0.93%	**64,938**	**67,973**	**73,514**	**78,572**
18	**BWater/SECoastal**	**508,150**	7.77%	**525,780**	7.71%	**539,431**	**564,641**	**610,666**	**652,683**
19	**U. Roanoke**	**345,840**	5.29%	**351,028**	5.15%	**360,141**	**376,972**	**407,700**	**435,752**
20	**L. Roanoke**	**85,890**	1.31%	**89,220**	1.31%	**91,536**	**95,814**	**103,624**	**110,754**
21	**Martinsville/Ararat****	**109,637**	1.68%	**96,076**	1.41%	**98,570**	**103,177**	**111,587**	**119,265**
22	**Danville****	**114,453**	1.75%	**121,436**	1.78%	**124,588**	**130,411**	**141,041**	**150,745**
23	**Upper New****	**111,705**	1.71%	**80,714**	1.18%	**82,809**	**86,679**	**93,745**	**100,195**
24	**Lower New****	**94,975**	1.45%	**126,522**	1.86%	**129,807**	**135,873**	**146,948**	**157,059**
25	**Holston**	**113,400**	1.73%	**113,122**	1.66%	**116,059**	**121,483**	**131,385**	**140,425**
26	**Clinch/Powell**	**46,280**	0.71%	**121,676**	1.78%	**124,835**	**130,669**	**141,321**	**151,044**
27	**Big Sandy**	**62,220**	0.95%	**61,182**	0.90%	**62,770**	**65,704**	**71,059**	**75,949**
	STATE TOTAL	**6,537,310**	100.00%	**6,819,937**	100.0%	**6,997,000**	**7,324,000**	**7,921,000**	**8,466,000**

VA2000 population*	6,997,000
VA2005 population*	7,324,000
VA2015 population*	7,921,000
VA2025 population*	8,466,000

*population projections from the US Census Bureau: http://www.census.gov/population/projections/state/stpjpop.txt

**USGS hydrologic unit and planning area boundaries are not coincidental;
1995 population estimates were evenly distributed over land area and may introduce discrepancies in population estimates.

***1995 population estimates from USGS demand data: ttp://water.usgs.gov/watuse/spread95.html

APPENDIX I: POPULATION PROJECTIONS FOR THE UPPER DAN, LOWER DAN AND UPPER NEW RIVER USGS CATALOGING UNITS IN NORTH CAROLINA

	Planning Area	1995 pop**	%pop	1998 projection^	2000 projection	2005 projection	2015 projection	2025 projection
22a	**Upper Dan**	**123,420**	1.72%	**129,411**	**133,403**	**141,122**	**151,638**	**160,369**
22b	**Lower Dan**	**48,910**	0.68%	**51,283**	**52,866**	**55,925**	**60,092**	**63,552**
23a	**Upper New**	**179,630**	2.50%	**188,618**	**194,160**	**205,395**	**220,699**	**233,407**

NC1995 population*	7,195,000
NC2000 population*	7,777,000
NC2005 population*	8,227,000
NC2015 population*	8,840,000
NC2025 population*	9,349,000

*population projections from the US Census Bureau: http://www.census.gov/population/projections/state/stpjpop.txt

**1995 population estimates from USGS demand data: http://water.usgs.gov/watuse/spread95.html

^1998 projections assume linear population growth in North Carolina between 1995 and 2000.

APPENDIX J: 1995 SECTOR DEMAND ESTIAMTES BY VIRGNIA PLANNING AREA AND THE UPPER DAN, LOWER DAN, AND UPPER NEW RIVER BASINS IN NORTH CAROLINA

UPPER POTOMAC

1995 Population	1,585,940
TOTAL FRESH OFFSTREAM USAGE (MGD)	465.53
Per Capita Withdrawal (gpcd)	293.54
Total consumptive uses (MGD)	183.42
Per capita consumptive uses (gpcd)	115.65
Total water consumed (MGD)	19.28
Consumption/consumptive withdrawal (%)	10.51%

FRESH WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	12.71	12.71	n/a
PS Domestic	n/a	n/a	127.77	n/a
Total Domestic	**n/a**	**n/a**	**140.48**	**13.05**
SS Commercial	3.22	2.07	5.29	n/a
PS Commercial	n/a	n/a	32.02	n/a
Total Commercial	**n/a**	**n/a**	**37.31**	**4.48**
SS Industrial	0	0	0	n/a
PS Industrial	n/a	n/a	3.89	n/a
Total Industrial	**n/a**	**n/a**	**3.89**	**0.46**
SS Thermoelectric	282.11	0	282.11	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**282.11**	**0**
Mining	**0.31**	**0.15**	**0.46**	**0.06**
Livestock	0.97	0.14	1.11	1.11
Animal Specialties	0	0	0	0
Total Livestock	**0.97**	**0.14**	**1.11**	**1.11**
Irrigation	**0.16**	**0.01**	**0.17**	**0.12**
FRESH TOTAL	**n/a**	**n/a**	**465.53**	**19.28**

SALINE WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-13	n/a
WW Returns (MGD)	n/a	n/a	100	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

LOWER POTOMAC

1995 Population	136,000
TOTAL FRESH OFFSTREAM USAGE (MGD)	273.18
Per Capita Withdrawal (gpcd)	2008.68
Total consumptive uses (MGD)	18.88
Per capita consumptive uses (gpcd)	138.82
Total water consumed (MGD)	2.94
Consumption/consumptive withdrawal (%)	15.57%

FRESH WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	5.03	5.03	n/a
PS Domestic	n/a	n/a	7.18	n/a
Total Domestic	**n/a**	**n/a**	**12.21**	**1.22**
SS Commercial	0.84	1.16	2	n/a
PS Commercial	n/a	n/a	2.58	n/a
Total Commercial	**n/a**	**n/a**	**4.58**	**0.55**
SS Industrial	0.01	0	0.01	n/a
PS Industrial	n/a	n/a	0.17	n/a
Total Industrial	**n/a**	**n/a**	**0.18**	**0.02**
SS Thermoelectric	254.11	0	254.11	n/a
PS Thermoelectric	n/a	n/a	0.19	n/a
Total Thermoelectric	**n/a**	**n/a**	**254.3**	**0**
Mining	**0**	**0.46**	**0.46**	**0.05**
Livestock	0.07	0.54	0.61	0.61
Animal Specialties	0	0	0	0
Total Livestock	**0.07**	**0.54**	**0.61**	**0.61**
Irrigation	**0.13**	**0.71**	**0.84**	**0.49**
FRESH TOTAL	**n/a**	**n/a**	**273.18**	**2.94**

SALINE WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-2.19	n/a
WW Returns (MGD)	n/a	n/a	4.47	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

UPPER SHENANDOAH/LAUREL

1995 Population	120,770
TOTAL FRESH OFFSTREAM USAGE (MGD)	33.50
Per Capita Withdrawal (gpcd)	277.39
Total consumptive uses plus losses (MGD)	37.22
Per capita consumptive uses (gpcd)	308.19
Total water consumed (MGD)	5.13
Consumption/consumptive withdrawal (%)	13.78%

FRESH WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	3.35	3.35	n/a
PS Domestic	n/a	n/a	5.72	n/a
Total Domestic	**n/a**	**n/a**	**9.07**	**0.9**
SS Commercial	0.17	1.03	1.2	n/a
PS Commercial	n/a	n/a	5.16	n/a
Total Commercial	**n/a**	**n/a**	**6.36**	**0.76**
SS Industrial	2.99	10.9	13.88	n/a
PS Industrial	n/a	n/a	2.5	n/a
Total Industrial	**n/a**	**n/a**	**16.38**	**1.96**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0.84	0.31	1.15	1.15
Animal Specialties	0	0	0	0
Total Livestock	**0.84**	**0.31**	**1.15**	**1.15**
Irrigation	**0.52**	**0.02**	**0.54**	**0.36**
FRESH TOTAL	**n/a**	**n/a**	**33.5**	**5.13**

SALINE WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	3.72	n/a
WW Returns (MGD)	n/a	n/a	4.47	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

LOWER SHENANDOAH/OPEQUON

1995 Population	235,890
TOTAL FRESH OFFSTREAM USAGE (MGD)	45.21
Per Capita Withdrawal (gpcd)	191.66
Total consumptive uses plus losses (MGD)	45.36
Per capita consumptive uses (gpcd)	192.29
Withdrawal plus hydroelectric (gpcd)	1,049.16
Per capita plus hydroelectric (gpcd)	4,447.67
Total water consumed (MGD)	10.17
Consumption/consumptive withdrawal (%)	22.42%

FRESH WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	8.65	8.65	n/a
PS Domestic	n/a	n/a	9.52	n/a
Total Domestic	**n/a**	**n/a**	**18.17**	**1.82**
SS Commercial	0.54	1.29	1.83	n/a
PS Commercial	n/a	n/a	7.74	n/a
Total Commercial	**n/a**	**n/a**	**9.57**	**1.16**
SS Industrial	1.9	6.81	8.71	n/a
PS Industrial	n/a	n/a	2.5	n/a
Total Industrial	**n/a**	**n/a**	**11.21**	**1.64**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0.17**	**0.2**	**0.37**	**0.04**
Livestock	3.76	1.03	4.79	4.79
Animal Specialties	0	0	0	0
Total Livestock	**3.76**	**1.03**	**4.79**	**4.79**
Irrigation	**0.88**	**0.22**	**1.1**	**0.72**
FRESH TOTAL	**n/a**	**n/a**	**45.21**	**10.17**

SALINE WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	903.8	0	1003.8	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	0.15	n/a
WW Returns (MGD)	n/a	n/a	5.29	n/a
Reservoir Evap (AC-FT/yr)	500	n/a	500	500

UPPER RAPPAHANNOCK

1995 Population	102,250
TOTAL FRESH OFFSTREAM WITHDRAWAL (MGD)	11.50
Per Capita Withdrawal (gpcd)	112.47
Total consumptive uses plus losses (MGD)	13.58
Per capita consumptive uses (gpcd)	132.81
Total water consumed (MGD)	2.29
Consumption/consumptive withdrawal (%)	16.86%

FRESH WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	5.5	5.5	n/a
PS Domestic	n/a	n/a	2.38	n/a
Total Domestic	**n/a**	**n/a**	**7.88**	**0.79**
SS Commercial	0.1	0.4	0.5	n/a
PS Commercial	n/a	n/a	1.14	n/a
Total Commercial	**n/a**	**n/a**	**1.64**	**0.2**
SS Industrial	0	0	0	n/a
PS Industrial	n/a	n/a	0.49	n/a
Total Industrial	**n/a**	**n/a**	**0.49**	**0.06**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0.95	0.09	1.04	1.04
Animal Specialties	0	0	0	0
Total Livestock	**0.95**	**0.09**	**1.04**	**1.04**
Irrigation	**0.41**	**0.04**	**0.45**	**0.2**
FRESH TOTAL	**n/a**	**n/a**	**11.5**	**2.29**

SALINE WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	2.08	n/a
WW Returns (MGD)	n/a	n/a	2.34	n/a
Reservoir Evap (AC-FT/yr)	1200	n/a	1200	1200

LOWER RAPPAHANNOCK

1995 Population	100,610
TOTAL FRESH OFFSTREAM USAGE (MGD)	17.72
Per Capita Withdrawal (gpcd)	176.13
Total consumptive uses (MGD)	17.72
Per capita consumptive uses (gpcd)	176.13
Total water consumed (MGD)	4.25
Consumption/consumptive withdrawal (%)	23.98%

FRESH WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	3.22	3.22	n/a
PS Domestic	n/a	n/a	4.29	n/a
Total Domestic	**n/a**	**n/a**	**7.51**	**0.75**
SS Commercial	0.31	1.65	1.96	n/a
PS Commercial	n/a	n/a	1.65	n/a
Total Commercial	**n/a**	**n/a**	**3.61**	**0.2**
SS Industrial	0	0.01	0.01	n/a
PS Industrial	n/a	n/a	0.38	n/a
Total Industrial	**n/a**	**n/a**	**0.39**	**0.05**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**2.14**	**0**	**2.14**	**0**
Livestock	1.82	0.17	1.99	1.99
Animal Specialties	0.02	0	0.02	0.02
Total Livestock	**1.84**	**0.17**	**2.01**	**2.01**
Irrigation	**2.03**	**0.03**	**2.06**	**1.24**
FRESH TOTAL	**n/a**	**n/a**	**17.72**	**4.25**

SALINE WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-0.28	n/a
WW Returns (MGD)	n/a	n/a	6.46	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

PAMUNKEY

1995 Population	126,690
TOTAL FRESH OFFSTREAM USAGE (MGD)	2108.69
Per Capita Withdrawal (gpcd)	16644.49
Total consumptive uses (MGD)	33.45
Per capita consumptive uses (gpcd)	264.03
Total water consumed (MGD)	5.96
Consumption/consumptive withdrawal (%)	17.82%

FRESH WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	5.86	5.86	n/a
PS Domestic	n/a	n/a	3.46	n/a
Total Domestic	**n/a**	**n/a**	**9.32**	**0.93**
SS Commercial	0.13	0.56	0.69	n/a
PS Commercial	n/a	n/a	2.3	n/a
Total Commercial	**n/a**	**n/a**	**2.99**	**0.36**
SS Industrial	0	0.05	0.05	n/a
PS Industrial	n/a	n/a	3.45	n/a
Total Industrial	**n/a**	**n/a**	**3.5**	**0.42**
SS Thermoelectric	2075.22	0.02	2075.24	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**2075.24**	**0**
Mining	**14.69**	**0**	**14.69**	**1.76**
Livestock	1.64	0.17	1.81	1.81
Animal Specialties	0.01	0	0.01	0.01
Total Livestock	**1.65**	**0.17**	**1.82**	**1.82**
Irrigation	**1.13**	**0**	**1.13**	**0.67**
FRESH TOTAL	**n/a**	**n/a**	**2108.69**	**5.96**

SALINE WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-2.65	n/a
WW Returns (MGD)	n/a	n/a	1.03	n/a
Reservoir Evap (AC-FT/yr)	26440	n/a	26440	26440

MATTAPONI

1995 Population	61,010
TOTAL FRESH OFFSTREAM USAGE (MGD)	29.05
Per Capita Withdrawal (gpcd)	476.15
Total consumptive uses plus losses (MGD)	30.82
Per capita consumptive uses (gpcd)	505.16
Total water consumed (MGD)	4.52
Consumption/consumptive withdrawal (%)	14.67%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	3.48	3.48	n/a
PS Domestic	n/a	n/a	1.84	n/a
Total Domestic	**n/a**	**n/a**	**5.32**	**0.53**
SS Commercial	0.04	0.62	0.66	n/a
PS Commercial	n/a	n/a	0.35	n/a
Total Commercial	**n/a**	**n/a**	**1.01**	**0.12**
SS Industrial	0	0	0	n/a
PS Industrial	n/a	n/a	20.86	n/a
Total Industrial	**n/a**	**n/a**	**20.86**	**2.5**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0.23**	**0**	**0.23**	**0.03**
Livestock	0.68	0.13	0.81	0.81
Animal Specialties	0	0	0	0
Total Livestock	**0.68**	**0.13**	**0.81**	**0.81**
Irrigation	**0.82**	**0**	**0.82**	**0.53**
FRESH TOTAL	**n/a**	**n/a**	**29.05**	**4.52**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	1.77	n/a
WW Returns (MGD)	n/a	n/a	0	n/a
Reservoir Evap (AC-FT/yr)	1690	n/a	1690	1690

UPPER JAMES/MAURY

1995 Population	119,430
TOTAL FRESH OFFSTREAM USAGE (MGD)	82.86
Per Capita Withdrawal (gpcd)	693.80
Total consumptive uses (MGD)	82.86
Per capita consumptive uses (gpcd)	693.80
Withdrawal plus hydroelectric (gpcd)	84.30
Per capita plus hydroelectric (gpcd)	705.85
Total water consumed (MGD)	10.63
Consumption/consumptive withdrawal (%)	12.83%

FRESH WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	3.4	3.4	n/a
PS Domestic	n/a	n/a	5.93	n/a
Total Domestic	**n/a**	**n/a**	**9.33**	**0.93**
SS Commercial	0.24	2.12	2.36	n/a
PS Commercial	n/a	n/a	4.82	n/a
Total Commercial	**n/a**	**n/a**	**7.18**	**0.87**
SS Industrial	53.44	10.5	63.92	n/a
PS Industrial	n/a	n/a	1.35	n/a
Total Industrial	**n/a**	**n/a**	**65.27**	**7.83**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0.52	0.3	0.82	0.82
Animal Specialties	0	0	0	0
Total Livestock	**0.52**	**0.3**	**0.82**	**0.82**
Irrigation	**0.24**	**0.02**	**0.26**	**0.18**
FRESH TOTAL	**n/a**	**n/a**	**82.86**	**10.63**

SALINE WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	1.44	0	1.44	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-2.88	n/a
WW Returns (MGD)	n/a	n/a	6.27	n/a
Reservoir Evap (AC-FT/yr)	5120	n/a	5120	5120

UPPER MIDDLE JAMES/RIVANNA

1995 Population	270,910
TOTAL FRESH OFFSTREAM USAGE (MGD)	170.03
Per Capita Withdrawal (gpcd)	627.63
Total consumptive uses plus losses (MGD)	55.66
Per capita consumptive uses (gpcd)	205.46
Withdrawal plus hydroelectric (gpcd)	3,245.18
Per capita plus hydroelectric (gpcd)	11,978.81
Total water consumed (MGD)	9.12
Consumption/consumptive withdrawal (%)	16.39%

FRESH WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	5.32	5.32	n/a
PS Domestic	n/a	n/a	12.48	n/a
Total Domestic	**n/a**	**n/a**	**17.8**	**1.78**
SS Commercial	1.08	0.93	2.01	n/a
PS Commercial	n/a	n/a	9.38	n/a
Total Commercial	**n/a**	**n/a**	**11.39**	**1.36**
SS Industrial	15.93	0.27	16.2	n/a
PS Industrial	n/a	n/a	4.01	n/a
Total Industrial	**n/a**	**n/a**	**20.21**	**2.39**
SS Thermoelectric	115.68	0.01	115.69	n/a
PS Thermoelectric	n/a	n/a	0.02	n/a
Total Thermoelectric	**n/a**	**n/a**	**115.71**	**0**
Mining	**1.03**	**0**	**1.03**	**0.12**
Livestock	2.51	0.25	2.76	2.76
Animal Specialties	0	0.02	0.02	0.02
Total Livestock	**2.51**	**0.27**	**2.78**	**2.78**
Irrigation	**1.11**	**0**	**1.11**	**0.69**
FRESH TOTAL	**n/a**	**n/a**	**170.03**	**9.12**

SALINE WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	3189.52	0	3189.52	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	1.34	n/a
WW Returns (MGD)	n/a	n/a	23.18	n/a
Reservoir Evap (AC-FT/yr)	1910	n/a	1910	1910

LOWER MIDDLE JAMES

1995 Population	249,150
TOTAL FRESH OFFSTREAM USAGE (MGD)	42.05
Per Capita Withdrawal (gpcd)	168.77
Total consumptive uses plus losses (MGD)	77.02
Per capita consumptive uses (gpcd)	309.13
Total water consumed (MGD)	5.52
Consumption/consumptive withdrawal (%)	7.17%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	3.61	3.61	n/a
PS Domestic	n/a	n/a	22.59	n/a
Total Domestic	**n/a**	**n/a**	**26.2**	**2.62**
SS Commercial	1.23	0.48	1.71	n/a
PS Commercial	n/a	n/a	8.02	n/a
Total Commercial	**n/a**	**n/a**	**9.73**	**1.17**
SS Industrial	0.13	0	0.13	n/a
PS Industrial	n/a	n/a	4.58	n/a
Total Industrial	**n/a**	**n/a**	**4.71**	**0.56**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0.25**	**0**	**0.25**	**0.03**
Livestock	0.93	0.22	1.15	1.14
Animal Specialties	0	0	0	0
Total Livestock	**0.93**	**0.22**	**1.15**	**1.14**
Irrigation	**0.01**	**0**	**0.01**	**0**
FRESH TOTAL	**n/a**	**n/a**	**42.05**	**5.52**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	34.97	n/a
WW Returns (MGD)	n/a	n/a	51.35	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

APPOMATTOX

1995 Population	286,160
TOTAL FRESH OFFSTREAM USAGE (MGD)	50.03
Per Capita Withdrawal (gpcd)	174.83
Total consumptive uses plus losses (MGD)	78.38
Per capita consumptive uses (gpcd)	273.90
Total water consumed (MGD)	7.59
Consumption/consumptive withdrawal (%)	9.68%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	8.99	8.99	n/a
PS Domestic	n/a	n/a	20.68	n/a
Total Domestic	**n/a**	**n/a**	**29.67**	**2.97**
SS Commercial	0	0.49	0.49	n/a
PS Commercial	n/a	n/a	4.99	n/a
Total Commercial	**n/a**	**n/a**	**5.48**	**0.66**
SS Industrial	0	0.02	0.02	n/a
PS Industrial	n/a	n/a	2.72	n/a
Total Industrial	**n/a**	**n/a**	**2.74**	**0.33**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**8.99**	**0.01**	**9**	**1.08**
Livestock	1.37	0.21	1.58	1.58
Animal Specialties	0.01	0	0.01	0.01
Total Livestock	**1.38**	**0.21**	**1.59**	**1.59**
Irrigation	**1.53**	**0.02**	**1.55**	**0.96**
FRESH TOTAL	**n/a**	**n/a**	**50.03**	**7.59**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	28.35	n/a
WW Returns (MGD)	n/a	n/a	10.63	n/a
Reservoir Evap (AC-FT/yr)	10220	n/a	10220	10220

LOWER JAMES

1995 Population	988,900
TOTAL FRESH OFFSTREAM USAGE (MGD)	1284.93
Per Capita Withdrawal (gpcd)	1299.35
Total consumptive uses plus losses (MGD)	440.83
Per capita consumptive uses (gpcd)	445.78
Total water consumed (MGD)	45.87
Consumption/consumptive withdrawal (%)	10.41%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	5.21	5.21	n/a
PS Domestic	n/a	n/a	85.41	n/a
Total Domestic	**n/a**	**n/a**	**90.62**	**9.06**
SS Commercial	0.69	3.51	4.2	n/a
PS Commercial	n/a	n/a	31.84	n/a
Total Commercial	**n/a**	**n/a**	**36.04**	**4.33**
SS Industrial	206.17	6.17	212.34	n/a
PS Industrial	n/a	n/a	28.45	n/a
Total Industrial	**n/a**	**n/a**	**240.79**	**28.75**
SS Thermoelectric	911.45	0.29	911.74	n/a
PS Thermoelectric	n/a	n/a	0.32	n/a
Total Thermoelectric	**n/a**	**n/a**	**912.06**	**0**
Mining	**1.04**	**0**	**1.04**	**0.12**
Livestock	1.96	0.48	2.44	2.43
Animal Specialties	0.02	0	0.02	0.02
Total Livestock	**1.98**	**0.48**	**2.46**	**2.45**
Irrigation	**1.84**	**0.08**	**1.92**	**1.16**
FRESH TOTAL	**n/a**	**n/a**	**1284.93**	**45.87**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	2300.63	0	2300.63	0
Industrial	4.71	0	4.71	0.57
SALINE TOTAL	**2305.34**	**0**	**2305.34**	**0.57**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	67.96	n/a
WW Returns (MGD)	n/a	n/a	202.5	n/a
Reservoir Evap (AC-FT/yr)	13990	n/a	13990	13990

MAINLAND CHESAPEAKE BAY/LOWER YORK

1995 Population	417,550
TOTAL FRESH OFFSTREAM USAGE (MGD)	47.61
Per Capita Withdrawal (gpcd)	114.02
Total consumptive uses (MGD)	47.61
Per capita consumptive uses (gpcd)	114.02
Total water consumed (MGD)	7.08
Consumption/consumptive withdrawal (%)	14.87%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	6.45	6.45	n/a
PS Domestic	n/a	n/a	24.38	n/a
Total Domestic	**n/a**	**n/a**	**30.83**	**3.08**
SS Commercial	0.13	0.94	1.07	n/a
PS Commercial	n/a	n/a	9.51	n/a
Total Commercial	**n/a**	**n/a**	**10.58**	**1.27**
SS Industrial	0	0.25	0.25	n/a
PS Industrial	n/a	n/a	3.52	n/a
Total Industrial	**n/a**	**n/a**	**3.77**	**0.44**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	1.68	0.37	2.05	2.05
Animal Specialties	0	0	0	0
Total Livestock	**1.68**	**0.37**	**2.05**	**2.05**
Irrigation	**0.32**	**0.06**	**0.38**	**0.24**
FRESH TOTAL	**n/a**	**n/a**	**47.61**	**7.08**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	428.23	0	428.23	0
Industrial	61.84	0	61.84	7.42
SALINE TOTAL	**490.07**	**0**	**490.07**	**7.42**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-11.67	n/a
WW Returns (MGD)	n/a	n/a	9.04	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

EASTERN SHORE

1995 Population	45,130
TOTAL FRESH OFFSTREAM USAGE (MGD)	16.00
Per Capita Withdrawal (gpcd)	354.53
Total consumptive uses (MGD)	16.00
Per capita consumptive uses (gpcd)	354.53
Total water consumed (MGD)	6.09
Consumption/consumptive withdrawal (%)	38.06%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	2.31	2.31	n/a
PS Domestic	n/a	n/a	1	n/a
Total Domestic	**n/a**	**n/a**	**3.31**	**0.32**
SS Commercial	0	1.56	1.56	n/a
PS Commercial	n/a	n/a	0.05	n/a
Total Commercial	**n/a**	**n/a**	**1.61**	**0.18**
SS Industrial	0	3.2	3.2	n/a
PS Industrial	n/a	n/a	0.33	n/a
Total Industrial	**n/a**	**n/a**	**3.53**	**0.42**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0.57	0.16	0.73	0.73
Animal Specialties	0	0	0	0
Total Livestock	**0.57**	**0.16**	**0.73**	**0.73**
Irrigation	**2.04**	**4.78**	**6.82**	**4.44**
FRESH TOTAL	**n/a**	**n/a**	**16**	**6.09**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-0.27	n/a
WW Returns (MGD)	n/a	n/a	0	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

MEHERRIN

1995 Population	40,090
TOTAL FRESH OFFSTREAM USAGE (MGD)	8.50
Per Capita Withdrawal (gpcd)	212.02
Total consumptive uses plus losses (MGD)	9.12
Per capita consumptive uses (gpcd)	227.49
Total water consumed (MGD)	1.69
Consumption/consumptive withdrawal (%)	18.53%

FRESH WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	1.71	1.71	n/a
PS Domestic	n/a	n/a	1.05	n/a
Total Domestic	**n/a**	**n/a**	**2.76**	**0.27**
SS Commercial	0	0.2	0.2	n/a
PS Commercial	n/a	n/a	0.82	n/a
Total Commercial	**n/a**	**n/a**	**1.02**	**0.12**
SS Industrial	0	0.19	0.19	n/a
PS Industrial	n/a	n/a	0.88	n/a
Total Industrial	**n/a**	**n/a**	**1.07**	**0.12**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**2.28**	**0**	**2.28**	**0.27**
Livestock	0.06	0.01	0.07	0.07
Animal Specialties	0	0	0	0
Total Livestock	**0.06**	**0.01**	**0.07**	**0.07**
Irrigation	**1.3**	**0**	**1.3**	**0.84**
FRESH TOTAL	**n/a**	**n/a**	**8.5**	**1.69**

SALINE WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	0.62	n/a
WW Returns (MGD)	n/a	n/a	0.82	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

NOTTOWAY

1995 Population	58,280
TOTAL FRESH OFFSTREAM USAGE (MGD)	16.88
Per Capita Withdrawal (gpcd)	289.64
Total consumptive uses plus losses (MGD)	33.30
Per capita consumptive uses (gpcd)	571.38
Total water consumed (MGD)	4.02
Consumption/consumptive withdrawal (%)	12.07%

FRESH WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	2.87	2.87	n/a
PS Domestic	n/a	n/a	1.11	n/a
Total Domestic	**n/a**	**n/a**	**3.98**	**0.4**
SS Commercial	0	0.82	0.82	n/a
PS Commercial	n/a	n/a	1.45	n/a
Total Commercial	**n/a**	**n/a**	**2.27**	**0.27**
SS Industrial	1.52	5.78	7.3	n/a
PS Industrial	n/a	n/a	0.37	n/a
Total Industrial	**n/a**	**n/a**	**7.67**	**0.92**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	1.22	0.24	1.46	1.46
Animal Specialties	0	0	0	0
Total Livestock	**1.22**	**0.24**	**1.46**	**1.46**
Irrigation	**1.5**	**0**	**1.5**	**0.97**
FRESH TOTAL	**n/a**	**n/a**	**16.88**	**4.02**

SALINE WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	16.42	n/a
WW Returns (MGD)	n/a	n/a	0	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

BLACKWATER/SE COASTAL

1995 Population	508,150
TOTAL FRESH OFFSTREAM USAGE (MGD)	89.11
Per Capita Withdrawal (gpcd)	175.36
Total consumptive uses (MGD)	89.11
Per capita consumptive uses (gpcd)	175.36
Total water consumed (MGD)	10.91
Consumption/consumptive withdrawal (%)	12.24%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	8.11	8.11	n/a
PS Domestic	n/a	n/a	31	n/a
Total Domestic	**n/a**	**n/a**	**39.11**	**3.91**
SS Commercial	0.08	1.32	1.4	n/a
PS Commercial	n/a	n/a	6.61	n/a
Total Commercial	**n/a**	**n/a**	**8.01**	**0.96**
SS Industrial	3.35	34.12	37.47	n/a
PS Industrial	n/a	n/a	3.23	n/a
Total Industrial	**n/a**	**n/a**	**40.7**	**4.89**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0.1	0.76	0.86	0.86
Animal Specialties	0	0	0	0
Total Livestock	**0.1**	**0.76**	**0.86**	**0.86**
Irrigation	**0.42**	**0.01**	**0.43**	**0.29**
FRESH TOTAL	**n/a**	**n/a**	**89.11**	**10.91**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-12.77	n/a
WW Returns (MGD)	n/a	n/a	1.22	n/a
Reservoir Evap (AC-FT/yr)	8210	n/a	8210	8210

UPPER ROANOKE

1995 Population	345,840
TOTAL FRESH OFFSTREAM USAGE (MGD)	57.54
Per Capita Withdrawal (gpcd)	166.38
Total consumptive uses (MGD)	57.10
Per capita consumptive uses (gpcd)	165.11
Withdrawal plus hydroelectric (gpcd)	2,921.30
Per capita plus hydroelectric (gpcd)	8,446.97
Total water consumed (MGD)	12.60
Consumption/consumptive withdrawal (%)	22.07%

FRESH WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	5.66	5.66	n/a
PS Domestic	n/a	n/a	21.62	n/a
Total Domestic	**n/a**	**n/a**	**27.28**	**2.73**
SS Commercial	2.32	4.25	6.57	n/a
PS Commercial	n/a	n/a	6.06	n/a
Total Commercial	**n/a**	**n/a**	**12.63**	**1.52**
SS Industrial	5.18	0.16	5.34	n/a
PS Industrial	n/a	n/a	4.16	n/a
Total Industrial	**n/a**	**n/a**	**9.5**	**1.14**
SS Thermoelectric	0.44	0	0.44	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0.44**	**0**
Mining	**0.01**	**0.01**	**0.02**	**0**
Livestock	3.96	2.33	6.29	6.29
Animal Specialties	0.01	0.01	0.02	0.02
Total Livestock	**3.97**	**2.34**	**6.31**	**6.31**
Irrigation	**1.25**	**0.11**	**1.36**	**0.9**
FRESH TOTAL	**n/a**	**n/a**	**57.54**	**12.6**

SALINE WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	2864.2	0	2864.2	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-0.11	n/a
WW Returns (MGD)	n/a	n/a	36.85	n/a
Reservoir Evap (AC-FT/yr)	44570	n/a	44570	44570

LOWER ROANOKE

1995 Population	85,890
TOTAL FRESH OFFSTREAM USAGE (MGD)	22.20
Per Capita Withdrawal (gpcd)	258.47
Total consumptive uses (MGD)	17.63
Per capita consumptive uses (gpcd)	205.26
Withdrawal plus hydroelectric (gpcd)	4,805.21
Per capita plus hydroelectric (gpcd)	55,946.09
Total water consumed (MGD)	4.12
Consumption/consumptive withdrawal (%)	23.37%

FRESH WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	4.03	4.03	n/a
PS Domestic	n/a	n/a	2.07	n/a
Total Domestic	**n/a**	**n/a**	**6.1**	**0.61**
SS Commercial	0.01	0.46	0.47	n/a
PS Commercial	n/a	n/a	0.71	n/a
Total Commercial	**n/a**	**n/a**	**1.18**	**0.14**
SS Industrial	5.51	0	5.51	n/a
PS Industrial	n/a	n/a	1.66	n/a
Total Industrial	**n/a**	**n/a**	**7.17**	**0.86**
SS Thermoelectric	4.56	0.01	4.57	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**4.57**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	1.03	0.24	1.27	1.27
Animal Specialties	0	0	0	0
Total Livestock	**1.03**	**0.24**	**1.27**	**1.27**
Irrigation	**1.9**	**0.01**	**1.91**	**1.24**
FRESH TOTAL	**n/a**	**n/a**	**22.2**	**4.12**

SALINE WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	4787.58	0	4787.58	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-2.58	n/a
WW Returns (MGD)	n/a	n/a	0.67	n/a
Reservoir Evap (AC-FT/yr)	89780	n/a	89780	89780

MARTINSVILLE/ARARAT

1995 Population	109,637
TOTAL FRESH OFFSTREAM USAGE (MGD)	49.73
Per Capita Withdrawal (gpcd)	453.57
Total consumptive uses (MGD)	49.73
Per capita consumptive uses (gpcd)	453.57
Withdrawal plus hydroelectric (gpcd)	352.93
Per capita plus hydroelectric (gpcd)	3,219.06
Total water consumed (MGD)	6.34
Consumption/consumptive withdrawal (%)	12.74%

FRESH WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	3.29	3.29	n/a
PS Domestic	n/a	n/a	4.03	n/a
Total Domestic	**n/a**	**n/a**	**7.32**	**0.73**
SS Commercial	0.12	0.29	0.41	n/a
PS Commercial	n/a	n/a	1.62	n/a
Total Commercial	**n/a**	**n/a**	**2.03**	**0.24**
SS Industrial	31.94	2.06	34	n/a
PS Industrial	n/a	n/a	5.57	n/a
Total Industrial	**n/a**	**n/a**	**39.57**	**4.75**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0.24	0.025	0.265	0.265
Animal Specialties	0	0	0	0
Total Livestock	**0.24**	**0.025**	**0.265**	**0.265**
Irrigation	**0.543**	**0**	**0.543**	**0.35**
FRESH TOTAL	**n/a**	**n/a**	**49.728**	**6.335**

SALINE WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	303.2	0	303.2	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-3.44	n/a
WW Returns (MGD)	n/a	n/a	45.32	n/a
Reservoir Evap (AC-FT/yr)	9490	n/a	9490	9490

UPPER DAN RIVER (North Carolina)

1995 Population	123,420
TOTAL FRESH OFFSTREAM USAGE (MGD)	957.25
Per Capita Withdrawal (gpcd)	7756.04
Total consumptive uses plus losses (MGD)	23.40
Per capita consumptive uses (gpcd)	189.60
Total water consumed (MGD)	9.74
Consumption/consumptive withdrawal (%)	41.62%

FRESH WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	6.01	6.01	n/a
PS Domestic	n/a	n/a	3.04	n/a
Total Domestic	**n/a**	**n/a**	**9.05**	**2.7**
SS Commercial	0	0.3	0.3	n/a
PS Commercial	n/a	n/a	0.92	n/a
Total Commercial	**n/a**	**n/a**	**1.22**	**0.06**
SS Industrial	0.23	0.02	0.25	n/a
PS Industrial	n/a	n/a	7.25	n/a
Total Industrial	**n/a**	**n/a**	**7.5**	**1.5**
SS Thermoelectric	934	0	934	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**934**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0.33	0.22	0.55	0.55
Animal Specialties	0	0	0	0
Total Livestock	**0.33**	**0.22**	**0.55**	**0.55**
Irrigation	**4.46**	**0.47**	**4.93**	**4.93**
FRESH TOTAL	**n/a**	**n/a**	**957.25**	**9.74**

SALINE WATER DEMAND (MGD)

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	0.15	n/a
WW Returns (MGD)	n/a	n/a	147.26	n/a
Reservoir Evap (AC-FT/yr)	11890	n/a	11890	11890

LOWER DAN RIVER (North Carolina)

1995 Population	48,910
TOTAL FRESH OFFSTREAM USAGE (MGD)	680.48
Per Capita Withdrawal (gpcd)	13912.90
Total consumptive uses (MGD)	681.16
Per capita consumptive uses (gpcd)	13,926.80
Total uses minus thermoelectric (MGD)	11.16
per capita use less termoelectric (gpcd)	228.17
Total water consumed less thermo (MGD)	4.95
consumption/consumptive withdrawal (%)	44.35%
Total water consumed (MGD)	35.95
Consumption/consumptive withdrawal (%)	5.28%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	2.39	2.39	n/a
PS Domestic	n/a	n/a	0.72	n/a
Total Domestic	**n/a**	**n/a**	**3.11**	**0.91**
SS Commercial	0.01	0.04	0.05	n/a
PS Commercial	n/a	n/a	0.44	n/a
Total Commercial	**n/a**	**n/a**	**0.49**	**0.02**
SS Industrial	0.5	0.21	0.71	n/a
PS Industrial	n/a	n/a	2.87	n/a
Total Industrial	**n/a**	**n/a**	**3.58**	**0.72**
SS Thermoelectric	670	0	670	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**670**	**31**
Mining	**0**	**0**	**0**	**0**
Livestock	0.11	0.27	0.38	0.38
Animal Specialties	0	0	0	0
Total Livestock	**0.11**	**0.27**	**0.38**	**0.38**
Irrigation	**1.37**	**1.55**	**2.92**	**2.92**
FRESH TOTAL	**n/a**	**n/a**	**680.48**	**35.95**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	0.68	n/a
WW Returns (MGD)	n/a	n/a	28.78	n/a
Reservoir Evap (AC-FT/yr)	22610	n/a	22610	22610

DANVILLE

1995 Population	114,453
TOTAL FRESH OFFSTREAM USAGE (MGD)	23.90
Per Capita Withdrawal (gpcd)	208.82
Total consumptive uses (MGD)	23.90
Per capita consumptive uses (gpcd)	208.82
Total water consumed (MGD)	4.11
Consumption/consumptive withdrawal (%)	17.20%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	3.5	3.5	n/a
PS Domestic	n/a	n/a	4.45	n/a
Total Domestic	**n/a**	**n/a**	**7.95**	**0.79**
SS Commercial	0.13	0.22	0.35	n/a
PS Commercial	n/a	n/a	1.64	n/a
Total Commercial	**n/a**	**n/a**	**1.99**	**0.23**
SS Industrial	6.25	0.42	6.67	n/a
PS Industrial	n/a	n/a	4.86	n/a
Total Industrial	**n/a**	**n/a**	**11.53**	**1.39**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0.13**	**0**	**0.13**	**0.02**
Livestock	0.46	0.06	0.52	0.52
Animal Specialties	0	0	0	0
Total Livestock	**0.46**	**0.06**	**0.52**	**0.52**
Irrigation	**1.76**	**0.02**	**1.78**	**1.16**
FRESH TOTAL	**n/a**	**n/a**	**23.9**	**4.11**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	-4.46	n/a
WW Returns (MGD)	n/a	n/a	16.15	n/a
Reservoir Evap (AC-FT/yr)	60	n/a	60	60

UPPER NEW (North Carolina)

1995 Population	179,630
TOTAL FRESH OFFSTREAM USAGE (MGD)	15.98
Per Capita Withdrawal (gpcd)	88.96
Total consumptive uses plus losses (MGD)	17.71
Per capita consumptive uses (gpcd)	98.59
Total water consumed (MGD)	7.06
Consumption/consumptive withdrawal (%)	39.86%

FRESH WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	4.71	4.71	n/a
PS Domestic	n/a	n/a	7.48	n/a
Total Domestic	**n/a**	**n/a**	**12.19**	**3.91**
SS Commercial	0	0.08	0.08	n/a
PS Commercial	n/a	n/a	0.55	n/a
Total Commercial	**n/a**	**n/a**	**0.63**	**0.03**
SS Industrial	0	0	0	n/a
PS Industrial	n/a	n/a	0.05	n/a
Total Industrial	**n/a**	**n/a**	**0.05**	**0.01**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0	0.72	0.72	0.72
Animal Specialties	0	0	0	0
Total Livestock	**0**	**0.72**	**0.72**	**0.72**
Irrigation	**0.71**	**1.68**	**2.39**	**2.39**
FRESH TOTAL	**n/a**	**n/a**	**15.98**	**7.06**

SALINE WATER DEMAND				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	1.73	n/a
WW Returns (MGD)	n/a	n/a	13.75	n/a
Reservoir Evap (AC-FT/yr)	540	n/a	540	540

UPPER NEW

1995 Population	111,705
TOTAL FRESH OFFSTREAM USAGE (MGD)	23.98
Per Capita Withdrawal (gpcd)	214.67
Total consumptive uses plus losses (MGD)	28.32
Per capita consumptive uses (gpcd)	253.52
Withdrawal plus hydroelectric (gpcd)	780.87
Per capita plus hydroelectric (gpcd)	6,990.47
Total water consumed (MGD)	2.80
Consumption/consumptive withdrawal (%)	9.89%

FRESH WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	3.56	3.56	n/a
PS Domestic	n/a	n/a	4.5	n/a
Total Domestic	**n/a**	**n/a**	**8.06**	**0.81**
SS Commercial	0.51	0.63	1.14	n/a
PS Commercial	n/a	n/a	2.91	n/a
Total Commercial	**n/a**	**n/a**	**4.05**	**0.47**
SS Industrial	8.57	0	8.57	n/a
PS Industrial	n/a	n/a	2.4	n/a
Total Industrial	**n/a**	**n/a**	**10.97**	**1.3**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0**	**0**	**0**	**0**
Livestock	0	0	0	0
Animal Specialties	0	0	0	0
Total Livestock	**0**	**0**	**0**	**0**
Irrigation	**0.89**	**0.01**	**0.9**	**0.22**
FRESH TOTAL	**n/a**	**n/a**	**23.98**	**2.8**

SALINE WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	752.55	0	752.55	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	4.34	n/a
WW Returns (MGD)	n/a	n/a	9.93	n/a
Reservoir Evap (AC-FT/yr)	6305	n/a	6305	6305

LOWER NEW

1995 Population	94,975
TOTAL FRESH OFFSTREAM USAGE (MGD)	262.00
Per Capita Withdrawal (gpcd)	2758.62
Total consumptive uses plus losses (MGD)	23.24
Per capita consumptive uses (gpcd)	244.70
Withdrawal plus hydroelectric (gpcd)	1,898.06
Per capita plus hydroelectric (gpcd)	19,984.84
Total water consumed (MGD)	2.56
Consumption/consumptive withdrawal (%)	11.02%

FRESH WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
SS Domestic	0	2.66	2.66	n/a
PS Domestic	n/a	n/a	3.88	n/a
Total Domestic	**n/a**	**n/a**	**6.54**	**0.81**
SS Commercial	0.48	0.53	1.01	n/a
PS Commercial	n/a	n/a	2.33	n/a
Total Commercial	**n/a**	**n/a**	**3.34**	**0.4**
SS Industrial	4.41	4.58	8.99	n/a
PS Industrial	n/a	n/a	1.46	n/a
Total Industrial	**n/a**	**n/a**	**10.45**	**1.24**
SS Thermoelectric	240.78	0	240.78	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**240.78**	**0**
Mining	**0.02**	**0.29**	**0.31**	**0**
Livestock	0	0	0	0
Animal Specialties	0	0	0	0
Total Livestock	**0**	**0**	**0**	**0**
Irrigation	**0.57**	**0.01**	**0.58**	**0.11**
FRESH TOTAL	**n/a**	**n/a**	**262**	**2.56**

SALINE WATER DEMAND

DEMAND	SW	GW	TOTAL	CONSUMED
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION

Hydroelectric (MGD)	1874.82	0	1874.82	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	2.02	n/a
WW Returns (MGD)	n/a	n/a	8.44	n/a
Reservoir Evap (AC-FT/yr)	3165	n/a	3165	3165

HOLSTON

1995 Population	113,400
TOTAL FRESH OFFSTREAM USAGE (MGD)	14.54
Per Capita Withdrawal (gpcd)	128.22
Total consumptive uses plus losses (MGD)	16.94
Per capita consumptive uses (gpcd)	149.38
Total water consumed (MGD)	1.73
Consumption/consumptive withdrawal (%)	10.21%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	0.88	0.88	n/a
PS Domestic	n/a	n/a	6.94	n/a
Total Domestic	**n/a**	**n/a**	**7.82**	**0.78**
SS Commercial	0.09	0.29	0.38	n/a
PS Commercial	n/a	n/a	3	n/a
Total Commercial	**n/a**	**n/a**	**3.38**	**0.4**
SS Industrial	0.23	0.56	0.79	n/a
PS Industrial	n/a	n/a	2.24	n/a
Total Industrial	**n/a**	**n/a**	**3.03**	**0.36**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**0.02**	**0**	**0.02**	**0**
Livestock	0.03	0.02	0.05	0.05
Animal Specialties	0	0	0	0
Total Livestock	**0.03**	**0.02**	**0.05**	**0.05**
Irrigation	**0.24**	**0**	**0.24**	**0.14**
FRESH TOTAL	**n/a**	**n/a**	**14.54**	**1.73**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	2.4	n/a
WW Returns (MGD)	n/a	n/a	2.94	n/a
Reservoir Evap (AC-FT/yr)	2830	n/a	2830	2830

CLINCH/POWELL

1995 Population	46,280
TOTAL FRESH OFFSTREAM USAGE (MGD)	27.71
Per Capita Withdrawal (gpcd)	598.75
Total consumptive uses plus losses (MGD)*	29.74
Per capita consumptive uses (gpcd)	642.61
Total water consumed (MGD)	11.00
Consumption/consumptive withdrawal (%)	36.99%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	3.42	3.42	n/a
PS Domestic	n/a	n/a	6.32	n/a
Total Domestic	**n/a**	**n/a**	**9.74**	**0.98**
SS Commercial	0.04	0.25	0.29	n/a
PS Commercial	n/a	n/a	2.54	n/a
Total Commercial	**n/a**	**n/a**	**2.83**	**0.34**
SS Industrial	0	0.13	0.13	n/a
PS Industrial	n/a	n/a	0.4	n/a
Total Industrial	**n/a**	**n/a**	**0.53**	**0.06**
SS Thermoelectric	9.71	0.03	9.74	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**9.74**	**8.84**
Mining	**3.26**	**1.39**	**4.65**	**0.56**
Livestock	0.16	0.06	0.22	0.22
Animal Specialties	0	0	0	0
Total Livestock	**0.16**	**0.06**	**0.22**	**0.22**
Irrigation	**0**	**0**	**0**	**0**
FRESH TOTAL	**n/a**	**n/a**	**27.71**	**11**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	2.03	n/a
WW Returns (MGD)	n/a	n/a	5.19	n/a
Reservoir Evap (AC-FT/yr)	0	n/a	0	0

BIG SANDY

1995 Population	62,220
TOTAL FRESH OFFSTREAM USAGE (MGD)	69.95
Per Capita Withdrawal (gpcd)	1124.24
Total consumptive uses plus losses (MGD)*	71.75
Per capita consumptive uses (gpcd)	1,153.17
Total water consumed (MGD)	8.30
Consumption/consumptive withdrawal (%)	11.57%

FRESH WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
SS Domestic	0	1.99	1.99	n/a
PS Domestic	n/a	n/a	2.17	n/a
Total Domestic	**n/a**	**n/a**	**4.16**	**0.41**
SS Commercial	0.02	0.18	0.2	n/a
PS Commercial	n/a	n/a	1.12	n/a
Total Commercial	**n/a**	**n/a**	**1.32**	**0.16**
SS Industrial	62.1	0	62.1	n/a
PS Industrial	n/a	n/a	0.07	n/a
Total Industrial	**n/a**	**n/a**	**62.17**	**7.45**
SS Thermoelectric	0	0	0	n/a
PS Thermoelectric	n/a	n/a	0	n/a
Total Thermoelectric	**n/a**	**n/a**	**0**	**0**
Mining	**1.73**	**0.57**	**2.3**	**0.28**
Livestock	0	0	0	0
Animal Specialties	0	0	0	0
Total Livestock	**0**	**0**	**0**	**0**
Irrigation	**0**	**0**	**0**	**0**
FRESH TOTAL	**n/a**	**n/a**	**69.95**	**8.3**

SALINE WATER DEMAND (MGD)				
DEMAND	**SW**	**GW**	**TOTAL**	**CONSUMED**
Thermoelectric	0	0	0	0
Industrial	0	0	0	0
SALINE TOTAL	**0**	**0**	**0**	**0**

OTHER INFORMATION				
Hydroelectric (MGD)	0	0	0	0
Losses(+)/Gains(-) (MGD)	n/a	n/a	1.8	n/a
WW Returns (MGD)	n/a	n/a	0	n/a
Reservoir Evap (AC-FT/yr)	2220	n/a	2220	2220

APPENDIX K: OFFSTREAM AND INSTREAM DEMAND PROJECTIONS BY PLANNING AREA

1 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	1,676,800	193.92	115.65	12.8	206.72	123.28	20.38	12.15
2000	1,720,300	198.95	115.65	12.8	211.75	123.09	20.91	12.15
2005	1,800,700	208.25	115.65	12.8	221.05	122.76	21.89	12.15
2015	1,947,500	225.23	115.65	12.8	238.03	122.22	23.67	12.15
2025	2,081,500	240.73	115.65	12.8	253.53	121.80	25.30	12.15

2 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	147,000	20.41	138.82	5.5	25.91	176.23	3.18	21.61
2000	150,900	20.95	138.82	5.5	26.45	175.27	3.26	21.61
2005	157,900	21.92	138.82	5.5	27.42	173.65	3.41	21.61
2015	170,800	23.71	138.82	5.5	29.21	171.02	3.69	21.61
2025	182,500	25.33	138.82	5.5	30.83	168.96	3.94	21.61

3 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	146,200	45.06	308.19	108.1	153.16	1,047.59	6.21	42.47
2000	150,000	46.23	308.19	108.1	154.33	1,028.86	6.37	42.47
2005	157,000	48.39	308.19	108.1	156.49	996.73	6.67	42.47
2015	169,800	52.33	308.19	108.1	160.43	944.82	7.21	42.47
2025	181,400	55.91	308.19	108.1	164.01	904.11	7.70	42.47

4 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	217,700	41.86	192.29	235.9	277.76	1,275.89	9.39	43.11
2000	223,300	42.94	192.29	235.9	278.84	1,248.72	9.63	43.11
2005	233,700	44.94	192.29	235.9	280.84	1,201.70	10.08	43.11
2015	252,800	48.61	192.29	235.9	284.51	1,125.44	10.90	43.11
2025	270,200	51.96	192.29	235.9	287.86	1,065.35	11.65	43.11

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	107,500	14.28	132.81	28.4	42.68	397.00	2.41	22.39
2000	110,300	14.65	132.81	28.4	43.05	390.29	2.47	22.39
2005	115,500	15.34	132.81	28.4	43.74	378.70	2.59	22.39
2015	124,900	16.59	132.81	28.4	44.99	360.19	2.80	22.39
2025	133,500	17.73	132.81	28.4	46.13	345.54	2.99	22.39

6

YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	104,600	18.42	176.13	52.8	71.22	680.91	4.42	42.24
2000	107,300	18.90	176.13	52.8	71.70	668.21	4.53	42.24
2005	112,300	19.78	176.13	52.8	72.58	646.30	4.74	42.24
2015	121,400	21.38	176.13	52.8	74.18	611.06	5.13	42.24
2025	129,800	22.86	176.13	52.8	75.66	582.91	5.48	42.24

7

YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	141,900	37.47	264.03	33	70.47	496.59	6.68	47.05
2000	145,600	38.44	264.03	33	71.44	490.68	6.85	47.05
2005	152,400	40.24	264.03	33	73.24	480.57	7.17	47.05
2015	164,800	43.51	264.03	33	76.51	464.27	7.75	47.05
2025	176,200	46.52	264.03	33	79.52	451.32	8.29	47.05

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	67,300	34.00	505.16	17.1	51.10	759.25	4.99	74.11
2000	69,000	34.86	505.16	17.1	51.96	752.99	5.11	74.11
2005	72,300	36.52	505.16	17.1	53.62	741.67	5.36	74.11
2015	78,200	39.50	505.16	17.1	56.60	723.83	5.80	74.11
2025	83,500	42.18	505.16	17.1	59.28	709.95	6.19	74.11

9 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	170,700	118.43	693.80	232.5	350.93	2,055.84
2000	175,100	121.48	693.80	232.5	353.98	2,021.61
2005	183,300	127.17	693.80	232.5	359.67	1,962.21
2015	198,200	137.51	693.80	232.5	370.01	1,866.86
2025	211,800	146.95	693.80	232.5	379.45	1,791.53

Projected MGD Consumed	Proj. cons. (gpcd)
15.19	89.01
15.59	89.01
16.32	89.01
17.64	89.01
18.85	89.01

10 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	279,100	57.34	205.46	379.2	436.54	1,564.11
2000	286,300	58.82	205.46	379.2	438.02	1,529.94
2005	299,700	61.58	205.46	379.2	440.78	1,470.73
2015	324,100	66.59	205.46	379.2	445.79	1,375.47
2025	346,400	71.17	205.46	379.2	450.37	1,300.15

Projected MGD Consumed	Proj. cons. (gpcd)
9.40	33.67
9.64	33.67
10.09	33.67
10.91	33.67
11.66	33.67

11 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	172,500	53.32	309.13	380.2	433.52	2,513.19
2000	177,000	54.72	309.13	380.2	434.92	2,457.15
2005	185,200	57.25	309.13	380.2	437.45	2,362.05
2015	200,300	61.92	309.13	380.2	442.12	2,207.28
2025	214,100	66.18	309.13	380.2	446.38	2,084.94

Projected MGD Consumed	Proj. cons. (gpcd)
3.82	22.16
3.92	22.16
4.10	22.16
4.44	22.16
4.75	22.16

12 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	270,500	74.09	273.90	44.9	118.99	439.89
2000	277,500	76.01	273.90	44.9	120.91	435.70
2005	290,500	79.57	273.90	44.9	124.47	428.46
2015	314,200	86.06	273.90	44.9	130.96	416.80
2025	335,800	91.98	273.90	44.9	136.88	407.61

Projected MGD Consumed	Proj. cons. (gpcd)
7.17	26.51
7.36	26.51
7.70	26.51
8.33	26.51
8.90	26.51

13

YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	1,068,200	476.18	445.78	453.6	929.78	870.42
2000	1,095,900	488.53	445.78	453.6	942.13	859.69
2005	1,147,100	511.35	445.78	453.6	964.95	841.21
2015	1,240,600	553.03	445.78	453.6	1006.63	811.41
2025	1,326,000	591.10	445.78	453.6	1044.70	787.86

Projected MGD Consumed	Proj. cons. (gpcd)
49.57	46.41
50.86	46.41
53.23	46.41
57.57	46.41
61.53	46.41

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	414,500	47.26	114.02	4.3	51.56	124.39
2000	425,200	48.48	114.02	4.3	52.78	124.13
2005	445,100	50.75	114.02	4.3	55.05	123.68
2015	481,400	54.89	114.02	4.3	59.19	122.95
2025	514,500	58.66	114.02	4.3	62.96	122.38

Projected MGD Consumed	Proj. cons. (gpcd)
7.03	16.95
7.21	16.95
7.55	16.95
8.16	16.95
8.72	16.95

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	45,000	15.95	354.53	n/a	n/a	n/a
2000	46,100	16.34	354.53	n/a	n/a	n/a
2005	48,300	17.12	354.53	n/a	n/a	n/a
2015	52,200	18.51	354.53	n/a	n/a	n/a
2025	55,800	19.78	354.53	n/a	n/a	n/a

Projected MGD Consumed	Proj. cons. (gpcd)
6.07	134.93
6.22	134.93
6.52	134.93
7.04	134.93
7.53	134.93

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	40,600	9.24	227.49	22.2	31.44	774.29
2000	41,600	9.46	227.49	22.2	31.66	761.14
2005	43,600	9.92	227.49	22.2	32.12	736.66
2015	47,100	10.71	227.49	22.2	32.91	698.83
2025	50,400	11.47	227.49	22.2	33.67	667.97

Projected MGD Consumed	Proj. cons. (gpcd)
1.71	42.15
1.75	42.15
1.84	42.15
1.99	42.15
2.12	42.15

17

YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	63,300	36.17	571.38	23.2	59.37	937.89	4.37	68.97
2000	64,900	37.08	571.38	23.2	60.28	928.85	4.48	68.97
2005	68,000	38.85	571.38	23.2	62.05	912.56	4.69	68.97
2015	73,500	42.00	571.38	23.2	65.20	887.03	5.07	68.97
2025	78,600	44.91	571.38	23.2	68.11	866.55	5.42	68.97

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	525,800	92.20	175.36	2.9	95.10	180.88	11.29	21.46
2000	539,400	94.59	175.36	2.9	97.49	180.74	11.58	21.46
2005	564,600	99.01	175.36	2.9	101.91	180.50	12.12	21.46
2015	610,700	107.09	175.36	2.9	109.99	180.11	13.11	21.46
2025	652,700	114.46	175.36	2.9	117.36	179.80	14.01	21.46

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	351,000	57.95	165.11	210.4	268.35	764.54	12.79	36.44
2000	360,100	59.46	165.11	210.4	269.86	749.39	13.12	36.44
2005	377,000	62.25	165.11	210.4	272.65	723.20	13.74	36.44
2015	407,700	67.32	165.11	210.4	277.72	681.18	14.86	36.44
2025	435,800	71.95	165.11	210.4	282.35	647.90	15.88	36.44

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YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	89,200	18.31	205.26	699.1	717.41	8,042.70	4.28	47.97
2000	91,500	18.78	205.26	699.1	717.88	7,845.70	4.39	47.97
2005	95,800	19.66	205.26	699.1	718.76	7,502.75	4.60	47.97
2015	103,600	21.26	205.26	699.1	720.36	6,953.33	4.97	47.97
2025	110,800	22.74	205.26	699.1	721.84	6,514.83	5.31	47.97

21 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	96,100	43.59	453.57	196.7	240.29	2,500.40	5.55	57.78
2000	98,600	44.72	453.57	196.7	241.42	2,448.50	5.70	57.78
2005	103,200	46.81	453.57	196.7	243.51	2,359.58	5.96	57.78
2015	111,600	50.62	453.57	196.7	247.32	2,216.11	6.45	57.78
2025	119,300	54.11	453.57	196.7	250.81	2,102.35	6.89	57.78

22 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	121,400	25.35	208.82	308.9	334.25	2,753.30	4.36	35.92
2000	124,600	26.02	208.82	308.9	334.92	2,687.95	4.48	35.92
2005	130,400	27.23	208.82	308.9	336.13	2,577.69	4.68	35.92
2015	141,000	29.44	208.82	308.9	338.34	2,399.60	5.06	35.92
2025	150,700	31.47	208.82	308.9	340.37	2,258.59	5.41	35.92

23 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	80,700	20.46	253.52	468.5	488.96	6,058.97	2.02	25.07
2000	82,800	20.99	253.52	468.5	489.49	5,911.73	2.08	25.07
2005	86,700	21.98	253.52	468.5	490.48	5,657.21	2.17	25.07
2015	93,700	23.75	253.52	468.5	492.25	5,253.52	2.35	25.07
2025	100,200	25.40	253.52	468.5	493.90	4,929.17	2.51	25.07

24 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)	Projected MGD Consumed	Proj. cons. (gpcd)
1998*	126,500	30.95	244.70	736.1	767.05	6,063.67	3.41	26.97
2000	129,800	31.76	244.70	736.1	767.86	5,915.73	3.50	26.97
2005	135,900	33.25	244.70	736.1	769.35	5,661.18	3.66	26.97
2015	146,900	35.95	244.70	736.1	772.05	5,255.59	3.96	26.97
2025	157,100	38.44	244.70	736.1	774.54	4,930.25	4.24	26.97

25 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	113,100	16.89	149.38	151.9	168.79	1,492.44
2000	116,100	17.34	149.38	151.9	169.24	1,457.73
2005	121,500	18.15	149.38	151.9	170.05	1,399.59
2015	131,400	19.63	149.38	151.9	171.53	1,305.39
2025	140,400	20.97	149.38	151.9	172.87	1,231.29

Projected MGD Consumed	Proj. cons. (gpcd)
1.86	16.46
1.91	16.46
2.00	16.46
2.16	16.46
2.31	16.46

26 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	121,700	78.21	642.61	116.4	194.61	1,599.06
2000	124,800	80.20	642.61	116.4	196.60	1,575.30
2005	130,700	83.99	642.61	116.4	200.39	1,533.20
2015	141,300	90.80	642.61	116.4	207.20	1,466.39
2025	151,000	97.03	642.61	116.4	213.43	1,413.47

Projected MGD Consumed	Proj. cons. (gpcd)
28.93	237.70
29.67	237.70
31.07	237.70
33.59	237.70
35.89	237.70

27 YEAR	Projected population	Projected consumptive uses (MGD)	Consumptive Off. D. (gpcd)	In.D. (MGD)	Instream+ Cons. Off. demand (MGD)	In.+Cons.Off. demand (gpcd)
1998*	61,200	70.57	1,153.17	9.3	79.87	1,305.13
2000	62,800	72.42	1,153.17	9.3	81.72	1,301.26
2005	65,700	75.76	1,153.17	9.3	85.06	1,294.72
2015	71,100	81.99	1,153.17	9.3	91.29	1,283.97
2025	75,900	87.53	1,153.17	9.3	96.83	1,275.70

Projected MGD Consumed	Proj. cons. (gpcd)
8.17	133.42
8.38	133.42
8.77	133.42
9.49	133.42
10.13	133.42

APPENDIX L: WATER SUPPLY AVAILABILITY BY PLANNING AREA 1998-2025

1 UP

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	**922.5**	**922.5**	**922.5**	**922.5**	**922.5**	100.00%
7Q10	**12.8**	**12.8**	**12.8**	**12.8**	**12.8**	1.39%
1Q30	**3.2**	**3.2**	**3.2**	**3.2**	**3.2**	0.35%
Q95	**45.3**	**45.3**	**45.3**	**45.3**	**45.3**	4.91%
Q90	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a
Q50	**406.7**	**406.7**	**406.7**	**406.7**	**406.7**	44.09%
MBFest	**440.7**	**440.7**	**440.7**	**440.7**	**440.7**	47.77%
Q10	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	193.92	12.8	206.72	728.58	-181.12	-190.72	-148.62	n/a	21.02%
2000	198.95	12.8	211.75	723.55	-186.15	-195.75	-153.65	n/a	21.57%
2005	208.25	12.8	221.05	714.25	-195.45	-205.05	-162.95	n/a	22.57%
2015	225.23	12.8	238.03	697.27	-212.43	-222.03	-179.93	n/a	24.42%
2025	240.73	12.8	253.53	681.77	-227.93	-237.53	-195.43	n/a	26.09%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	715.78	-193.92	-203.52	-161.42	n/a
2000	710.75	-198.95	-208.55	-166.45	n/a
2005	701.45	-208.25	-217.85	-175.75	n/a
2015	684.47	-225.23	-234.83	-192.73	n/a
2025	668.97	-240.73	-250.33	-208.23	n/a

2 LP

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	**392.2**	**392.2**	**392.2**	**392.2**	**392.2**	100.00%
7Q10	**5.5**	**5.5**	**5.5**	**5.5**	**5.5**	1.39%
1Q30	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**	0.35%
Q95	**19.3**	**19.3**	**19.3**	**19.3**	**19.3**	4.91%
Q90	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a
Q50	**172.9**	**172.9**	**172.9**	**172.9**	**172.9**	44.09%
MBFest	**187.4**	**187.4**	**187.4**	**187.4**	**187.4**	47.77%
Q10	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	20.41	5.5	25.91	371.76	-14.96	-19.05	-1.14	n/a	5.20%
2000	20.95	5.5	26.45	371.22	-15.50	-19.59	-1.68	n/a	5.34%
2005	21.92	5.5	27.42	370.25	-16.47	-20.56	-2.66	n/a	5.59%
2015	23.71	5.5	29.21	368.45	-18.26	-22.35	-4.45	n/a	6.05%
2025	25.33	5.5	30.83	366.83	-19.88	-23.97	-6.07	n/a	6.46%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	366.26	-20.46	-24.55	-6.64	n/a
2000	365.72	-21.00	-25.09	-7.18	n/a
2005	364.75	-21.97	-26.06	-8.16	n/a
2015	362.95	-23.76	-27.85	-9.95	n/a
2025	361.33	-25.38	-29.47	-11.57	n/a

3 US/L

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	$\%Q_{am}$
Q_{am}	770.5	770.5	770.5	770.5	770.5	100.00%
7Q10	108.1	108.1	108.1	108.1	108.1	14.03%
1Q30	89.0	89.0	89.0	89.0	89.0	11.55%
Q95	138.2	138.2	138.2	138.2	138.2	17.94%
Q90	176.5	176.5	176.5	176.5	176.5	22.90%
Q50	447.0	447.0	447.0	447.0	447.0	58.02%
MBFest	522.0	522.0	522.0	522.0	522.0	67.75%
Q10	1573.4	1573.4	1573.4	1573.4	1573.4	204.20%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	45.06	108.1	153.16	725.48	63.02	43.91	93.17	131.40	5.85%
2000	46.23	108.1	154.33	724.30	61.85	42.74	92.00	130.23	6.00%
2005	48.39	108.1	156.49	722.15	59.69	40.58	89.84	128.07	6.28%
2015	52.33	108.1	160.43	718.20	55.75	36.63	85.89	124.13	6.79%
2025	55.91	108.1	164.01	714.63	52.17	33.06	82.32	120.55	7.26%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	617.38	-45.08	-64.19	-14.93	23.30
2000	616.20	-46.25	-65.36	-16.10	22.13
2005	614.05	-48.41	-67.52	-18.26	19.97
2015	610.10	-52.35	-71.47	-22.21	16.03
2025	606.53	-55.93	-75.04	-25.78	12.45

4 LS/O

Flow	flow (MGD)	$\%Q_{am}$	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	**1914.3**	100.00%	**1908.1**	**1907.9**	**1907.6**	**1907.1**	**1906.6**
7Q10	**235.9**	12.32%	**229.7**	**229.5**	**229.3**	**228.7**	**228.2**
1Q30	**153.8**	8.04%	**147.6**	**147.5**	**147.2**	**146.6**	**146.1**
Q95	**n/a**	n/a	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Q90	**403.1**	21.06%	**396.9**	**396.7**	**396.4**	**395.9**	**395.4**
Q50	**1078.9**	56.36%	**1072.7**	**1072.5**	**1072.3**	**1071.7**	**1071.2**
MBFest	**n/a**	n/a	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Q10	**3846.6**	200.95%	**3840.4**	**3840.3**	**3840.0**	**3839.4**	**3838.9**

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	41.86	235.9	277.76	1,866.19	187.85	105.76	n/a	355.01	2.19%
2000	42.94	235.9	278.84	1,864.95	186.61	104.53	n/a	353.77	2.24%
2005	44.94	235.9	280.84	1,862.66	184.31	102.23	n/a	351.48	2.35%
2015	48.61	235.9	284.51	1,858.44	180.10	98.01	n/a	347.26	2.54%
2025	51.96	235.9	287.86	1,854.60	176.26	94.17	n/a	343.42	2.71%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,630.29	-48.05	-130.14	n/a	119.11
2000	1,629.05	-49.29	-131.37	n/a	117.87
2005	1,626.76	-51.59	-133.67	n/a	115.58
2015	1,622.54	-55.80	-137.89	n/a	111.36
2025	1,618.70	-59.64	-141.73	n/a	107.52

CUMULATIVE SHEN. BASIN

YEAR	Proj. Off. D. (MGD)	Q_{AM} (MGD)	Off. D. / Q_{AM}(%)
1998	86.92	1914.3	4.54%
2000	89.17	1914.3	4.66%
2005	93.33	1914.3	4.88%
2015	100.94	1914.3	5.27%
2025	107.87	1914.3	5.63%

5 URa

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	**1144**	**1144**	**1144**	**1144**	**1144**	100.00%
7Q10	**28.4**	**28.4**	**28.4**	**28.4**	**28.4**	2.48%
1Q30	**7.6**	**7.6**	**7.6**	**7.6**	**7.6**	0.66%
Q95	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a
Q90	**151**	**151**	**151**	**151**	**151**	13.20%
Q50	**709**	**709**	**709**	**709**	**709**	61.98%
MBFest	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a
Q10	**2303**	**2303**	**2303**	**2303**	**2303**	201.31%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	14.28	28.4	42.68	1,129.72	14.12	-6.68	n/a	136.72	1.25%
2000	14.65	28.4	43.05	1,129.35	13.75	-7.05	n/a	136.35	1.28%
2005	15.34	28.4	43.74	1,128.66	13.06	-7.74	n/a	135.66	1.34%
2015	16.59	28.4	44.99	1,127.41	11.81	-8.99	n/a	134.41	1.45%
2025	17.73	28.4	46.13	1,126.27	10.67	-10.13	n/a	133.27	1.55%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,101.32	-14.28	-35.08	n/a	108.32
2000	1,100.95	-14.65	-35.45	n/a	107.95
2005	1,100.26	-15.34	-36.14	n/a	107.26
2015	1,099.01	-16.59	-37.39	n/a	106.01
2025	1,097.87	-17.73	-38.53	n/a	104.87

6 LRa

Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	**1865.0**	100.00%	**1,862.6**	**1,862.5**	**1,862.4**	**1,862.2**	**1,862.0**
7Q10	**52.8**	2.83%	**50.3**	**50.3**	**50.2**	**50.0**	**49.8**
1Q30	**16.2**	0.87%	**13.7**	**13.7**	**13.6**	**13.4**	**13.2**
Q95	**164.8**	8.84%	**162.4**	**162.4**	**162.3**	**162.1**	**161.9**
Q90	**260.5**	13.97%	**258.1**	**258.0**	**257.9**	**257.7**	**257.5**
Q50	**1099.0**	58.93%	**1,096.6**	**1,096.5**	**1,096.4**	**1,096.2**	**1,096.0**
MBFest	**1024.3**	54.92%	**1,021.9**	**1,021.8**	**1,021.7**	**1,021.5**	**1,021.3**
Q10	**3670.7**	196.82%	**3,668.2**	**3,668.2**	**3,668.1**	**3,667.9**	**3,667.7**

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	18.42	52.8	71.22	1,844.18	31.92	-4.68	144.02	239.63	0.99%
2000	18.90	52.8	71.70	1,843.60	31.38	-5.21	143.48	239.09	1.01%
2005	19.78	52.8	72.58	1,842.62	30.39	-6.21	142.48	238.10	1.06%
2015	21.38	52.8	74.18	1,840.82	28.57	-8.02	140.67	236.28	1.15%
2025	22.86	52.8	75.66	1,839.14	26.90	-9.70	139.00	234.61	1.23%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,791.38	-20.88	-57.48	91.22	186.83
2000	1,790.80	-21.42	-58.01	90.68	186.29
2005	1,789.82	-22.41	-59.01	89.68	185.30
2015	1,788.02	-24.23	-60.82	87.87	183.48
2025	1,786.34	-25.90	-62.50	86.20	181.81

CUMULATIVE RAPP. BASIN

YEAR	Proj. Off. D. (MGD)	Q_{AM} (MGD)	Off. D. / Q_{AM} (%)
1998	32.70	1865.0	1.75%
2000	33.55	1865.0	1.80%
2005	35.12	1865.0	1.88%
2015	37.97	1865.0	2.04%
2025	40.59	1865.0	2.18%

7 Pa

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	
Q_{am}	1028.4	1028.4	1028.4	1028.4	1028.4	
7Q10	33.0	33.0	33.0	33.0	33.0	
1Q30	14.7	14.7	14.7	14.7	14.7	1.43%
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	109.2	109.2	109.2	109.2	109.2	10.62%
Q50	554.7	554.7	554.7	554.7	554.7	53.94%
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	2403.7	2403.7	2403.7	2403.7	2403.7	233.73%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	37.47	33	70.47	990.94	-4.49	-22.79	n/a	71.71	3.64%
2000	38.44	33	71.44	989.96	-5.47	-23.77	n/a	70.74	3.74%
2005	40.24	33	73.24	988.17	-7.26	-25.56	n/a	68.94	3.91%
2015	43.51	33	76.51	984.89	-10.54	-28.83	n/a	65.67	4.23%
2025	46.52	33	79.52	981.88	-13.55	-31.84	n/a	62.66	4.52%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	957.94	-37.49	-55.79	n/a	38.71
2000	956.96	-38.47	-56.77	n/a	37.74
2005	955.17	-40.26	-58.56	n/a	35.94
2015	951.89	-43.54	-61.83	n/a	32.67
2025	948.88	-46.55	-64.84	n/a	29.66

8 Ma

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	576.3	576.3	576.3	576.3	576.3	100.00%
7Q10	17.1	17.1	17.1	17.1	17.1	2.96%
1Q30	8.0	8.0	8.0	8.0	8.0	1.39%
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	63.7	63.7	63.7	63.7	63.7	11.05%
Q50	370.5	370.5	370.5	370.5	370.5	64.29%
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	1313.3	1313.3	1313.3	1313.3	1313.3	227.89%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	34.00	17.1	51.10	542.27	-16.91	-25.99	n/a	29.71	5.90%
2000	34.86	17.1	51.96	541.42	-17.77	-26.85	n/a	28.85	6.05%
2005	36.52	17.1	53.62	539.75	-19.44	-28.52	n/a	27.18	6.34%
2015	39.50	17.1	56.60	536.77	-22.42	-31.50	n/a	24.20	6.86%
2025	42.18	17.1	59.28	534.09	-25.10	-34.17	n/a	21.52	7.32%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	525.17	-34.01	-43.09	n/a	12.61
2000	524.32	-34.87	-43.95	n/a	11.75
2005	522.65	-36.54	-45.62	n/a	10.08
2015	519.67	-39.52	-48.60	n/a	7.10
2025	516.99	-42.20	-51.27	n/a	4.42

9 UJ/M

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	2372.7	2372.7	2372.7	2372.7	2372.7	100.00%
7Q10	232.5	232.5	232.5	232.5	232.5	9.80%
1Q30	179.8	179.8	179.8	179.8	179.8	7.58%
Q95	305.1	305.1	305.1	305.1	305.1	12.86%
Q90	460.6	460.6	460.6	460.6	460.6	19.41%
Q50	1185.7	1185.7	1185.7	1185.7	1185.7	49.97%
MBFest	1274.8	1274.8	1274.8	1274.8	1274.8	53.73%
Q10	5236.5	5236.5	5236.5	5236.5	5236.5	220.70%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	118.43	232.5	350.93	2,254.27	114.07	61.37	186.67	342.17	4.99%
2000	121.48	232.5	353.98	2,251.22	111.02	58.32	183.62	339.12	5.12%
2005	127.17	232.5	359.67	2,245.53	105.33	52.63	177.93	333.43	5.36%
2015	137.51	232.5	370.01	2,235.19	94.99	42.29	167.59	323.09	5.80%
2025	146.95	232.5	379.45	2,225.75	85.55	32.85	158.15	313.65	6.19%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	2,021.77	-118.43	-171.13	-45.83	109.67
2000	2,018.72	-121.48	-174.18	-48.88	106.62
2005	2,013.03	-127.17	-179.87	-54.57	100.93
2015	2,002.69	-137.51	-190.21	-64.91	90.59
2025	1,993.25	-146.95	-199.65	-74.35	81.15

10 UMJ/R	Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
	Q_{am}	4572.1	100.00%	4,556.9	4,556.5	4,555.8	4,554.5	4,553.2
	7Q10	379.2	8.29%	364.0	363.7	362.9	361.6	360.4
	1Q30	247.6	5.42%	232.4	232.0	231.3	230.0	228.8
	Q95	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Q90	922.3	20.17%	907.1	906.7	906.0	904.7	903.5
	Q50	2659.5	58.17%	2,644.3	2,643.9	2,643.2	2,641.9	2,640.7
	MBFest	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Q10	9744.2	213.12%	9,729.0	9,728.6	9,727.9	9,726.5	9,725.3

YEAR	Proj consum Off. D. (MGD)	In. D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	10%Q_{am}-OffD (MGD)	20%Q_{am}-OffD (MGD)	Off D as % Qam
1998*	57.34	379.2	436.54	4,499.56	306.70	175.07	n/a	849.78	399.87	857.08	1.25%
2000	58.82	379.2	438.02	4,497.69	304.83	173.20	n/a	847.91	398.39	855.60	1.29%
2005	61.58	379.2	440.78	4,494.21	301.35	169.72	n/a	844.43	395.63	852.84	1.35%
2015	66.59	379.2	445.79	4,487.87	295.01	163.38	n/a	838.09	390.62	847.83	1.46%
2025	71.17	379.2	450.37	4,482.08	289.22	157.58	n/a	832.29	386.04	843.25	1.56%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	4,120.36	-72.50	-204.13	n/a	470.58
2000	4,118.49	-74.37	-206.00	n/a	468.71
2005	4,115.01	-77.85	-209.48	n/a	465.23
2015	4,108.67	-84.19	-215.82	n/a	458.89
2025	4,102.88	-89.98	-221.62	n/a	453.09

CUMULATIVE JAMES BASIN

YEAR	Proj. Off. D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)
1998	175.77	4572.1	3.84%
2000	180.3	4572.1	3.94%
2005	188.75	4572.1	4.13%
2015	204.1	4572.1	4.46%
2025	218.12	4572.1	4.77%

11 LMJ

Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	**4985.0**	100.00%	**4,960.4**	**4,959.8**	**4,958.6**	**4,956.4**	**4,954.5**
7Q10	**404.8**	8.12%	**380.2**	**379.6**	**378.4**	**376.3**	**374.3**
1Q30	**255.0**	5.11%	**230.4**	**229.7**	**228.6**	**226.4**	**224.4**
Q95	**687.0**	13.78%	**662.4**	**661.8**	**660.6**	**658.4**	**656.5**
Q90	**1005.2**	20.16%	**980.6**	**979.9**	**978.8**	**976.6**	**974.7**
Q50	**3112.6**	62.44%	**3,088.0**	**3,087.4**	**3,086.2**	**3,084.0**	**3,082.1**
MBFest	**2792.3**	56.01%	**2,767.7**	**2,767.1**	**2,765.9**	**2,763.8**	**2,761.8**
Q10	**10467.7**	209.98%	**10,443.1**	**10,442.5**	**10,441.3**	**10,439.1**	**10,437.2**

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	53.32	404.8	458.12	4,907.06	326.92	177.05	609.07	927.26	1.07%
2000	54.72	404.8	459.52	4,905.03	324.90	175.02	607.04	925.23	1.10%
2005	57.25	404.8	462.05	4,901.32	321.18	171.31	603.33	921.52	1.15%
2015	61.92	404.8	466.72	4,894.50	314.37	164.49	596.51	914.70	1.24%
2025	66.18	404.8	470.98	4,888.27	308.14	158.27	590.28	908.47	1.33%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	4,502.26	-77.88	-227.75	204.27	522.46
2000	4,500.23	-79.90	-229.78	202.24	520.43
2005	4,496.52	-83.62	-233.49	198.53	516.72
2015	4,489.70	-90.43	-240.31	191.71	509.90
2025	4,483.47	-96.66	-246.53	185.48	503.67

CUMULATIVE JAMES BASIN

YEAR	Proj. Off. D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)
1998	229.09	4985.0	4.60%
2000	235.02	4985.0	4.71%
2005	246.00	4985.0	4.93%
2015	266.02	4985.0	5.34%
2025	284.30	4985.0	5.70%

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Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	1079.9	1079.9	1079.9	1079.9	1079.9	100.00%
7Q10	44.9	44.9	44.9	44.9	44.9	4.16%
1Q30	24.9	24.9	24.9	24.9	24.9	2.31%
Q95	103.4	103.4	103.4	103.4	103.4	9.57%
Q90	123.7	123.7	123.7	123.7	123.7	11.46%
Q50	540.3	540.3	540.3	540.3	540.3	50.04%
MBFest	475.4	475.4	475.4	475.4	475.4	44.03%
Q10	2690.0	2690.0	2690.0	2690.0	2690.0	249.11%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	74.09	44.9	118.99	1,005.81	-29.18	-49.15	29.28	49.61	6.86%
2000	76.01	44.9	120.91	1,003.89	-31.10	-51.07	27.37	47.69	7.04%
2005	79.57	44.9	124.47	1,000.33	-34.66	-54.63	23.81	44.13	7.37%
2015	86.06	44.9	130.96	993.84	-41.15	-61.12	17.31	37.64	7.97%
2025	91.98	44.9	136.88	987.92	-47.06	-67.03	11.40	31.72	8.52%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	960.91	-74.08	-94.05	-15.62	4.71
2000	958.99	-76.00	-95.97	-17.53	2.79
2005	955.43	-79.56	-99.53	-21.09	-0.77
2015	948.94	-86.05	-106.02	-27.59	-7.26
2025	943.02	-91.96	-111.93	-33.50	-13.18

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Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	**5885.3**	100.00%	**5849.7**	**5848.8**	**5,847.1**	**5,844.0**	**5,841.4**
7Q10	**453.6**	7.71%	**418.0**	**417.1**	**415.4**	**412.3**	**409.4**
1Q30	**233.5**	3.97%	**197.9**	**197.0**	**195.3**	**192.2**	**189.3**
Q95	**n/a**	n/a	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Q90	**764.2**	12.98%	**728.6**	**727.7**	**726.0**	**722.9**	**720.0**
Q50	**3454.4**	58.70%	**3418.8**	**3417.9**	**3,416.2**	**3,413.1**	**3,410.2**
MBFest	**n/a**	n/a	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Q10	**13106.1**	222.69%	**13070.5**	**13069.6**	**13,067.9**	**13,064.8**	**13,061.9**

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	476.18	453.6	929.78	5,373.52	-58.18	-278.28	n/a	252.42	8.09%
2000	488.53	453.6	942.13	5,360.27	-71.45	-291.55	n/a	239.17	8.30%
2005	511.35	453.6	964.95	5,335.75	-95.98	-316.08	n/a	214.65	8.69%
2015	553.03	453.6	1006.63	5,290.97	-140.77	-360.87	n/a	169.87	9.40%
2025	591.10	453.6	1044.70	5,250.00	-181.68	-401.78	n/a	128.90	10.04%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	4,919.92	-511.78	-731.88	n/a	-201.18
2000	4,906.67	-525.05	-745.15	n/a	-214.43
2005	4,882.15	-549.58	-769.68	n/a	-238.95
2015	4,837.37	-594.37	-814.47	n/a	-283.73
2025	4,796.40	-635.28	-855.38	n/a	-324.70

CUMULATIVE JAMES BASIN

YEAR	Proj. Off. D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)
1998	779.36	5885.3	13.24%
2000	799.56	5885.3	13.59%
2005	836.92	5885.3	14.22%
2015	905.11	5885.3	15.38%
2025	967.38	5885.3	16.44%

14 MC/Y

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	793.5	793.5	793.5	793.5	793.5	100.00%
7Q10	4.3	4.3	4.3	4.3	4.3	0.54%
1Q30	n/a	n/a	n/a	n/a	n/a	n/a
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	49.3	49.3	49.3	49.3	49.3	6.22%
Q50	553.4	553.4	553.4	553.4	553.4	69.75%
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	1766.9	1767.9	1768.9	1769.9	1770.9	222.69%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	47.26	4.3	51.56	746.24	-42.96	n/a	n/a	2.04	5.96%
2000	48.48	4.3	52.78	745.02	-44.18	n/a	n/a	0.82	6.11%
2005	50.75	4.3	55.05	742.75	-46.45	n/a	n/a	-1.45	6.40%
2015	54.89	4.3	59.19	738.61	-50.59	n/a	n/a	-5.59	6.92%
2025	58.66	4.3	62.96	734.84	-54.36	n/a	n/a	-9.36	7.39%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	741.94	-47.26	n/a	n/a	-2.26
2000	740.72	-48.48	n/a	n/a	-3.48
2005	738.45	-50.75	n/a	n/a	-5.75
2015	734.31	-54.89	n/a	n/a	-9.89
2025	730.54	-58.66	n/a	n/a	-13.66

15 ES	Avg rain (inches)	Scenario A 41	Scenario B 42	Scenario C 43
	recharge (% precip)	recharge (MGD)	recharge (MGD)	recharge (MGD)
	2	37.48	38.39	39.31
	3	56.22	57.59	58.96
	4	74.96	76.78	78.61
	6	112.44	115.18	117.92
	8	149.91	153.57	157.23
	10	187.39	191.96	196.53
	12	224.87	230.35	235.84
	14	262.35	268.75	275.15

ES(A)	YEAR	Projected Off. D. (MGD)	2%- Off. D. (MGD)	3%- Off. D. (MGD)	4%- Off. D. (MGD)	6%- Off. D. (MGD)	8%- Off. D. (MGD)	10%- Off. D. (MGD)	12%- Off. D. (MGD)	14%- Off. D. (MGD)
	1998*	15.95	21.52	40.26	59.00	96.48	133.96	171.44	208.92	246.39
	2000	16.34	21.13	39.87	58.61	96.09	133.57	171.05	208.53	246.00
	2005	17.12	20.35	39.09	57.83	95.31	132.79	170.27	207.75	245.22
	2015	18.51	18.97	37.71	56.45	93.93	131.41	168.89	206.36	243.84
	2025	19.78	17.70	36.43	55.17	92.65	130.13	167.61	205.09	242.57
ES(B)	YEAR	Projected Off. D. (MGD)	2%- Off. D. (MGD)	3%- Off. D. (MGD)	4%- Off. D. (MGD)	6%- Off. D. (MGD)	8%- Off. D. (MGD)	10%- Off. D. (MGD)	12%- Off. D. (MGD)	14%- Off. D. (MGD)
	1998*	15.95	22.44	41.63	60.83	99.22	137.62	176.01	214.40	252.79
	2000	16.34	22.05	41.24	60.44	98.83	137.23	175.62	214.01	252.40
	2005	17.12	21.27	40.46	59.66	98.05	136.45	174.84	213.23	251.62
	2015	18.51	19.89	39.08	58.28	96.67	135.06	173.46	211.85	250.24
	2025	19.78	18.61	37.81	57.00	95.39	133.79	172.18	210.57	248.96
ES(C)	YEAR	Projected Off. D. (MGD)	2%- Off. D. (MGD)	3%- Off. D. (MGD)	4%- Off. D. (MGD)	6%- Off. D. (MGD)	8%- Off. D. (MGD)	10%- Off. D. (MGD)	12%- Off. D. (MGD)	14%- Off. D. (MGD)
	1998*	15.95	23.35	43.01	62.66	101.97	141.27	180.58	219.89	259.19
	2000	16.34	22.96	42.62	62.27	101.58	140.88	180.19	219.50	258.80
	2005	17.12	22.18	41.84	61.49	100.80	140.10	179.41	218.72	258.02
	2015	18.51	20.80	40.45	60.11	99.41	138.72	178.03	217.33	256.64
	2025	19.78	19.52	39.18	58.83	98.14	137.44	176.75	216.06	255.36

16 Me

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	**675.5**	**675.5**	**675.5**	**675.5**	**675.5**	100.00%
7Q10	**22.2**	**22.2**	**22.2**	**22.2**	**22.2**	3.29%
1Q30	**8.9**	**8.9**	**8.9**	**8.9**	**8.9**	1.32%
Q95	**9.9**	**9.9**	**9.9**	**9.9**	**9.9**	1.46%
Q90	**68.5**	**68.5**	**68.5**	**68.5**	**68.5**	10.14%
Q50	**347.4**	**347.4**	**347.4**	**347.4**	**347.4**	51.43%
MBFest	**359.0**	**359.0**	**359.0**	**359.0**	**359.0**	53.14%
Q10	**1389.5**	**1389.5**	**1389.5**	**1389.5**	**1389.5**	205.71%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	9.24	22.2	31.44	666.22	12.96	-0.33	0.64	59.27	1.37%
2000	9.46	22.2	31.66	665.99	12.73	-0.56	0.41	59.05	1.40%
2005	9.92	22.2	32.12	665.54	12.27	-1.01	-0.05	58.59	1.47%
2015	10.71	22.2	32.91	664.74	11.48	-1.81	-0.84	57.80	1.59%
2025	11.47	22.2	33.67	663.99	10.73	-2.56	-1.59	57.04	1.70%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	644.02	-9.24	-22.53	-21.56	37.07
2000	643.79	-9.47	-22.76	-21.79	36.85
2005	643.34	-9.93	-23.21	-22.25	36.39
2015	642.54	-10.72	-24.01	-23.04	35.60
2025	641.79	-11.47	-24.76	-23.79	34.84

17 No

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	1065.5	1065.5	1065.5	1065.5	1065.5	100.00%
7Q10	23.2	23.2	23.2	23.2	23.2	2.18%
1Q30	12.6	12.6	12.6	12.6	12.6	1.18%
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	79.9	79.9	79.9	79.9	79.9	7.50%
Q50	581.3	581.3	581.3	581.3	581.3	54.56%
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	2648.1	2648.1	2648.1	2648.1	2648.1	248.53%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	36.17	23.2	59.37	1,029.33	-12.95	-23.61	n/a	43.74	3.39%
2000	37.08	23.2	60.28	1,028.41	-13.87	-24.52	n/a	42.83	3.48%
2005	38.85	23.2	62.05	1,026.64	-15.64	-26.30	n/a	41.06	3.65%
2015	42.00	23.2	65.20	1,023.50	-18.78	-29.44	n/a	37.92	3.94%
2025	44.91	23.2	68.11	1,020.59	-21.70	-32.35	n/a	35.00	4.21%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,006.13	-36.15	-46.81	n/a	20.54
2000	1,005.21	-37.07	-47.72	n/a	19.63
2005	1,003.44	-38.84	-49.50	n/a	17.86
2015	1,000.30	-41.98	-52.64	n/a	14.72
2025	997.39	-44.90	-55.55	n/a	11.80

18 B/SEC

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	929.7	929.7	929.7	929.7	929.7	100.00%
7Q10	2.9	2.9	2.9	2.9	2.9	0.32%
1Q30	0.9	0.9	0.9	0.9	0.9	0.09%
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	12.1	12.1	12.1	12.1	12.1	1.31%
Q50	555.2	555.2	555.2	555.2	555.2	59.71%
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	2427.9	2427.9	2427.9	2427.9	2427.9	261.15%

YEAR	Proj consum Off. D. (MGD)	7Q10 (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	92.20	2.9	95.10	837.50	-89.27	-91.35	n/a	-80.06	9.92%
2000	94.59	2.9	97.49	835.12	-91.66	-93.73	n/a	-82.45	10.17%
2005	99.01	2.9	101.91	830.70	-96.08	-98.15	n/a	-86.87	10.65%
2015	107.09	2.9	109.99	822.61	-104.16	-106.23	n/a	-94.95	11.52%
2025	114.46	2.9	117.36	815.25	-111.53	-113.60	n/a	-102.32	12.31%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	834.60	-92.17	-94.25	n/a	-82.96
2000	832.22	-94.56	-96.63	n/a	-85.35
2005	827.80	-98.98	-101.05	n/a	-89.77
2015	819.71	-107.06	-109.13	n/a	-97.85
2025	812.35	-114.43	-116.50	n/a	-105.22

19 URo

Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	$\%Q_{am}$
Q_{am}	1363.1	1363.1	1363.1	1363.1	1363.1	100.00%
7Q10	210.4	210.4	210.4	210.4	210.4	15.44%
1Q30	38.8	38.8	38.8	38.8	38.8	2.84%
Q95	39.6	39.6	39.6	39.6	39.6	2.90%
Q90	211.2	211.2	211.2	211.2	211.2	15.50%
Q50	814.8	814.8	814.8	814.8	814.8	59.78%
MBFest	815.6	815.6	815.6	815.6	815.6	59.84%
Q10	2721.4	2721.4	2721.4	2721.4	2721.4	199.65%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	57.95	210.4	268.35	1,305.11	152.48	-19.19	-18.40	153.27	4.25%
2000	59.46	210.4	269.86	1,303.60	150.98	-20.69	-19.90	151.77	4.36%
2005	62.25	210.4	272.65	1,300.81	148.19	-23.48	-22.69	148.98	4.57%
2015	67.32	210.4	277.72	1,295.74	143.12	-28.55	-27.76	143.91	4.94%
2025	71.95	210.4	282.35	1,291.10	138.48	-33.19	-32.40	139.27	5.28%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,094.71	-57.92	-229.59	-228.80	-57.13
2000	1,093.20	-59.42	-231.09	-230.30	-58.63
2005	1,090.41	-62.21	-233.88	-233.09	-61.42
2015	1,085.34	-67.28	-238.95	-238.16	-66.49
2025	1,080.70	-71.92	-243.59	-242.80	-71.13

20 LRo

Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	5047.5	100.00%	4976.9	4974.8	4970.9	4965.0	4959.9
7Q10	699.1	13.85%	628.5	626.4	622.5	616.6	611.5
1Q30	255.0	5.05%	184.4	182.3	178.4	172.5	167.4
Q95	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Q90	1512.4	29.96%	1441.8	1439.7	1435.8	1429.9	1424.8
Q50	3205.2	63.50%	3134.6	3132.5	3128.6	3122.7	3117.6
MBFest	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Q10	9363.7	185.51%	9293.1	9291.0	9287.1	9281.2	9276.1

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	18.31	739.4	757.71	4,958.59	610.19	166.09	n/a	1423.49	0.36%
2000	18.78	739.4	758.18	4,956.02	607.62	163.52	n/a	1420.92	0.37%
2005	19.66	739.4	759.06	4,951.24	602.84	158.74	n/a	1416.14	0.39%
2015	21.26	739.4	760.66	4,943.74	595.34	151.24	n/a	1408.64	0.42%
2025	22.74	739.4	762.14	4,937.16	588.76	144.66	n/a	1402.06	0.45%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	4,219.19	-129.21	-573.31	n/a	684.09
2000	4,216.62	-131.78	-575.88	n/a	681.52
2005	4,211.84	-136.56	-580.66	n/a	676.74
2015	4,204.34	-144.06	-588.16	n/a	669.24
2025	4,197.76	-150.64	-594.74	n/a	662.66

CUMULATIVE ROANOKE BASIN

1* YEAR	Proj.Off.D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)	2* YEAR	Proj.Off.D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)
1998	883.94	5047.5	17.51%	1998	181.44	5047.5	3.59%
2000	910.53	5047.5	18.04%	2000	186.34	5047.5	3.69%
2005	961.56	5047.5	19.05%	2005	195.47	5047.5	3.87%
2015	1,034.28	5047.5	20.49%	2015	211.10	5047.5	4.18%
2025	1,095.75	5047.5	21.71%	2025	225.18	5047.5	4.46%

1* Includes Lower Dan in NC Thermoelectric withdrawal as an offstream demand

2* Does not include Lower Dan in NC Thermoelectric withdrawal as an offstream demand

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Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	907.6	907.6	907.6	907.6	907.6	100.00%
7Q10	196.7	196.7	196.7	196.7	196.7	21.67%
1Q30	83.3	83.3	83.3	83.3	83.3	9.18%
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	344.4	344.4	344.4	344.4	344.4	37.95%
Q50	690.5	690.5	690.5	690.5	690.5	76.08%
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	1583.8	1583.8	1583.8	1583.8	1583.8	174.50%

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	43.59	196.7	240.29	864.01	153.11	39.71	n/a	300.81	4.80%
2000	44.72	196.7	241.42	862.88	151.98	38.58	n/a	299.68	4.93%
2005	46.81	196.7	243.51	860.79	149.89	36.49	n/a	297.59	5.16%
2015	50.62	196.7	247.32	856.98	146.08	32.68	n/a	293.78	5.58%
2025	54.11	196.7	250.81	853.49	142.59	29.19	n/a	290.29	5.96%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	667.31	-43.59	-156.99	n/a	104.11
2000	666.18	-44.72	-158.12	n/a	102.98
2005	664.09	-46.81	-160.21	n/a	100.89
2015	660.28	-50.62	-164.02	n/a	97.08
2025	656.79	-54.11	-167.51	n/a	93.59

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Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	**2265.4**	100.00%	**2211.9**	**2210.3**	**2207.2**	**2202.8**	**2199.1**
7Q10	**308.9**	13.64%	**255.5**	**253.8**	**250.7**	**246.3**	**242.6**
1Q30	**100.7**	4.45%	**47.3**	**45.6**	**42.5**	**38.1**	**34.5**
Q95	**n/a**	n/a	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Q90	**704.9**	31.12%	**651.5**	**649.8**	**646.7**	**642.3**	**638.7**
Q50	**1509.0**	66.61%	**1455.5**	**1453.9**	**1450.7**	**1446.4**	**1442.7**
MBFest	**n/a**	n/a	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Q10	**4077.2**	179.98%	**4023.7**	**4022.1**	**4019.0**	**4014.6**	**4010.9**

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	25.35	308.9	334.25	2,186.56	230.10	21.91	n/a	626.11	1.12%
2000	26.02	308.9	334.92	2,184.26	227.81	19.62	n/a	623.82	1.15%
2005	27.23	308.9	336.13	2,179.93	223.48	15.28	n/a	619.48	1.20%
2015	29.44	308.9	338.34	2,173.34	216.88	8.69	n/a	612.89	1.30%
2025	31.47	308.9	340.37	2,167.63	211.18	2.98	n/a	607.19	1.39%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,877.66	-78.80	-286.99	n/a	317.21
2000	1,875.36	-81.09	-289.28	n/a	314.92
2005	1,871.03	-85.42	-293.62	n/a	310.58
2015	1,864.44	-92.02	-300.21	n/a	303.99
2025	1,858.73	-97.72	-305.92	n/a	298.29

CUMULATIVE DAN BASIN

1* YEAR	Proj.Off.D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)	2* YEAR	Proj.Off.D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)
1998	807.68	2265.4	35.65%	**1998**	105.18	2265.4	4.64%
2000	832.29	2265.4	36.74%	**2000**	108.10	2265.4	4.77%
2005	879.65	2265.4	38.83%	**2005**	113.56	2265.4	5.01%
2015	945.70	2265.4	41.75%	**2015**	122.52	2265.4	5.41%
2025	1,001.06	2265.4	44.19%	**2025**	130.49	2265.4	5.76%

1* Includes Thermoelectric withdrawal as an offstream demand   2* Does not include Thermoelectric withdrawal as an offstream demand

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Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	**2101.7**	100.00%	**2094.3**	**2094.0**	**2093.6**	**2093.0**	**2092.5**
7Q10	**468.5**	22.29%	**461.1**	**460.9**	**460.5**	**459.9**	**459.4**
1Q30	**329.2**	15.66%	**321.8**	**321.6**	**321.1**	**320.5**	**320.0**
Q95	**616.5**	29.34%	**609.1**	**608.9**	**608.5**	**607.9**	**607.4**
Q90	**717.4**	34.13%	**709.9**	**709.7**	**709.3**	**708.7**	**708.2**
Q50	**1576.9**	75.03%	**1569.5**	**1569.3**	**1568.8**	**1568.2**	**1567.7**
MBFest	**1393.4**	66.30%	**1386.0**	**1385.7**	**1385.3**	**1384.7**	**1384.2**
Q10	**3787.2**	180.20%	**3779.7**	**3779.5**	**3779.1**	**3778.5**	**3778.0**

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	20.46	468.5	488.96	2,073.81	440.68	301.34	588.67	689.49	0.97%
2000	20.99	468.5	489.49	2,073.04	439.91	300.57	587.90	688.72	1.00%
2005	21.98	468.5	490.48	2,071.62	438.50	299.16	586.49	687.31	1.05%
2015	23.75	468.5	492.25	2,069.25	436.12	296.78	584.12	684.93	1.13%
2025	25.40	468.5	493.90	2,067.10	433.97	294.64	581.97	682.79	1.21%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,605.31	-27.82	-167.16	120.17	220.99
2000	1,604.54	-28.59	-167.93	119.40	220.22
2005	1,603.12	-30.00	-169.34	117.99	218.81
2015	1,600.75	-32.38	-171.72	115.62	216.43
2025	1,598.60	-34.53	-173.86	113.47	214.29

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Flow	flow (MGD)	%Q_{am}	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)
Q_{am}	**3322.3**	100.00%	**3312.9**	**3312.6**	**3312.1**	**3311.3**	**3310.6**
7Q10	**736.1**	22.16%	**726.7**	**726.4**	**725.9**	**725.1**	**724.4**
1Q30	**571.8**	17.21%	**562.3**	**562.0**	**561.5**	**560.7**	**560.1**
Q95	**806.7**	24.28%	**797.3**	**797.0**	**796.5**	**795.7**	**795.0**
Q90	**1019.8**	30.70%	**1010.4**	**1010.1**	**1009.6**	**1008.8**	**1008.1**
Q50	**2425.4**	73.00%	**2415.9**	**2415.7**	**2415.1**	**2414.4**	**2413.7**
MBFest	**2096.5**	63.11%	**2087.1**	**2086.8**	**2086.3**	**2085.5**	**2084.9**
Q10	**6380.5**	192.05%	**6371.1**	**6370.8**	**6370.3**	**6369.5**	**6368.8**

YEAR	Proj consum Off. D. (MGD)	In.D. (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	30.95	736.1	767.05	3,281.92	695.72	531.38	766.32	979.44	0.93%
2000	31.76	736.1	767.86	3,280.82	694.63	530.28	765.23	978.35	0.96%
2005	33.25	736.1	769.35	3,278.81	692.61	528.27	763.21	976.33	1.00%
2015	35.95	736.1	772.05	3,275.34	689.14	524.80	759.75	972.87	1.08%
2025	38.44	736.1	774.54	3,272.18	685.98	521.64	756.59	969.71	1.16%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	2,545.82	-40.38	-204.72	30.22	243.34
2000	2,544.72	-41.47	-205.82	29.13	242.25
2005	2,542.71	-43.49	-207.83	27.11	240.23
2015	2,539.24	-46.96	-211.30	23.65	236.77
2025	2,536.08	-50.12	-214.46	20.49	233.61

CUMULATIVE NEW BASIN

YEAR	Proj.Off.D. (MGD)	Q_{AM} (MGD)	Off.D. / Q_{AM} (%)
1998	70.11	3322.3	2.11%
2000	71.94	3322.3	2.17%
2005	75.48	3322.3	2.27%
2015	81.46	3322.3	2.45%
2025	86.85	3322.3	2.61%

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Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	**1230.5**	**1114.8**	**1114.8**	**1114.8**	**1114.8**	100.00%
7Q10	**151.9**	**138.9**	**138.9**	**138.9**	**138.9**	12.34%
1Q30	**99.2**	**88.5**	**88.5**	**88.5**	**88.5**	8.06%
Q95	**219.0**	**202.0**	**202.0**	**202.0**	**202.0**	17.80%
Q90	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a
Q50	**765.9**	**711.1**	**711.1**	**711.1**	**711.1**	62.24%
MBFest	**843.1**	**783.6**	**783.6**	**783.6**	**783.6**	68.51%
Q10	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	n/a

YEAR	Proj consum Off. D. (MGD)	7Q10 (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	16.89	151.9	168.79	1,213.65	135.00	82.30	202.08	n/a	1.37%
2000	17.34	151.9	169.24	1,213.20	134.55	81.85	201.64	n/a	1.41%
2005	18.15	151.9	170.05	1,212.39	133.74	81.04	200.83	n/a	1.47%
2015	19.63	151.9	171.53	1,210.91	132.26	79.57	199.35	n/a	1.60%
2025	20.97	151.9	172.87	1,209.57	130.92	78.22	198.01	n/a	1.70%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,061.75	-16.90	-69.60	50.18	n/a
2000	1,061.30	-17.35	-70.05	49.74	n/a
2005	1,060.49	-18.16	-70.86	48.93	n/a
2015	1,059.01	-19.64	-72.33	47.45	n/a
2025	1,057.67	-20.98	-73.68	46.11	n/a

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Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	1762.4	1762.4	1762.4	1762.4	1762.4	100.00%
7Q10	116.4	116.4	116.4	116.4	116.4	6.60%
1Q30	95.7	95.7	95.7	95.7	95.7	5.43%
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	n/a	n/a	n/a	n/a	n/a	n/a
Q50	938.2	939.2	940.2	941.2	942.2	53.23%
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	n/a	n/a	n/a	n/a	n/a	n/a

YEAR	Proj consum Off. D. (MGD)	7Q10 (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	78.21	116.4	194.61	1,684.19	38.19	17.49	n/a	n/a	4.44%
2000	80.20	116.4	196.60	1,682.20	36.20	15.50	n/a	n/a	4.55%
2005	83.99	116.4	200.39	1,678.41	32.41	11.71	n/a	n/a	4.77%
2015	90.80	116.4	207.20	1,671.60	25.60	4.90	n/a	n/a	5.15%
2025	97.03	116.4	213.43	1,665.37	19.37	-1.33	n/a	n/a	5.51%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	1,567.79	-78.21	-98.91	n/a	n/a
2000	1,565.80	-80.20	-100.90	n/a	n/a
2005	1,562.01	-83.99	-104.69	n/a	n/a
2015	1,555.20	-90.80	-111.50	n/a	n/a
2025	1,548.97	-97.03	-117.73	n/a	n/a

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Flow	1998 (MGD)	2000 (MGD)	2005 (MGD)	2015 (MGD)	2025 (MGD)	%Q_{am}
Q_{am}	814.4	814.4	814.4	814.4	814.4	100.00%
7Q10	9.3	9.3	9.3	9.3	9.3	1.14%
1Q30	3.2	3.2	3.2	3.2	3.2	0.39%
Q95	n/a	n/a	n/a	n/a	n/a	n/a
Q90	n/a	n/a	n/a	n/a	n/a	n/a
Q50	n/a	n/a	n/a	n/a	n/a	n/a
MBFest	n/a	n/a	n/a	n/a	n/a	n/a
Q10	n/a	n/a	n/a	n/a	n/a	n/a

YEAR	Proj consum Off. D. (MGD)	7Q10 (MGD)	TOTAL D (MGD)	Q_{am}-OffD (MGD)	$7Q_{10}$-OffD (MGD)	$1Q_{30}$-OffD (MGD)	Q_{95}-OffD (MGD)	Q_{90}-OffD (MGD)	Off D as % Qam
1998*	70.57	9.3	79.87	743.83	-61.27	-67.37	n/a	n/a	8.67%
2000	72.42	9.3	81.72	741.98	-63.12	-69.22	n/a	n/a	8.89%
2005	75.76	9.3	85.06	738.64	-66.46	-72.56	n/a	n/a	9.30%
2015	81.99	9.3	91.29	732.41	-72.69	-78.79	n/a	n/a	10.07%
2025	87.53	9.3	96.83	726.87	-78.23	-84.33	n/a	n/a	10.75%

YEAR	Q_{am}-TotD (MGD)	$7Q_{10}$-TotD (MGD)	$1Q_{30}$-TotD (MGD)	Q_{95}-TotD (MGD)	Q_{90}-TotD (MGD)
1998*	734.53	-70.57	-76.67	n/a	n/a
2000	732.68	-72.42	-78.52	n/a	n/a
2005	729.34	-75.76	-81.86	n/a	n/a
2015	723.11	-81.99	-88.09	n/a	n/a
2025	717.57	-87.53	-93.63	n/a	n/a

APPENDIX M: A GUIDE TO VIRGINIA WATER RESOURCES INFORMATION

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