Water Supply Demands and Resources Analysis in the Potomac River Basin

Prepared for

The Maryland Department of the Environment

by

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November, 2000

Report No. 00 - 5

Acknowledgment

The authors would like to thank the Maryland Department of the Environment (MDE) for the financial support which made this work possible. People who have been particularly instrumental include Herbert M. Sachs and Matthew G. Pajerowski of MDE who provided comments and assembled an Advisory Committee to guide this work. Judy Wheeler of the U.S. Geological Survey was especially helpful in providing consistently derived population and water use data and information for a base year used in the analyses of this study.

This report was prepared by the Interstate Commission on the Potomac River Basin. Funds were provided for its preparation by the Maryland Department of the Environment. The opinions expressed are those of the authors and should not be construed as representing the opinions or policies of the United States or any of its agencies, the several states, or the Commissioners of the Interstate Commission on the Potomac River Basin.

Table of Contents

Acknowledgment i

Table of Contents ii

Appendices iv

List of Figures v

List of Tables vi

List of Acronyms viii

I. Executive Summary 1
- A. Introduction 1
- B. Study method used to develop state and county based forecasts of consumptive water use 2
- C. Study method used to develop forecasts of consumptive water use by HUC region . . 2
- D. Demand forecast results 3
- E. Resource Assessment 7
- F. Conclusions 8
- G. Future Work 9

II. Introduction 10

III. Overview of method used to develop forecasts of consumptive use by HUC watershed . . . 14
- A. Domestic sector method 15
- B. Commercial sector method 16
- C. Industrial sector method 16
- D. Thermoelectric sector method 16
- E. Mining sector method 17
- F. Livestock sector method 17
- G. Irrigation sector method 17

IV. Overview of method used to develop forecasts of consumptive use by State and the District of Columbia 19
- A. Maryland 21
- B. District of Columbia 21
- C. Pennsylvania 22
- D. Virginia 22
- E. West Virginia 23

V. 8-Digit Hydrologic Unit Code watershed-based forecast 25
A. Population 25
B. USGS estimates of 1995 average annual consumptive use by HUC 26
C. Estimates of 1995 base year seasonal consumptive use by HUC, assuming hot and dry conditions 27
D. Forecasts of June through August consumptive use by HUC, 2000 to 2030 assuming hot and dry conditions 29

VI. Resource assessment 31
A. Small scale individual HUC region analysis 31
B. Medium scale combined HUC region analysis 35
C. Large scale basin analysis upstream of Little Falls 38
D. Ground water 41
E. Small upstream reservoirs 41
F. Climate change effect on resources 41

VII. Summary of Results 43

VIII. Conclusions 45
A. Study conclusions 45
B. Future work 46

IX. References 47

Appendices

A: Water demand forecasts in the Potomac River basin, state summary tables

A-MD: Maryland Water Supply and Forecast Summary Tables: 2000 - 2030

A-DC: District of Columbia Water Supply and Forecast Summary Tables: 2000 - 2030

A-PA: Pennsylvania Water Supply and Forecast Summary Tables: 2000 - 2030

A-VA: Virginia Water Supply and Forecast Summary Tables: 2000 - 2030

A-WV: West Virginia Water Supply and Forecast Summary Tables: 2000 - 2030

B: Worksheets for non-metro supplied populations of the counties partially supplied by WSSC, FCWA, and/or WA

C: Summary of households, population, and employment statistics for the Washington metropolitan area water suppliers

D: Summary of population forecasts, by state and county, served by water resources in the non-tidal Potomac River basin and/or associated resources (Patuxent, Occoquan/Manassas)

E: Effects of the Energy Policy Act of 1992 on projected WMA water use

F: Chesapeake Bay Program population estimates by HUC - method

G: Water demand forecasts in the Potomac River basin, by 8-digit hydrologic unit code and state

H: Calculation of domestic consumptive water use for the Potomac River basin

I: Calculation of irrigation consumptive use for the Potomac basin

J: Streamflow derivation by HUC

K: Streamflow derivation and validation for medium scale resource analysis

L: Large scale basin resource analysis: method and tools

List of Figures

Figure No.	Title
ES - 1	Counties entirely or partially within the Potomac River basin
ES - 2	Hydrologic Unit Code boundaries for the non-tidal Potomac River basin
2 - 1	Trend in national water withdrawals and total US population
2 - 2	Trend in national consumptive water use and total US population
6 - 1	HUC flow diagram

List of Tables

Table No.	Title
ES - 1	Population, Total Water Use, and Consumptive Use: Non-tidal Potomac River Basin
ES - 2	Estimated 1995 levels of June through August Potomac River basin consumptive use by HUC watershed and by category of use estimated for a drought year
ES - 3	Forecast of average June through August consumptive water use by HUC given hot and dry conditions
ES - 4	Summary of resource assessment results
3 - 1	Consumptive use forecast method in the Potomac River basin upstream of the WMA 2000 to 2030
5 - 1	Population estimates for non-tidal Potomac River basin by HUC (a), excluding metro study area
5 - 2	Percent population growth as compared to 1995 base year by HUC
5 - 3	Compilation of USGS 1995 average annual Potomac consumptive use by HUC and by type of user, mgd
5 - 4	Estimated 1995 levels of June through August Potomac consumptive use by HUC and by category of user estimated for a drought year
5 - 5	Forecast of average June through August consumptive water use by HUC given hot and dry conditions
5 - 6	Sensitivity analysis of consumptive use for the Potomac River basin upstream of the WMA (Impact of 10 percent change in growth of factor for the period 2000 to 2030)
6 - 1a	Potomac HUC watershed calculated flows, and seasonal consumptive use
6 - 1b	Seasonal consumptive use as a percentage of minimum flow and of 7Q10 flow for each HUC region
6 - 2	Simulated Potomac augmented flows and cumulative seasonal consumptive demands

6 - 3 Cumulative demand as a percentage of minimum flow and of 7Q10 flow for each HUC confluence point

6 - 4 Forecast year and minimum combined Jennings Randolph and Little Seneca storage remaining and number of restriction years for *Baseline* and *Seasonal Consumptive Use* scenarios

6 - 5 Years in historical record in which releases would have been required given 2030 demands, and number of days of releases for each year for *Baseline* and *Seasonal Consumptive Use* scenarios

7 - 1 Summary of resource assessment results

List of Acronyms

7Q10	Lowest 7-day average flow expected once in 10 years
CBP	Chesapeake Bay Program (of the US EPA)
EPA	Environmental Protection Agency
HUC	Hydrologic Unit Code (sub-basin area)
USGS	United States Geological Survey
WMA	Washington, D.C. metropolitan area

I. Executive Summary

A. Introduction

The objectives of the study include an assessment of current and future water demands (with a focus on consumptive use) to the year 2030, and an estimate of available resources in the non-tidal portion of the Potomac River basin. The Potomac River basin upstream of, and including the Washington metropolitan area is defined as the non-tidal portion. The assessment of future water use in this study will assist the regulatory agencies and water utilities in addressing the future adequacy of fresh water resources in the Potomac River basin.

Consumptive use upstream in the Potomac River basin reduces the amount of water allocatable and available for further use by those downstream. The concept of *consumptive use* as used here is consistent with that of others in the field, including the U.S. Geological Survey (USGS): "That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment," (USGS, 1998).

This is not a study that examines the environmental effects of low flow on the flora and fauna of the Potomac River, nor does this study attempt to evaluate future sources of water supply in the basin. This study does not identify potential instances where withdrawals may be greater than flow at the local scale, i.e., in particular tributaries in the headwaters of the Potomac River basin; but instead compares consumptive demand to Potomac River flows at a broader spatial scale.

Two main approaches were used in the study. The first approach provided a summary of water use forecasts by state and the District of Columbia. This approach provides **annual average** values of consumptive use. Analyses by state were not adjusted to include dry year or seasonal effects on consumptive use. No resource analysis was conducted based on the summary of forecasts by state.

The second approach provided a summary of water use forecasts by watershed, Hydrologic Unit Code[1] (HUC). This approach provided estimates of consumptive use that were adjusted to represent **dry year** and **seasonal** effects on consumptive use.

A major element of the study is the resource analysis, which was conducted using the seasonal estimates of consumptive use via the HUC watershed approach. The conclusions of the report are based on the resource analysis conducted using the HUC watershed approach.

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[1]A Hydrologic Unit Code refers to a USGS designated natural drainage basin or hydrologic area. There are 9 HUC regions in the Potomac River basin upstream of the Washington DC area. The USGS provides its water use data by HUC region.

This study relies on data and information compiled and analyzed from a wide range of sources. The data and information are associated with almost as many time periods as the sources from which they are drawn. The present study focuses on a forecast of water demand out to the year 2030. Although it was intended to use existing data and information as much as possible, in many cases forecasts have had to be extended to consistently reach the year 2030. The discussion of the analysis describes those cases where documented information has been extended for completeness and consistency.

It should be noted that extended forecasts are an extrapolation of prior trends, and were not conducted with regard to economic considerations or capacity issues.

B. Study method used to develop state and county based forecasts of consumptive water use

USGS water use data were summarized in the basin on a state and county-level basis in order to provide a readily recognizable geo-political frame of reference. In general, water use was assessed for the broad categories: domestic, commercial, industrial, and agricultural, separately for water that is supplied by community systems and for that which is self-supplied by the consumer. Water consumptively used was tallied for each of the broad use categories for a base year. Forecasts were performed at 10-year intervals for the forecast period: 2000 through 2030.

C. Study method used to develop forecasts of consumptive water use by HUC region

The USGS has compiled uniformly collected baseline estimates of water use data for the nation at 5-year intervals since 1950. Consumptive water use estimates were obtained from the USGS (1995) by categories of domestic, commercial, industrial, thermoelectric, mining, livestock and irrigation water use. In the present study, the data were compiled for the Potomac River basin for a base year (1995) and were extrapolated using forecasts of households, population and irrigated acreage as appropriate. USGS consumptive use data for 1995 provided the basis of the forecast for all but the domestic category. The method for developing forecasts of domestic consumptive water use was based on calculations of regional per household consumptive use for the Washington metropolitan area and on projections of the number of households in the basin.

In order to compare the total consumptive use to summertime low flows, potential variation in **seasonal water use** patterns and in **drought year use** were quantified. Seasonal year variation in agricultural irrigation withdrawals and outdoor domestic water use could change the magnitude of summertime consumptive use, especially as compared to annual average values. Domestic outdoor water use and irrigation water use are also higher during drought years. Estimates of current and future domestic and irrigation consumptive use were estimated for the peak use months of June, July and August and were also adjusted to represent demands during drought years. Commercial, industrial, thermoelectric, mining, and livestock consumptive demands were assumed to be unchanged by drought versus normal year conditions or by seasonal factors.

D. Demand forecast results

Forecasts of population and other water use factors were based on forecasts derived from state, county and regional planning agencies, and the Chesapeake Bay Program of the U.S. EPA; and on the expected water use impacts of the Federal Energy Policy Act of 1992.

Forecasts of consumptive water use and population are presented by county and by state (Figure ES - 1) for the following water use sectors: domestic, commercial, industrial, and agricultural categories and are further defined by supply source (self supplied or public supply).

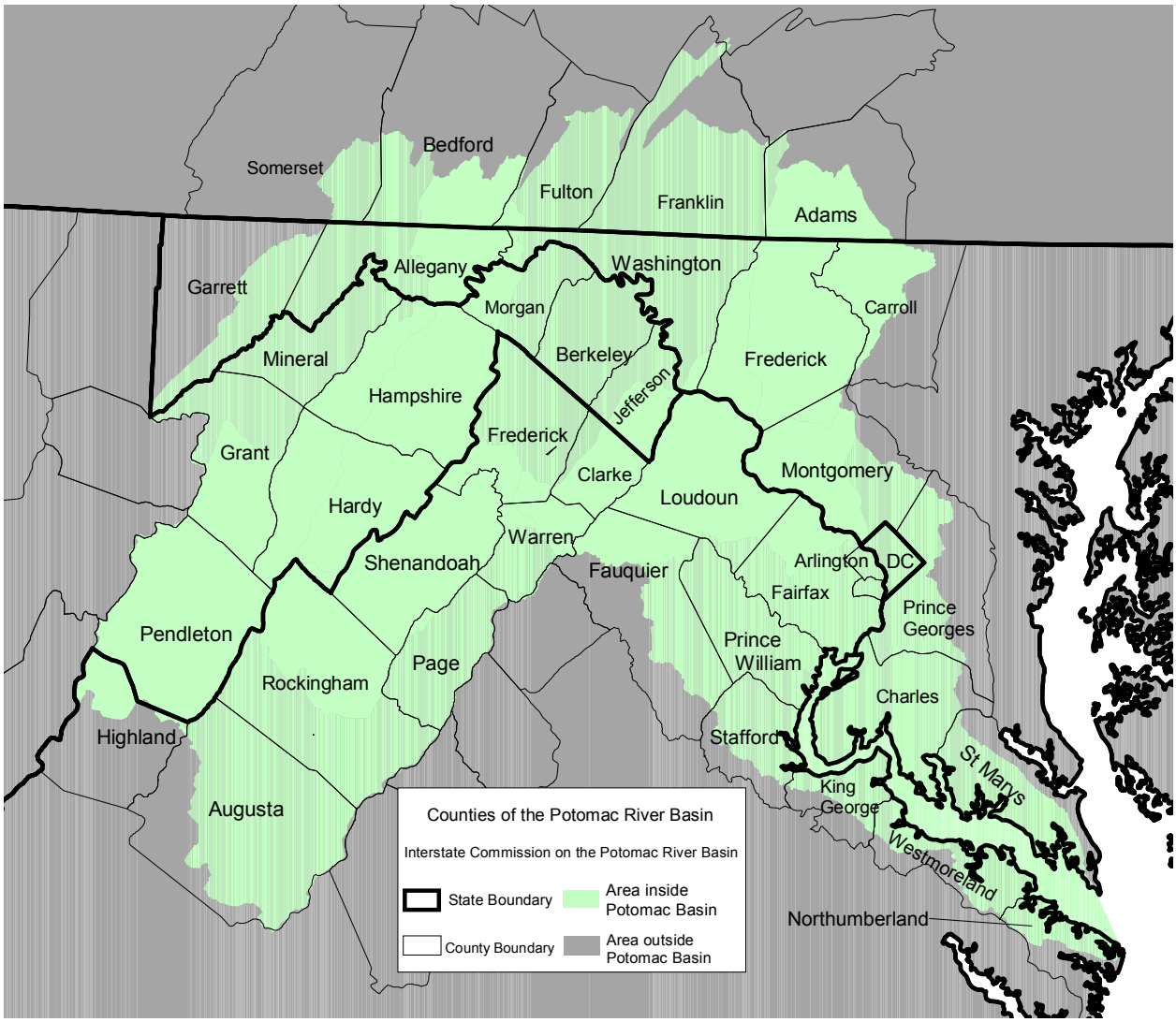

Figure ES - 1: Counties entirely or partially within the Potomac River basin

The water use forecast results are also presented by 8-digit HUC region (Figure ES - 2) for the following water use sectors: domestic, commercial, industrial, thermoelectric, mining, livestock, and irrigation.

The vast majority of the population of the study area lives in the Maryland and Virginia suburbs of the District of Columbia, and in the city itself. Water use is reflected in this population pattern. The largest increases in population and water use are forecast to follow the same pattern – extending to a somewhat wider area around the current metropolitan area.

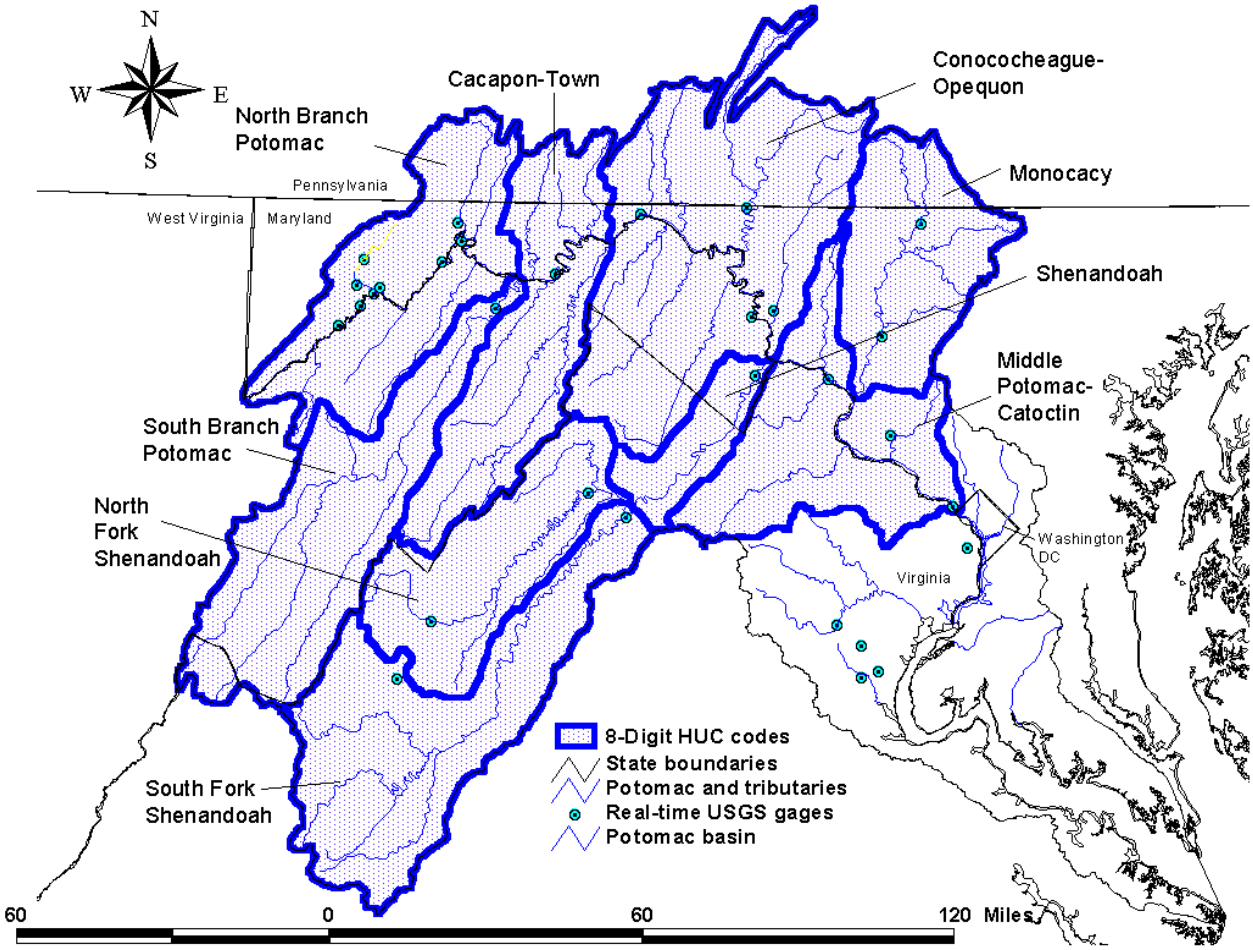

Figure ES - 2: Hydrologic Unit Code boundaries for the non-tidal Potomac River basin

A summary of daily water use forecasts, including the increase from 2000 to 2030, is presented by state and the District of Columbia in Table ES - 1, as values averaged over a whole year. Values from this table have not been adjusted to include dry year or seasonal effects on consumptive use.

Table ES - 1: Population, Total Water Use, and Consumptive Use: Non-tidal Potomac River Basin

Non-Tidal Potomac Basin Part or Whole Jurisdiction	Year 2000		Year 2030		2000 to 2030 Increase	
	Population (thousands)	Total Use (mgd)	Population (thousands)	Total Use (mgd)	Population (thousands)	Total Use (mgd)
Maryland	2,036.2	338.3	2,546.6	410.4	510.4	72.1
District of Columbia	518.1	130.4	669.0	154.5	150.9	24.1
Pennsylvania	179.8	29.7	195.8	31.0	16.0	1.3
Virginia	2,135.1	303.7	2,984.8	414.1	849.7	110.4
West Virginia	207.5	62.3	270.3	74.8	62.7	12.5
Total	5,076.8	864.4	6,666.5	1,084.8	1,589.8	220.4

Notes:

1. All data are shown as average annual values.
2. Population is resident population served by sources in the non-tidal Potomac River basin and by the associated sources: Patuxent reservoirs and Occoquan/Manassas reservoirs.
3. Total use refers to water used for all purposes: domestic, commercial, industrial, agricultural, and unaccounted.
4. The consumptive use in the area served by the Washington, DC metropolitan area water utilities is not calculated or included in this table, because its impact is assumed to be negligible on the non-tidal Potomac River.
5. Water use presented in the table is the sum of all use, including consumptive use, and does not take into account sequential down stream re-use of treated waste water after it is returned to rivers and streams. However, cumulative consumptive use is addressed in the Hydrologic Unit Code (HUC) sub-watershed analyses later in this report.

When seasonal and drought year factors are included in the HUC region analyses, a higher estimate of consumptive use is derived than that of the state analyses shown in Table ES-1. Estimates of average June through August consumptive use assuming dry year conditions are presented by HUC region in Table ES-2. Agricultural water use was forecast differently between the two analyses. The state analyses assumed agricultural use would remain constant at 1995 levels; whereas, more detailed analyses were conducted by HUC region in which resource adequacy was also assessed. In the HUC region analyses consumptive use by livestock was assumed to increase in proportion to increases in human population, and use by irrigation was assumed to increase in proportion to forecast increases in irrigated acreage.

Table ES-2. Estimated 1995 levels of June through August Potomac River basin consumptive use by HUC watershed and by category of use estimated for a drought year.

HUC 8 Name	Domestic	Commercial	Industrial	Thermo-electric	Mining	Livestock	Irrigation	**Totals**
South Branch Potomac	1.5	1	2.4	0	0	0.9	0	**5.8**
North Branch Potomac	5.6	0.2	7	10.5 (b)	0.3	0.5	0.3	**24.5**
Cacapon-Town	1.2	0	0	0	0	0.6	0.1	**1.9**
Conococheague-Opequon	21.2	1.2	2.6	0.3	0.3	3.3	4.8	**33.6**
South Fork Shenandoah	10.8	1.1	2.9	0	0	1.6	1.8	**18.2**
North Fork Shenandoah	3.1	0.5	0.4	0	0	2.6	1.4	**8**
Shenandoah	2.3	0.5	0.9	0	0	1.5	0.4	**5.6**
Middle Pot.-Catoctin (a)	4.7	0.2	0.1	3.3	0	1.1	3.4	**12.8**
Monocacy	12.3	0.7	0.8	0	0.3	2	5.9	**21.9**
Totals	**62.8**	**5.3**	**17.3**	**14**	**0.9**	**14.1**	**18.1**	**132.4**
Totals excluding Mt. Storm (b)	**62.8**	**5.3**	**17.3**	**3.6**	**0.9**	**14.1**	**18.1**	**121.9**

Notes:
(a) The middle Potomac-Catoctin HUC only includes those totals for the non-metro portions of the Washington metropolitan area.
(b) Mount Storm in the North Branch is upstream of river regulating reservoirs and its consumptive demand is mitigated by minimum streamflow releases from the downstream reservoirs.

The data in Table ES-2 show that consumptive use in a hot dry year would have been approximately 122 million gallons per day (mgd) in 1995 during the months of June, July and August. The most significant consumptive uses of water are the domestic (62.8 mgd), irrigation (18.1 mgd), and industrial (17.3 mgd) categories of water use. These three categories would have accounted for about 80 percent of the consumptive use in the basin during June through August, had a drought occurred in 1995.

The data in Table ES-3 show a forecast of consumptive use for the basin through 2030 given a repeat of drought conditions, and adjusted to represent June through August consumptive use patterns.

Table ES-3: Forecast of average June through August consumptive water use by HUC given hot and dry conditions

HUC 8 name	2000	2010	2020	2030
South Branch Potomac	5.9	6	6.1	6.2
North Branch Potomac	24.5	24.6	24.7	24.7
Cacapon-Town	2	2.1	2.2	2.4
Conococheague-Opequon	35.4	38.4	40.9	43.5
South Fork Shenandoah	18.9	19.9	20.9	21.9
North Fork Shenandoah	8.5	9.2	9.9	10.6
Shenandoah	6	6.6	7.2	7.8
Middle Potomac-Catoctin (a)	13.8	15.6	17	18.5
Monocacy	24.1	27.9	30.4	33.5
Totals	**139.1**	**150.4**	**159.3**	**169.1**
Totals without Mount Storm (b)	**128.6**	**139.9**	**148.8**	**158.6**

Notes:
(a) The middle Potomac-Catoctin HUC only includes those totals for the non-metro portions of the Washington metropolitan area.
(b) Mount Storm in the North Branch is upstream of river regulating reservoirs and its consumptive demand is mitigated by minimum streamflow releases from the downstream reservoirs.

Table ES-3 shows that consumptive demand is expected to grow from 129 mgd in 2000 to159 mgd in 2030 (a net change of 30 mgd over 30 years) during hot and dry conditions for the months of June through August.

The effect of potential climate change on resources was not considered in the present study. There are numerous and substantial uncertainties associated with anticipated climate change, not least of which is the lack of any clear climate result for this region from the five different global circulation models previously examined; therefore, no potential climate change impacts were incorporated in the analysis of resources for the present study.

A sensitivity analysis shows a ten percent change in the growth factors for each sector had the biggest impact on the domestic sector, accounting for 48 percent of the total change in demand for all sectors. The next biggest change was irrigation at 15 percent of the total change, followed by thermoelectric at 12 percent and industrial at 10 percent. Commercial and mining categories accounted for less than 5 percent each of the total change.

E. Resource Assessment

A resource assessment was conducted to compare consumptive demands with Potomac River flow at several scales. Table ES-4 provides a summary of the resource assessment results.

Table ES-4: Summary of resource assessment results

Scale	Conclusion
Individual HUCs	Consumptive withdrawals in some parts of the Middle Potomac HUC region appear to be nearly equal to total low flow during drought periods. The Monocacy HUC's consumptive withdrawals are presently nearly equal to total low flow during drought periods, and are predicted to increase higher than the minimum 1930 historical streamflow by 2030. For the remaining HUC regions, the estimates of consumptive demands for 2000 are approximately 7 to 43 percent of the minimum flow for each HUC. The estimates of consumptive demand for 2030 are 8 to 56 percent of the minimum flow
Regional (grouped HUCs)	Resources will be adequate to meet water supply demands in the Potomac River upstream of Washington DC in the year 2030. Withdrawals were calculated to be 13 to 27 percent of the minimum flow in 2000 and 14 to 33 percent of the minimum flow in 2030 for all groups evaluated. Withdrawals were calculated to be 10 to 16 percent of the 7Q10 flow in 2000 and 11 to 20 percent of the minimum flow in 2030.

Scale	Conclusion
Basin-wide (Potomac at DC)	Resources will be adequate to meet water supply demands and current environmental flow recommendations in the Potomac River at Washington DC in the year 2030 under a repeat of the historical drought of record, but resources nearly would be depleted in this scenario. If climate change were to occur, demands could increase and streamflow resources could decrease relative to historical conditions. Sensitivity analysis shows that given a reduction in historical streamflow of 5 percent and a 9.5 percent increase in Washington area water supply demands, the system of reservoirs could meet demands in 2020 but reserve storage would be nearly depleted. Consumptive demands have an impact on long-term water supply resource availability at DC, decreasing the amount of remaining water supply in the reservoirs and increasing the frequency of voluntary and mandatory restrictions required to meet demands for the Washington metropolitan area in the year 2030. Consumptive demands increase the frequency and duration of low flows in the Potomac River at Little Falls; however, the release of water from upstream reservoirs to meet local environmental flow requirements limits the effect of the increased consumptive demand on the magnitude of extreme low flows.

F. Conclusions

Cumulative consumptive demands for the Potomac basin upstream of the WMA were combined with current and forecast water supply withdrawals for the WMA and compared to historical river flow at Little Falls near Washington, D.C., which is downstream of all major Potomac River basin water supply intakes. For the Washington metropolitan area, resources will be adequate to meet demands in the year 2030 under a repeat of the historical drought of record but resources would be nearly depleted in this scenario. Consumptive demands have an impact on long-term water supply resource availability at DC, decreasing the amount of remaining water supply in the reservoirs in future years and increasing the frequency of voluntary and mandatory restrictions required so that demands can be met for the WMA. Consumptive demands increase the frequency and duration of low flows in the Potomac River at Little Falls, but because of reservoir regulation to meet environmental flow requirements, the magnitude of extreme low flows is not affected by increasing consumptive demands.

Cumulative demands on the Potomac River itself were evaluated throughout the basin through the medium scale analysis (grouped HUC region analysis). Resources will be adequate to meet water supply demands in the year 2030 in the Potomac River upstream of Washington DC. Consumptive demands throughout the basin upstream of DC are currently at most about a quarter of the total flow in the free flowing Potomac during a repeat of the historical lowest flows. The consumptive demand is forecast to increase to up to a third of the historic low flow by 2030. Given flows that have a ten percent probability of occurring in any year, the current consumptive demand throughout the basin is less than a sixth of the flow at any point, and is forecast to be up to about a fifth of the flow in 2030.

At the individual HUC scale, two of the seven HUC regions evaluated may not have enough flow

to meet current and predicted consumptive demand during a repeat of the lowest historical minimum flow (Monocacy and Middle Potomac Catoctin). For the remaining individual HUC regions, estimates of consumptive demands range from approximately 7 to 43 percent of the minimum flow in 2000 and from 8 to 56 percent of the minimum daily flow in 2030.

This analysis did not attempt to identify potential problems at the local scale, i.e., for individual tributary streams in the headwaters of the Potomac.

G. Future Work

Although the present study was expected to rely primarily on existing data and information, a significant amount of important new work was performed in the course of producing the results presented herein. During the study, several other potentially important areas of investigation were identified, but limitations on time and resources did not permit further work. Future effort spent on the following issues would lead to significant refinements in the forecast of water demand and the adequacy of resources to meet those demands in the future.

- Analyses of demands and resources within small watersheds (HUCs) would identify potential future resource availability problems at the local scale. In order to address the problems noted above for the Monocacy and Middle Potomac HUC regions, and to identify potential problems at the local scale, a forecast for each of the major components of seasonal demand (for the Potomac the major components are domestic, commercial, industrial, thermoelectric, livestock, and irrigation) would need to be identified spatially. GIS tools could be used to assist in combination with soil type, gage information, and areal adjustment could be used to identify 7Q10 and minimum historical flows at each withdrawal point. Cumulative upstream withdrawals could be accounted for using these spatial tools. The contribution to supply from small locally important upstream reservoirs would also be considered.

- Consumptive water use forecasts for the largest water using sector would be more confidently conducted if the assumption that outdoor domestic water use for the several housing types is the same throughout the basin as it is for the WMA could be tested.

- Future work might verify the USGS estimates of consumptive use for commercial, industrial, thermoelectric, livestock, and irrigation withdrawals in the basin, and resolve whether seasonal variations in consumptive demands for these categories of water use were significant.

- A more detailed consideration of ground water as a resource would provide useful refinements to the results.

- A thorough discussion of other issues (e.g. climate change, minimum instream flow requirements) impacting or potentially impacting demands and resources throughout the watershed would help integrate resources management issues for the Potomac basin.

II. Introduction

The objectives of the study include an assessment of current and future water demands (with a focus on consumptive use) to the year 2030, and an estimate of available resources in the non-tidal portion of the Potomac River basin. The Potomac River basin upstream of, and including the Washington metropolitan area is defined as the non-tidal portion. The assessment of future water use in this study will assist the regulatory agencies and water utilities in addressing the future adequacy of fresh water resources in the Potomac River basin.

Consumptive use upstream in the Potomac River basin reduces the amount of water allocatable and available for further use by those downstream. The concept of *consumptive use* as used here is consistent with that of others in the field, including the U.S. Geological Survey (USGS): "That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment," (USGS, 1998).

This is not a study that examines the environmental effects of low flow on the flora and fauna of the Potomac River, nor does this study attempt to evaluate future sources of water supply in the basin. This study does not identify potential instances where withdrawals may be greater than flow at the local scale, i.e., in particular tributaries in the headwaters of the Potomac River basin; but instead compares consumptive demand to Potomac River flows at a broader spatial scale.

Two main approaches were used in the study. The first approach provides a summary of **annual average** water use forecasts by state and the District of Columbia. Analyses by state were not adjusted to include dry year or seasonal effects on consumptive use. No resource analysis was conducted based on the summary of forecasts by state.

The second approach provided a summary of water use forecasts by watershed, Hydrologic Unit Code[2] (HUC). This approach provided estimates of consumptive use that were adjusted to represent **dry year** and **seasonal** effects on consumptive use.

A major element of the study is the resource analysis, which was conducted using the seasonal estimates of consumptive use via the HUC watershed approach. The conclusions of the report are based on the resource analysis conducted using the HUC watershed approach.

This study relies on data and information compiled and analyzed from a wide range of sources. The data and information are associated with almost as many time periods as the sources from which they are drawn. The present study focuses on a forecast of water demand out to the year 2030. Although it was intended to use existing data and information as much as possible, in many

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[2]A Hydrologic Unit Code refers to a USGS designated natural drainage basin or hydrologic area. There are 9 HUC regions in the Potomac River basin upstream of the Washington DC area. The USGS provides its water use data by HUC region.

cases forecasts have had to be extended to consistently reach the year 2030. The discussion of the analysis describes those cases where documented information has been extended for completeness and consistency

It should be noted that extended forecasts are an extrapolation of prior trends, and were not conducted with regard to economic considerations or capacity issues.

For much of the basin, water withdrawn from the river is returned to the river a short distance downstream via wastewater treatment plants. The analysis in this study accounts for this returned water and assumes that it is of adequate quality for further use. Water that is not returned is considered a consumptive use. However, most water withdrawn for drinking water supply in the Washington, DC metropolitan area is not assumed to be available for flow augmentation in the non-tidal Potomac. Most of DC's wastewater is sent to the Blue Plains wastewater treatment plant located in the Potomac's tidal estuary, downstream of the water supply intakes. Thus, all water withdrawn for drinking water supply in the DC area that is not returned to the non-tidal Potomac river is considered a net consumptive use in this study.

Water that is lost through line leakage, meter mis-registration, and unbilled use is referred to as unaccounted water. Estimates of unaccounted water were prepared for the Washington, DC metropolitan area study and incorporated into this study because it generally cannot return to the non-tidal basin as a resource for downstream users. Unaccounted for water in the non-tidal Potomac River basin upstream of the metro area is not considered a use in the present study because it is returned to the hydrologic environment far enough up stream in the basin that it does not significantly impact the quantity of the available water supply resource.

The effect of potential climate change on resources was not considered in the present study. There are numerous and substantial uncertainties associated with anticipated climate change, not least of which is the lack of any clear climate result for this region from five different global circulation models as discussed in Section VI. F.; therefore, no potential climate change impacts were incorporated in the analysis of resources for the present study.

Recent water use trends at the national level can be examined using USGS data. The USGS has compiled estimates of water use for the nation at 5-year intervals since 1950. In the most recent water use survey, the USGS concludes that after continual increases in national water use from 1950 to 1980, withdrawals declined from 1980 to 1995 (Solley, 1998) as shown in Figure 2-1. This decline in water withdrawals occurred even though population increased 16 percent from 1980 to 1995.

The USGS began tracking consumptive use in 1960. Figure 2-2 shows trends in consumptive use at the national scale from 1960 through 1995 (Solley, 1998). The figure shows that consumptive use, at the national level, increased from 1960 through 1980 but has not increased over the period 1980 to 1995. Consumptive use has not increased since 1980 despite the 16 percent increase in population over that same time period. These trends are not incorporated into the present study but show trends at the national level.

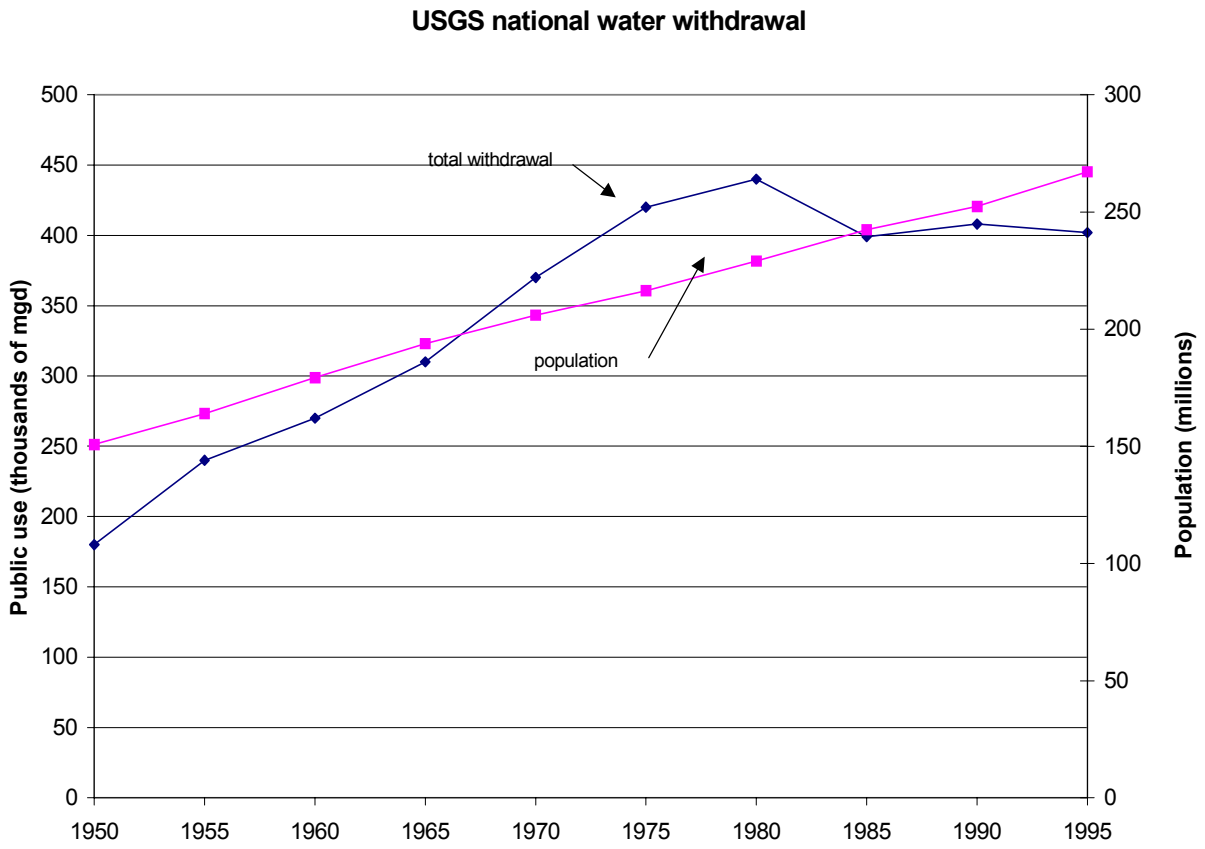

Figure 2-1: Trend in national water withdrawals and total US population

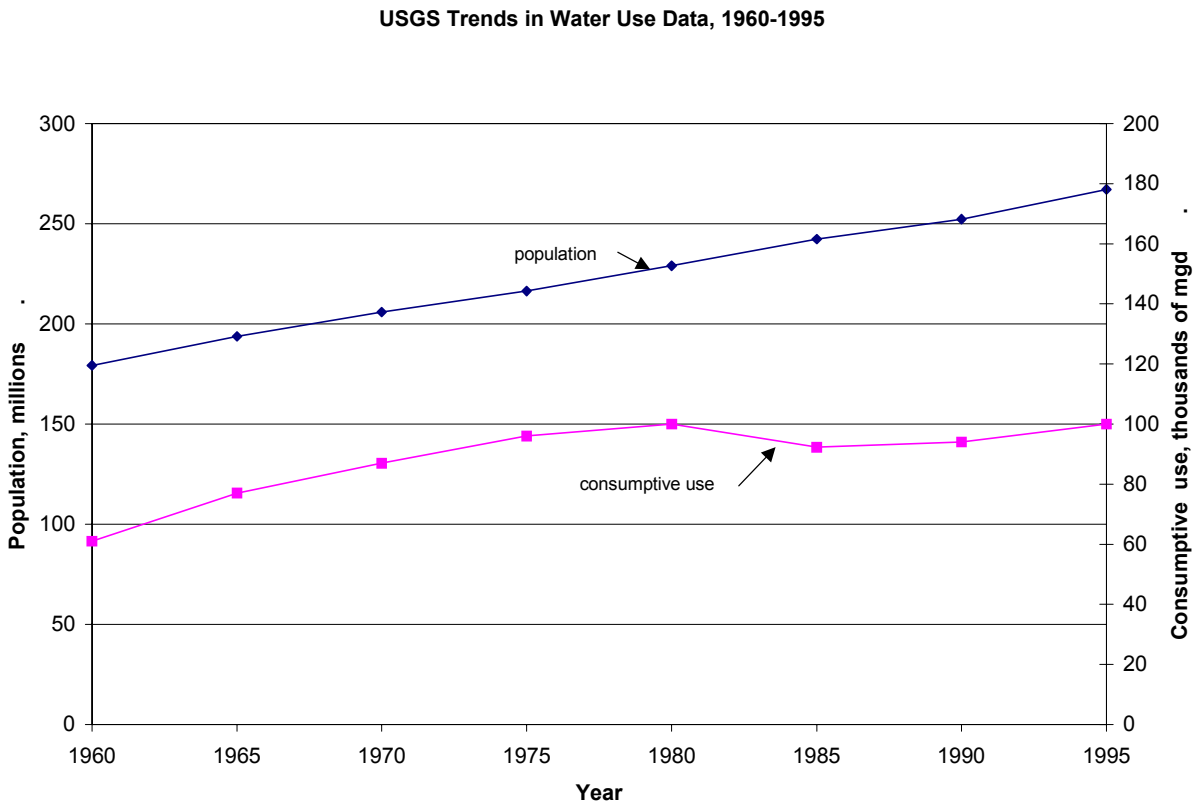

Figure 2-2: Trend in national consumptive water use and total US population

III. Overview of method used to develop forecasts of consumptive use by HUC watershed

The emphasis of this study is on the HUC watershed forecast and resource analysis, and conclusions of the study are based on the resource analysis conducted using the HUC watershed approach. This approach provided estimates of consumptive use that were adjusted to represent **dry year** and **seasonal** effects on consumptive use. The water use categories for the HUC watershed analysis were organized as: domestic, commercial, industrial, thermoelectric, mining, livestock, and agricultural irrigation.

Forecasts developed in state and county format were done so by reference to state and county population forecasts and by simply extrapolating existing trends in demands and are described in Section IV. Forecasts developed for the WMA were based on projections of numbers of households and employees, and are incorporated with the HUC-based analysis described below in Section VI.

The HUC watershed analysis relied on USGS (1995) water use data for initial conditions, and forecasts of population obtained from the U.S. EPA Chesapeake Bay Program (CBP), located in Annapolis. A description of the CBP method is presented in Appendix F. Detailed results are presented by HUC watershed and by state in Appendix G.

Forecasts of consumptive demand developed in this work for the Potomac basin depend on large part on the consumptive use data collected by the USGS. The data are compiled for the basin for a base year (1995) and are extrapolated using forecasts of households, population and irrigated acreage.

Consumptive water use estimates were obtained from the USGS (1995) by water use categories of domestic, commercial, industrial, thermoelectric, mining, livestock and irrigation. Forecasts of consumptive use were made for each of these categories. USGS consumptive data for 1995 provided the basis of the forecast for all but the domestic category. The method for developing forecasts of domestic consumptive water use was based on calculations of regional consumptive use for the Washington metropolitan area. The procedure for conducting forecasts of Potomac basin consumptive withdrawals for each of these categories is summarized in Table 3-1. A more detailed discussion of the assumptions used in the development of the consumptive use forecast method follows.

Table 3-1 Consumptive use forecast method in the Potomac River basin upstream of the WMA 2000 to 2030

Sector	Method for developing annual average consumptive use	Seasonal and dry year adjustments
Domestic	Based on WMA single family household use, adjusted by population rate of growth	As WMA single family June through August household use during a dry year
Commercial	USGS 1995 base adjusted by population rate of growth	none
Industrial	USGS 1995 base - constant, no growth	none
Thermoelectric	USGS 1995 base (minus Mt. Storm) - regulation limited	none
Mining	USGS 1995 base - constant, no growth	none
Livestock	USGS 1995 base adjusted by population rate of growth	none
Irrigation	USGS 1995 base adjusted by eastern national percentage increase, (Brown, 2000)	Seasonal and dry year adjustments

A. Domestic sector method

Average annual consumptive use for the domestic category of water use was 9.5 mgd, based on a summary of USGS 1995 Water Use Data (USGS, 1998). The 9.5 mgd is less than half of the value of the basin's average annual domestic consumptive use as calculated in Appendix H, discussed below, and as based on the WMA single family outdoor water use.

Domestic outdoor water use varies by season and are higher during drought years. The USGS estimate of domestic use does not reflect seasonal factors nor represent consumptive demands for a drought year. In order to compare the total consumptive use to summertime low flows, potential variation in **seasonal water use** patterns and in **drought year use** were quantified in this study. Seasonal and drought year variation in outdoor domestic water use could change the magnitude of summertime consumptive use, especially as compared to annual average values.

Estimates of current and future domestic consumptive use were estimated for the peak use months of June, July and August and were also adjusted to represent demands during drought years. Estimates of monthly variation in domestic consumptive use are provided in Appendix H.

The domestic consumptive water use for the basin was based on factors developed using data from the WMA for single family outdoor water use. The WMA single family outdoor water use was calculated for a drought year and was based on a series of assumptions (Appendix H). The calculated single family outdoor water use for the WMA was similar to or slightly higher than measurements of outdoor single family water use for nearby and mid-Atlantic study cities and for cities with non-arid climates (Table 2, Appendix H), which is consistent with the WMA outdoor single family water use being calculated using data from a drought year.

B. Commercial sector method

Consumptive water use in the commercial sector would occur largely due to activities conducted at shops and stores, barbershops and beauty parlors, restaurants, and office of all kinds, etc. In the course of conducting this study, it was assumed that commercial activity would increase in direct proportion to the growth in population. Therefore, consumptive water use in the commercial sector was assumed to increase in proportion to the growth in population, without any appreciable seasonal or drought year differences.

C. Industrial sector method

Throughout the Potomac River basin, water using industries have been on the decline for decades. Although there may be some increase in a few areas such as food processing, it is assumed that any such increase will be offset by further decline in heavy water using industries such as manufacturing. Therefore, consumptive water use in the industrial sector was assumed to remain constant at the year 1995 base level throughout the forecast period, without any appreciable seasonal or drought year differences.

D. Thermoelectric sector method

Thermoelectricly generated power is produced at relatively few sites in the Potomac River basin: Mt. Storm, WV, AES Cumberland, and R.P. Smith and Dickerson on the mainstem of the river. Any likely growth in consumptive use at the Mt. Storm power station would be mitigated a short distance down the North Branch Potomac River by significant minimum releases from Jennings Randolph and Savage River reservoirs in order to meet minimum flow requirements at Luke, Maryland. The impact of increased consumptive use of Potomac River water at R.P. Smith and/or Dickerson would be capped at one million gallons per day (mgd) each under the terms of the Maryland Consumptive Use Regulation (Department of the Environment, Title 26). The AES Cumberland power plant is relatively small. Therefore, consumptive water use in the thermoelectric power generating sector was assumed to increase by a maximum amount of 2 mgd above the year 1995 base level throughout the forecast period, without any appreciable seasonal or drought year differences.

E. Mining sector method

Like heavy industry, mining in the Potomac River basin has been declining for decades. Although some mining may continue in future years, significant growth in consumptive water use is unlikely. Therefore, consumptive water use in the mining sector was assumed to remain constant at the year 1995 base level throughout the forecast period, without any appreciable seasonal or drought year differences.

F. Livestock sector method

Activities associated with livestock rearing were assumed to include the production of terrestrial and aquatic animals for human consumption. The land area of the Potomac River basin is finite, and as more land is converted to residential and commercial development, less and less is available for agriculture. Fish farming is included in the livestock sector, and is practiced in a modest way at several locations in the basin: Mettiki mine site in the North Branch, Jennings Randolph Reservoir stilling basin, Stickley family near Flintstone, MD, Fresh Water Institute near Shepherdstown, WV, and hatcheries and/or rearing pens near Hagerstown, MD, Leetown, WV, and Ft. Loudon, PA. Consumptive use of water associated with fish farming is essentially evaporation from the water surface of the facilities. For this study, it is assumed that fish farming has a very small impact on consumptive use, that the best sites are already in use, and that the activity is unlikely to increase much.

However, the establishment of concentrated animal feeding operations (CAFOs) in the basin has shown that other livestock, including poultry, can still be produced in large numbers on limited acreage. A number of factors, each with a high degree of uncertainty in the future, influence the production of livestock; including, federal economic policies affecting agriculture, and the capacity of the associated land and water to assimilate the waste products generated by the animals, as controlled by state and federal regulations. Three other factors affect the future amount of water used consumptively in the production of livestock: the degree to which the basin is a net importer or exporter of livestock products, the amount of water used in the production of a unit (say a pound) of livestock product, and the pounds of livestock products consumed per resident of the basin. The scope of this study does not provide for the prediction of any of the foregoing factors, which are to some extent cross-compensating in the amount of water used consumptively. In the calculation of future consumptive water use in the livestock production sector it was assumed that the basin was neutral with respect to import/export, that water use per pound of product produced and pounds consumed per person would remain constant, and that other factors would not affect production. Therefore, consumptive water use was assumed to increase in proportion to the increase in human population throughout the forecast period, without any appreciable seasonal or drought year differences.

G. Irrigation sector method

The calculation of water used consumptively for agricultural irrigation in the basin was based on information from the USGS Water Use Data (USGS, 1995). USGS calculates the consumptive

use for irrigation by dividing the annual total irrigation water use by the number of days in the year. For this study, it was assumed that irrigation water use is 100 percent consumptive demand, and takes place in the summer. Therefore, the forecast of irrigation water use in this study reallocated the USGS annual daily average use to the growing season, and adjusted the use for hot dry conditions. In addition, the forecast was based on trends in eastern U.S. percentage increase in irrigated acreage as described by Brown (2000). Details of the method used to forecast water consumptively used by agricultural irrigation are presented in Appendix I.

IV. Overview of method used to develop forecasts of consumptive use by State and the District of Columbia

In this study, the forecast of consumptive water use was conducted using two approaches, a summary of forecasts by state and county, and a summary by HUC watershed. The HUC region-based approach was presented in Section III of the report. The state, county and District of Columbia approach to demand forecasting is summarized in this Section.

The state and District of Columbia forecast is presented in terms of **annual average** values of consumptive use. Values of consumptive use forecast by state were not adjusted to include dry year or seasonal effects. No resource analysis was conducted based on the summary of forecasts by state.

USGS water use data were summarized in the basin on a state and county-level basis in order to provide a readily recognizable geo-political frame of reference. In general, water use was assessed for the broad categories: domestic, commercial, and industrial, separately for water that is supplied by community systems and for that which is self-supplied by the consumer. The analysis was begun with the further disaggregation of use by source: surface water or ground water. The uncertainties of forecasting use by source became so large that this line of analysis was not pursued; however, the tables of results in Appendix A retain surface and ground water column headings. Forecasts were performed at 10-year intervals for the forecast period: 2000 through 2030. The detailed results are tabulated in Appendix A.

The population estimates for the base year of 1995 for the counties wholly or partially in the Potomac River basin, but upstream of the Washington D.C. metropolitan area (WMA) were derived from the U.S. Geological Survey information (USGS, 1995). This source provided population data for residents supplied by public water systems as well as those who were self-supplied. Population and water use information for the WMA were developed in another study: *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Metro Study), (Hagen and Steiner, 2000) and were incorporated in this work. Generally, water demand forecasts were derived from estimates of future population. Details of the methodology are presented in Appendix A.

Water that is withdrawn, but not delivered to metered customers (i.e. line leakage, fire fighting, mains flushing, parks landscaping and other public purposes) is generally referred to as "unaccounted for." Water use information attributed to this category was produced in the metropolitan water supply study and is included for completeness in the state summary tables of Appendix A of this report for Maryland, the District of Columbia, and Virginia, only, because it is not available as a freshwater resource in the down stream tidal river.

An important source of water use forecast information for the District of Columbia and all or parts of counties served by the large utilities in the Washington, D.C. metropolitan area is the Metro Study. Data and information compiled from and/or based upon that study is indicated by the label "(metro)" in the District of Columbia and applicable counties in the state water supply and

forecast summary tables of results. Because of the rather more intensive analysis of information and detailed forecasting associated with those areas, this study did not have to rely upon population or water use information from years prior to 2000. Employment of all kinds, including commercial and industrial was combined in that study, and is likewise combined in the present study and placed in the commercial category.

For the counties in the non-tidal Potomac River basin, but not subject to the detailed Metro Study, it was determined in conversations with county planning personnel that growth in population will occur more where there are utility services (e.g. community water supply systems) than where they are absent (e.g. self-supplied water). This issue is incorporated in the forecasts by arbitrarily selecting and applying 70 percent of the projected county growth to the system-supplied, and the remainder to the self-supplied sector. Population forecasts for the present study are summarized and presented by state and county in Appendix D.

Rates of growth of commercial and, especially, industrial water use are difficult to forecast because of unpredictable factors on which they depend. The areas subject to the detailed Metro Study benefitted from forecasts of employees produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) in cooperation with planning personnel in each of the counties. The Council of Governments' forecasts are summarized in Appendix C. The commercial and industrial water use forecasts for these areas are thus combined with results for the rest of the non-tidal Potomac River basin and reported in the state summaries (Appendix A: Tables: A - MD, A - DC, A - PA, A - VA, and A - WV) in the "commercial" category. For the outlying areas, both commercial and industrial water use are projected to increase in proportion to forecast increases in system-supplied and self-supplied population, depending on the source of supply.

Agricultural water use was calculated on the basis state (human) populations within the Potomac River basin. County-based forecasts, especially those counties with high (human) population growth forecasts, would be misleading under the method chosen. Therefore, increases in livestock water use were calculated as being proportional to human population growth by state in the Potomac River basin, and water used for irrigation was forecast to increase with the forecast in irrigated acreage as described for the HUC watershed analysis presented in Appendix I. It should be noted, however, that the state-based forecasts presented in Appendix A are expressed as **annual average** values.

The impact of the *Federal Energy Policy Act of 1992* (102D Congress, 1992) on water demand was incorporated in the forecasts for the state, county and District of Columbia approach. The impacts on water use in the counties of Maryland and Virginia which were the subject of the metropolitan area study were incorporated in those results as they were folded into the present study. For the other counties within the non-tidal Potomac River basin, information from the *Residential End Uses of Water* study (Mayer, et. al., 1999) was also applied to the present forecast study. Households where the effects of the Act have been implemented are able to effect an average reduction in daily water use of 15.7 gallons. The *Residential End Uses of Water* study found that the average household size was 2.71 persons. Therefore, it can be expected that the

Act will result in 5.79 gallons per person per day (gpcpd) less water use. This reduction in water use was applied to all **growth** in population throughout the forecast period. Also, in order to account for home remodeling and fixture replacement, the 5.79 gpcpd savings was applied to the population **existing** in 1995 at a constant rate of 2 percent per annum. This is roughly equivalent to assuming that fixtures have a useful life of approximately 50 years. A more detailed description of the effect of the *Federal Energy Policy Act of 1992* on projected water use is presented in Appendix E.

Source information for population and water use data, and forecasts to the year 2030, are presented below for each Potomac River basin state and the District of Columbia.

A. Maryland

A large portion of Maryland lies within the Potomac River basin. All of Allegany, Washington and Frederick counties, and parts of Garrett, Carroll, and Montgomery, counties drain to the non-tidal Potomac River. Although Prince George's County does not drain to the non-tidal Potomac River, that portion supplied by the combined metro D.C. resources is included in this study. The more western counties are rural with sparse population outside the few towns and cities. The predominant land use in the west is forest and agriculture. The eastern counties are more heavily populated, with the predominant land uses being agriculture and suburban/urban development. Water use reflects the land use and population across the region.

A particularly difficult issue in the present study involved the reconciliation of differences in forecasts evident in reference materials for the same areas. For instance, for Maryland, the three main references were the county water and sewerage plans (population forecasts and water use), U.S. Geological Survey information (USGS, 1995) which contains population and water use data, and population forecasts provided by the Maryland Office of Planning, State Data Center (2000). Generally speaking, per capita water use ratios and county to state population ratios were developed from the county water and sewerage plans and the USGS information, and then indexed to the population forecasts available from the Maryland Office of Planning. The population of the state, within the basin, is estimated to grow from approximately 2,036,000 in the year 2000 to 2,547,000 in the year 2030. The water use information from the US Geological Survey (USGS, 1995) formed the basis from which population-based forecasts were developed in the other Potomac River basin portions of the state. Total water use for all categories is expected to increase from 338.3 mgd to 410.4 mgd during the forecast period. Population and water use information for the portions of Maryland counties located in the Potomac River basin are presented in Appendix A and summarized in Table A - MD for the forecast period.

B. District of Columbia

The District of Columbia is at the center of the largest metropolitan area and concentration of population in the Potomac River basin. The metropolitan area includes significant densely populated suburbs in Maryland and Virginia. The land of the city is fully developed, but is undergoing a constant process of redevelopment. The redevelopment will have an impact on the

future population of the city, and on the water use by the residents and businesses there. Population and water use information for the District of Columbia were developed in the Metro Study and are presented in Appendix A and summarized in Table A - DC. Total water use for all categories is expected to increase from 130.4 mgd to 154.5 mgd during the forecast period.

C. Pennsylvania

A relatively small portion of south-central Pennsylvania lies within the Potomac River basin. No Pennsylvania county is wholly in the basin; therefore, population data were apportioned for each of the affected counties: Adams, Bedford, Franklin, Fulton, and Somerset. The population of the counties was apportioned to the Potomac River basin by overlaying census tract boundaries (and population information) (ESRI, 2000) with a digital outline of the river basin. Population forecasts were based on whole-county projections obtained from the Pennsylvania State Data Center (pasdc.hbg.psu.edu). The future projections from the State Data Center were available through the year 2020. Whole-county projections to the year 2030 were developed for the present study by extending prior trends; then, apportioned to the river basin using census tract boundaries and assuming relative proportions of population among census tracts would remain essentially constant throughout the forecast period. The total population of the state, in the basin, is expected to grow from approximately 179,800 in the year 2000 to 195,810 in the year 2030.

Land use in the Potomac basin portion of the state is predominantly forest and agriculture, with rural communities and several modest towns and cities. The water use information from the US Geological Survey (USGS, 1995) formed the basis from which population-based forecasts were developed in the other Potomac River basin portions of the state. Water use is consistent with the land use and population patterns. Industrial and agricultural water use is highest in Adams and Franklin counties. Total water use for all categories is expected to increase from 29.7 mgd to 31.0 mgd during the forecast period.

Population and water use information for the portions of Pennsylvania counties located in the Potomac River basin are presented in Appendix A and summarized in Table A - PA for the forecast period.

D. Virginia

A large portion of Virginia lies within the Potomac River basin. All of the major D.C. area suburban counties are included: Arlington, Fairfax, and Loudoun, counties drain to the non-tidal Potomac River. The Shenandoah valley counties also contribute to the non-tidal Potomac River: Frederick, Clarke, Shenandoah, Warren, Page, Rockingham, and most of Augusta counties. The more western counties are rural with sparse population outside the few towns and cities. The predominant land use in the west is agriculture, especially in the Shenandoah valley. Forest occupies the higher ground and ridges. The eastern counties are more heavily populated, with the predominant land uses being suburban/urban development. Water use is reflected in the land use and the density of population across the region. The Virginia portion of the basin contains a number of independent cities with statistics that are kept separate from the surrounding county. In

the course of the present study, water use for those areas was analyzed separately in the early years of the forecast period, because separate forecasts of population were available. However, during the latter years, only state level forecasts were available; therefore, for consistency, all results were combined to county level for presentation.

Virginia water use and population data, and forecasts, were obtained from a number of sources. By far, the larger portion of the population and water use in the state, in the Potomac River basin, was examined in the Metro Study. The water use information from the US Geological Survey (USGS, 1995) formed the basis from which population-based forecasts were developed in the other Potomac River basin portions of the state. Present and near term population data were obtained from the Weldon Cooper Center for Public Service at the University of Virginia. Both the water use and population data were available separately for Virginia counties and associated independent cities through the year 2010. For the later years of the forecasts, 2020 through 2025, state level population information was obtained from the U.S. Bureau of the Census (1997). State level population for 2030 was derived by extrapolation. County level population data for the years 2020 and 2030 were derived by extrapolating year 2010 forecasts of county population as constant percents of state population.

The population of the state, in the basin, is expected to grow from approximately 2,135,090 in the year 2000 to 2,984,820 in the year 2030. Total water use for all categories is expected to increase from 303.7 mgd to 414.1 mgd during the forecast period. Population and water use information for the portions of Virginia counties located in the Potomac River basin are presented in Appendix A and summarized in Table A - VA for the forecast period.

E. West Virginia

The portion of West Virginia within the Potomac River basin extends from the headwaters of the North Branch Potomac River (Grant County) and the headwaters of the South Branch Potomac River (Pendleton County) to the tip of the eastern panhandle(Jefferson County). The character of land use changes from steep wooded mountains and narrow farming valleys with small towns in the west to largely agricultural areas and bigger cities in the east. Water use is consistent with the land use, including the processing of agricultural products.

The population projection data for the state counties were obtained from the West Virginia Regional Research Institute of West Virginia University. The Institute is the state's official representative in the Federal-State Cooperative Programs for Population Estimation and Projection. The Institute conducts methodological research, prepares estimates and projections for all counties, and studies population change. The Institute's projections are widely used for planning purposes by businesses, government agencies, and health service providers. The population forecasts were available on a county basis through the present study's forecast period (2000 - 2030) based on both short-term migration patterns and long-term patterns. In the absence of any guidance from the Institute with regard to priority of pattern to use, the two projections for each year were averaged for each county and used in the present study.

Water use forecasts were developed from USGS baseline data (1995). Domestic water use forecasts take into account the effects of implementing the *Federal Energy Policy Act of 1992* (102D Congress, 1992) which are expected to impact newly installed and replacement plumbing fixtures during the period of the forecast.

The total population of the state, in the basin, is expected to grow from approximately 207,540 in the year 2000 to 270,270 in the year 2030. Total water use for all categories is expected to increase from 62.3 mgd to 74.8 mgd during the forecast period. Population and water use information for the portions of West Virginia counties located in the Potomac River basin are presented in Appendix A and summarized in Table A - WV for the forecast period.

V. 8-Digit Hydrologic Unit Code watershed-based forecast

A Hydrologic Unit Code (HUC) refers to a USGS designated natural drainage basin or hydrologic area. There are 9 HUC watersheds in the Potomac Basin upstream of the Washington DC area. The USGS provides its water use data by HUC watershed. In addition to partitioning the non-tidal portion of the Potomac River basin along state and county boundaries, 8-digit HUC areas provide a watershed basis for analyzing consumptive water use and water resource availability.

Population estimates were developed for each HUC and were used to help develop forecasts of water use.

A. Population

Population estimates for HUC watersheds in the Potomac basin were compiled from information supplied by the Chesapeake Bay Program (Chesapeake Bay Program, 2000) as shown in Table 5-1. The Chesapeake Bay Program's population estimates are based on population forecast information supplied by the states and on 1990 census information. Appendix F provides a complete description of the method by which the Chesapeake Bay Program derived the population estimates.

Table 5-1: Population estimates for non-tidal Potomac River basin by HUC (a), excluding metro study area

HUC watershed	1990	1995	2000	2010	2020	2030 (b)
South Branch Potomac	29,122	29,645	30,167	31,203	32,106	33,098
North Branch Potomac	107,877	109,035	110,193	110,632	110,961	111,363
Cacapon-Town	21,436	22,472	23,507	25,127	26,462	27,987
Conococheague-Opequon	384,654	407,739	430,823	468,696	500,348	536,147
South Fork Shenandoah	201,640	209,266	216,891	229,177	241,728	254,102
North Fork Shenandoah	57,186	60,296	63,406	68,684	73,964	79,243
Shenandoah	41,730	45,209	48,688	55,146	60,818	67,014
Middle Potomac-Catoctin (c)	77,646	89,610	101,573	121,093	137,302	155,718
Monocacy	204,857	233,233	261,609	307,597	337,796	378,521
Totals	1,126,148	1,206,503	1,286,857	1,417,355	1,521,485	1,643,194

Notes:
(a) Data source - Chesapeake Bay Program http://www.chesapeakebay.net/wshed.htm
(b) 2030 estimates developed by ICPRB using least squares best-fit of 2000 to 2020 populations
(c) Population estimate is based on that portion of the sub-watershed not served by CO-OP utilities. Total 1995 population including those served by CO-OP utilities is approximately 751,300 (USGS, 1998).

All HUC watersheds are forecast to grow in population. The population in the Potomac basin upstream of Little Falls and not served by the CO-OP utilities is forecast to grow from approximately 1,287,000 in 2000 to 1,643,000 in the year 2030, a net change of 356,000 or 28 percent.

The three HUC watersheds with the largest forecast of population growth over the period 2000 to

2030 are the Monocacy at approximately117,000, the Conococheague-Opequon at approximately 105,000, and the Middle Potomac-Catoctin at approximately 54,000. Note that the population forecast for the Middle Potomac-Catoctin applies only to that portion of the watershed not in the service area of the CO-OP utilities. The South Fork of the Shenandoah is forecast to increase by approximately 37,000, the Shenandoah by approximately 18,000, and the North Fork Shenandoah by approximately 16,000. The remaining HUC watersheds (South Branch Potomac, North Branch Potomac, and Cacapon-Town) are each forecast to grow by less than 5,000.

The percentage increase in population for each HUC as compared to 1995 levels is shown in Table 5-2.

Table 5-2: Percent population growth as compared to 1995 base year by HUC

HUC watershed	2000	2010	2020	2030
South Branch Potomac	102%	105%	108%	112%
North Branch Potomac	101%	101%	102%	102%
Cacapon-Town	105%	112%	118%	125%
Conococheague-Opequon	106%	115%	123%	131%
South Fork Shenandoah	104%	110%	116%	121%
North Fork Shenandoah	105%	114%	123%	131%
Shenandoah	108%	122%	135%	148%
Middle Potomac-Catoctin (a)	113%	135%	153%	174%
Monocacy	112%	132%	145%	162%

Notes:
(a) Population percentage is based on that portion of the population outside of the Washington metropolitan area that is not served by the three major WMA utilities or their wholesale customers (Fairfax County Water Authority, the Washington Suburban Sanitary Commission, and the Washington Aqueduct Division of the U.S. Army Corps of Engineers.)

The three HUC watersheds with the highest percent change in forecast of growth are the Middle Potomac-Catoctin at 174 percent, the Monocacy at 162 percent, and the Shenandoah at 148 percent. Note that the Middle Potomac-Catoctin HUC percent population growth applies only to that portion of the watershed not already served by the three major WMA utilities.

A comparison of 1995 population estimates developed using both USGS and the Chesapeake Bay Program data show good agreement at the basin-wide level. The total population for the Potomac basin that is not served by the CO-OP utilities and is upstream of Little Falls is estimated to be 1,210,000 as calculated using USGS data, and 1,207,000 as calculated using the Chesapeake Bay Program data.

B. USGS estimates of 1995 average annual consumptive use by HUC

Consumptive water use by USGS's 8 digit Hydrologic Unit Code (HUC) was summarized for each HUC as based on USGS 1995 Water Use Data (USGS, 1998). Information is available from USGS for portions of each HUC but disaggregated by state boundaries. Water use information was compiled for each HUC by summing each state's water use for a given HUC watershed. Consumptive use data are summarized in Table 5-3 by HUC for domestic, commercial, industrial,

thermoelectric, mining, livestock, and irrigation categories.

Table 5-3: Compilation of USGS 1995 average annual Potomac consumptive use by HUC and by type of user, mgd

HUC watershed	Domestic	Commercial	Industrial	Thermo - electric	Mining	Livestock	Irrigation	**Totals**
South Branch Potomac	0.2	1.0	2.4	0.0	0.0	0.9	0.0	**4.6**
North Branch Potomac	1.1	0.2	7.0	10.5	0.3	0.5	0.1	**19.7**
Cacapon-Town	0.2	0.0	0.0	0.0	0.0	0.6	0.0	**0.9**
Conococheague-Opequon	3.2	1.2	2.6	0.3	0.3	3.3	1.4	**12.2**
South Fork Shenandoah	1.3	1.1	2.9	0.0	0.0	1.6	0.5	**7.5**
North Fork Shenandoah	0.7	0.5	0.4	0.0	0.0	2.6	0.4	**4.6**
Shenandoah	0.3	0.5	0.9	0.0	0.0	1.5	0.1	**3.3**
Middle Potomac-Catoctin (a)	0.6	0.2	0.1	3.3	0.0	1.1	1.0	**6.3**
Monocacy	1.9	0.7	0.8	0.0	0.3	2.0	1.7	**7.4**
Totals (b)	**9.5**	**5.3**	**17.3**	**14.0**	**0.9**	**14.1**	**5.2**	**66.3**
Totals excluding Mount Storm (c)	**9.5**	**5.3**	**17.3**	**3.6**	**0.9**	**14.1**	**5.2**	**55.9**

Notes:
(a) The Middle Potomac-Catoctin HUC includes a major portion of the populations of the metropolitan Washington area that are served by the three major WMA water supply utilities (Fairfax County Water Authority, Washington Suburban Sanitary Commission, and the Washington Aqueduct Division of the U.S. Army Corps of Engineers or their wholesale customers. The consumptive use shown above has been estimated for that portion of the HUC watershed not served by these utilities.
(b) Figures may not add to totals because of independent rounding.
(c) Mount Storm is located upstream of Jennings Randolph Reservoir (see text explanation below).

Table 5-3 shows that the highest levels of thermoelectric water use are in the North Branch Potomac HUC area (10.5 mgd). However, thermoelectric use in the North Branch HUC does not directly affect low flows in the Potomac, since thermoelectric withdrawals are made upstream of the river regulating reservoirs (Jennings Randolph and Savage). The U.S. Army Corps of Engineers Baltimore District regulates flow with releases from Jennings Randolph and Savage so as to meet a minimum target of 77.6 mgd (120 cfs) at Luke, after all upstream consumptive withdrawals. The effects of any upstream consumptive water use is thus mitigated by the downstream reservoir regulation. Excluding the consumptive thermoelectric use upstream of Jennings Randolph Reservoir in the North Branch, the annual average total consumptive use in the Potomac basin upstream of the metropolitan water supply intakes for 1995 was 55.9 mgd.

C. Estimates of 1995 base year seasonal consumptive use by HUC, assuming hot and dry conditions

Domestic outdoor water use and irrigation water use vary by season and are higher during drought years. The USGS estimate of domestic and irrigation use does not reflect seasonal factors nor represent consumptive demands for a drought year. In order to compare the total consumptive use to summertime low flows, potential variation in **seasonal water use** patterns and in **drought year**

use must be quantified. Seasonal and drought year variation in irrigation withdrawals and outdoor domestic water use could change the magnitude of summertime consumptive use, especially as compared to an annual average value.

Estimates of current and future domestic and irrigation consumptive use were estimated for the peak use months of June, July and August and were also adjusted to represent demands during drought years. Estimates of monthly variation in domestic consumptive use is provided in Appendix H, and estimates of monthly variation in irrigation water use is provided in Appendix I. Other categories of water use (commercial, industrial, thermoelectric, mining, and livestock) were based on the USGS average annual values and were assumed to remain unchanged by seasonal cycles or by extreme drought events.

The method used to develop the forecast of June through August consumptive use by HUC is described in more detail in Section III and in Appendices H and I.

When seasonal and drought year factors are included in the analysis, a higher estimate of consumptive use is derived than that shown in Table 5-3. Table 5-4 provides estimates of average June through August consumptive use given dry year conditions.

Table 5-4: Estimated 1995 levels of June through August Potomac consumptive use by HUC and by category of user estimated for a drought year.

HUC 8 Name	Domestic	Commercial	Industrial	Thermo-electric	Mining	Livestock	Irrigation	**Totals**
South Branch Potomac	1.5	1	2.4	0	0	0.9	0	**5.8**
North Branch Potomac	5.6	0.2	7	10.5 (b)	0.3	0.5	0.3	**24.5**
Cacapon-Town	1.2	0	0	0	0	0.6	0.1	**1.9**
Conococheague-Opequon	21.2	1.2	2.6	0.3	0.3	3.3	4.8	**33.6**
South Fork Shenandoah	10.8	1.1	2.9	0	0	1.6	1.8	**18.2**
North Fork Shenandoah	3.1	0.5	0.4	0	0	2.6	1.4	**8**
Shenandoah	2.3	0.5	0.9	0	0	1.5	0.4	**5.6**
Middle Pot.-Catoctin (a)	4.7	0.2	0.1	3.3	0	1.1	3.4	**12.8**
Monocacy	12.3	0.7	0.8	0	0.3	2	5.9	**21.9**
Totals	**62.8**	**5.3**	**17.3**	**14**	**0.9**	**14.1**	**18.1**	**132.4**
Totals excluding Mt. Storm (b)	**62.8**	**5.3**	**17.3**	**3.6**	**0.9**	**14.1**	**18.1**	**121.9**

Notes:
(a) The middle Potomac-Catoctin HUC only includes those totals for the non-metro portions of the Washington metropolitan area.
(b) Mount Storm in the North Branch is upstream of river regulating reservoirs and its consumptive demand is mitigated by minimum streamflow releases from the downstream reservoirs.

Table 5-4 shows that consumptive use in a hot dry year would have been approximately 122 million gallons per day (mgd) in 1995 during the months of June, July, and August. The most significant consumptive uses of water are domestic (62.8 mgd), irrigation (18.1 mgd), and industrial (17.3 mgd) categories of water use. These three categories would have accounted for about 80 percent of the consumptive use in the basin during June through August given drought conditions in 1995.

D. Forecasts of June through August consumptive use by HUC, 2000 to 2030 assuming hot and dry conditions

The method used to develop the forecast of June through August consumptive use by HUC is described in Section III and in Appendices H and I.

Table 5-5 shows a forecast of consumptive use for the basin through 2030 given hot and dry conditions

Table 5-5: Forecast of average June through August consumptive water use by HUC given hot and dry conditions

HUC 8 name	2000	2010	2020	2030
South Branch Potomac	5.9	6	6.1	6.2
North Branch Potomac	24.5	24.6	24.7	24.7
Cacapon-Town	2	2.1	2.2	2.4
Conococheague-Opequon	35.4	38.4	40.9	43.5
South Fork Shenandoah	18.9	19.9	20.9	21.9
North Fork Shenandoah	8.5	9.2	9.9	10.6
Shenandoah	6	6.6	7.2	7.8
Middle Potomac-Catoctin (a)	13.8	15.6	17	18.5
Monocacy	24.1	27.9	30.4	33.5
Totals	**139.1**	**150.4**	**159.3**	**169.1**
Totals without Mount Storm (b)	**128.6**	**139.9**	**148.8**	**158.6**

Notes:
(a) The middle Potomac-Catoctin HUC only includes those totals for the non-metro portions of the Washington metropolitan area.
(b) Mount Storm in the North Branch is upstream of river regulating reservoirs and its consumptive demand is mitigated by minimum streamflow releases from the downstream reservoirs.

Table 5-5 shows that consumptive demand is expected to grow from 129 mgd in 2000 to159 mgd in 2030 (a net change of 30 mgd over 30 years) during hot and dry conditions for the months of June through August.

A sensitivity analysis was conducted to determine which sectors had most impact on changes in demand forecasts. Table 5-6 lists the factors that were used to develop a forecast of demand for each sector and shows the impact of a 10 percent change in growth of each factor for the period 2000 to 2030 on the forecast of total demand.

Table 5-6: Sensitivity analysis of consumptive use for the Potomac River basin upstream of the WMA (Impact of 10 percent change in growth of factor for the period 2000 to 2030)

Sector	Factor	July-August		
		2030 forecast, mgd	2030 forecast plus 10 percent change in forecast factor, mgd	Change, percentage of total change
Domestic	Number of single family households, apartments, mobile homes	84.4	92.9	54%
Commercial	All resident human population	7	7.7	4%
Industrial	USGS 1995 data	17.3	19	11%
Thermoelectric (a)	2 mgd (b)	5.6	5.8	1%
Mining	USGS 1995 data	0.9	1	1%
Livestock	All resident human population	19.3	21.3	13%
Irrigation	Eastern U.S. irrigated acreage percentage increase estimated from Fig. 10 (Brown, 2000)	26.2	28.8	16%
	Totals	160.7	176.4	

Notes:
(a) totals excluding Mt. Storm
(b) expansion at Dickerson, MD and Williamsport, MD existing facilities assumed limited to 1 mgd each under the Maryland Consumptive Use Regulation

Table 5-6 shows that a ten percent change in the growth factors for each sector had the biggest impact on the domestic sector, accounting for 54 percent of the total change in demand for all sectors. The next biggest change was irrigation at 16 percent of the total change, followed by at livestock13 percent and industrial at 11 percent. Commercial, thermoelectric and mining categories accounted for less than 5 percent each of the total change.

VI. Resource assessment

A resource assessment was conducted at three scales, a small scale corresponding to the individual HUC regions, a medium scale corresponding to groups of HUC regions, and at the largest possible basin scale just upstream of Little Falls, corresponding to the Washington metropolitan area.

Monthly variation in consumptive demand was considered adequate for the purpose of the present study, and no consideration was given to peak daily or peak weekly consumptive demands. For a resource evaluation at the individual HUC scale, this assumption may not be most appropriate. The monthly scale is more appropriate when a resource analysis for cumulative consumptive demand is conducted through the basin, and is best when cumulative demand at the basin scale is considered. Differences in the timing of peak daily or weekly consumptive demands for different parts of the basin will be offsetting in the downstream direction through the basin, given differences in basin wide travel times. Importantly, a resource analysis at the basin wide scale includes consideration of river augmentation from upstream reservoirs. Peak daily or weekly demands are essentially insignificant in comparison to the longer term (monthly) consumptive demand, because peak daily or weekly demands can be met with short-term reservoir releases. At the broader basin scale, monthly variation in consumptive demand is most appropriate. The consumptive demands used in the following analyses are those calculated to occur during the June-August period of peak use.

Not considered in this report was that Maryland water users can be required to reduce or cease water use to maintain flows in streams. To meet flow requirements on water use permits, a reduction in use could be achieved by ceasing or reducing outdoor watering, thereby substantially reducing the consumptive use in a watershed.

The current work conservatively assumes that all withdrawals from groundwater are actually from the river. However, much of the groundwater withdrawn to meet peak demand will not have an immediate affect on streamflow, leading to possible over-estimates of consumptive use.

Effects of climate change were examined for the region in a previous study (Steiner et al., 1997), but there was a lack of any clear climate change for this region. Therefore, no potential climate change impacts were incorporated in the analysis of resources for the present study.

A. Small scale individual HUC region analysis

Consumptive demands for each of the nine HUC regions were evaluated throughout the basin and compared to flows. The WMA demands were not considered in this analysis, but are included in Section VI. C below.

There were few gages directly measuring the flow at the downstream end of the 8-digit HUC code drainage areas. However, sets of daily flows for each 8-digit HUC were developed using the area-adjustment method. The area-adjustment method was used to transform data from a nearby gage

to represent the flow at the point of interest. Measured flow from the gaged drainage area was multiplied by a ratio of drainage areas, namely that area of the watershed at the point of interest, divided by the area of the gaged watershed. Note that the area-adjustment method is not appropriate for determining peak flows because of differences in the time-of-concentration between the (generally) smaller gaged watershed and the larger HUC watershed.

Flow statistics for the individual HUC watersheds represent flow that is produced from each watershed and does not include flow entering individual HUC regions from upstream HUC watersheds.

In the Potomac River, upstream regulation in the headwaters of the basin has changed the pattern and magnitude of low flow events. Water quality storage in Jennings Randolph and Savage reservoirs is released over the course of the summer in order to maximize the minimum flow in the North Branch Potomac River. Therefore, the low flow in the Potomac that one might have experienced given hydrologic conditions in the 1930's would be different today even if the identical weather conditions were to be repeated.

Hydrologic analysis was conducted to separate the effects of upstream regulation from the streamflow record. A streamflow database was developed that represents streamflow that would have occurred had the river been regulated by Jennings Randolph and Savage reservoirs for the entire period of record. Statistics that are based on the latter data should be considered a better representation of those flows that might be expected in the future, given current regulated conditions. Flows are based on regulated flow minimum of 78 mgd at Luke, MD plus contribution from downstream drainage in the North Branch HUC. Simulation modeling analysis at a daily model time step shows that this minimum flow can be met even through the worst drought of record in 1930-1931. The USCOE has maintained this minimum flow at Luke via releases from Jennings Randolph and Savage reservoirs since 1981. This minimum flow is assumed to be viable through the 30 year forecast period of the present study.

Version 2.0 of DFLOW[3] was used to calculate “7Q10" values for various points throughout the watershed. The 7Q10 value corresponds to the lowest 7-day average flow which has a 10 percent chance of occurring in any given year based upon a period of record analysis. The minimum flows calculated for each HUC watershed and for various points throughout the watershed were also calculated.

Table 6-1a shows the drainage area, 7Q10, minimum flow production, and consumptive use for 2000 and 2030 for each HUC watershed excluding contributions from upstream HUCs. A discussion of the derivation of these statistics for each HUC watershed is included in Appendix J. The method used to develop the consumptive use estimates is provided in Section III and in Appendices H and I.

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[3]DFLOW is a U.S. EPA supported computer program to calculate specific stream flow statistics. Documentation is available at http://www.epa.gov/OST/library/modeling/wlabook6chapter1.pdf

Table 6-1a: Potomac HUC watershed calculated flows, and seasonal consumptive use

HUC-8 Name	Drainage Area, square miles	7Q10 for HUC, mgd (a)	Minimum one-day historical flow HUC, mgd	Seasonal consumptive use, 2000, mgd (b)	Seasonal consumptive use, 2030, mgd (b)
South Branch Potomac	1,482	48	33	5.9	6.2
North Branch Potomac (c)	1,345	111	99	24.5 (d)	24.7 (d)
Cacapon-Town	1,206	44	29	2.0	2.4
Conococheague - Opequon	2,281	249	148	35.4	43.5
South Fork Shenandoah	1,660	128	68	18.9	21.9
North Fork Shenandoah	1,044	81	43	8.5	10.6
Shenandoah	352	27	14	6	7.8
Middle Potomac - Catoctin (e)	1,227	4	1	13.8 (f)	18.5 (f)
Monocacy	986	41	14	24.1	33.5

Notes:
(a) 7Q10 and minimum flow calculated for flow production specific to each HUC and does not include flow entering the HUC from upstream watersheds.
(b) Assuming hot and dry drought year conditions for the period June through August.
(c) Flows are based on regulated flow minimum of 78 mgd at Luke plus contribution from downstream drainage in the North Branch HUC.
(d) Includes 10.5 mgd consumptive use from Mount Storm, upstream of Jennings Randolph
(e) Inflow from upstream HUCs was not included in the table, but upstream inflow is used to meet some consumptive demand.
(f) Consumptive use shown for non-metro portion of HUC only. Consumptive use of 13.8 mgd includes 3.3 mgd consumptive use for a thermoelectric power plant on the Potomac River.

Table 6-1b summarizes the seasonal consumptive use as a percentage of minimum flow and of 7Q10 flow for each HUC region shown in Table 6-1a.

Table 6-1b: Seasonal consumptive use as a percentage of minimum flow and of 7Q10 flow for each HUC region.

HUC region	2000 demands, percentage of minimum flow	2030 demands, percentage of minimum flow	2000 demands, percentage of 7Q10	2030 demands, percentage of 7Q10
South Branch Potomac	18%	19%	12%	13%
North Branch Potomac	25%	25%	22%	22%
Cacapon-Town	7%	8%	5%	5%
Conococheague - Opequon	24%	29%	14%	17%
South Fork Shenandoah	28%	32%	15%	17%
North Fork Shenandoah	20%	25%	10%	13%
Shenandoah	43%	56%	22%	29%
Middle Potomac - Catoctin	1380%	1850%	345%	463%
Monocacy	172%	239%	59%	82%

Tables 6-1a and 6-1b must be interpreted with caution. Even if the historical minimum flow and 7Q10 flows are greater than the current and predicted consumptive demand, there may be problems in the HUC watershed that are not uncovered by this level of analysis. Consumptive use within HUC watershed is not referenced spatially in the USGS's water use data, so demands were calculated and totaled for each HUC watershed in its entirety without reference to spatial

resolution. At the local scale, potential problems can only be determined by analyzing exactly where a given withdrawal occurs in the HUC watershed, the magnitude of the withdrawals, and the magnitude of the streamflow that occurs at the point of withdrawal. For example, a large consumptive water user located on a small stream in the headwaters of a HUC region could potentially have higher demands than the stream's minimum flow. Because the present study totaled all the consumptive demands for a HUC and compared them with the total streamflow available in a HUC, problems at the local scale could not be discovered.

Conversely, in the Monocacy and Middle Potomac HUC regions, where historical minimum flow is less than total consumptive demand, conclusions about potential problems must be evaluated carefully because the consumptive data are not spatially resolved and because the flow data set itself may be influenced by upstream consumptive withdrawals. Many current and future withdrawals may be from the Potomac river, reducing the consumptive use effects for the Monocacy or other tributaries within the HUC regions.

In the Middle Potomac HUC region, the total consumptive use in the watershed is greater than the minimum historical flow and the 7Q10 flow calculated for that watershed. These comparisons seem to indicate that potential problems exist in the Middle Potomac HUC region during low flow periods. However, this comparison may be misleading. Flow statistics shown in Table 6-1a for the individual HUC regions represent flow that is produced from each HUC region and does not include flow entering individual HUC regions from upstream HUCs. The Middle Potomac HUC region has Potomac flow entering the HUC from upstream. The total consumptive demands calculated for the Middle Potomac includes those consumptive withdrawals taken from the Potomac itself. For example, some consumptive demands included in the totals shown for the Middle Potomac HUC in Table 6-1a are withdrawn from the Potomac, such as consumptive demands for the town of Leesburg and for Dickerson power plant. The total consumptive demand that is specific to the Middle Potomac HUC and not from the Potomac could not be calculated without spatially resolved consumptive data.

For the Middle Potomac HUC region, The USGS's *Goose Creek at Leesburg, VA* gage flow record was examined. This gage measures flow from a drainage area of 332 square miles. During drought periods, flows can drop below 1 cfs for this gage as they did in 1941, 1985, 1986, and 1999. Streamflow at this gage indicates that upstream withdrawals in some parts of the Middle Potomac HUC region appear to be nearly equal to total low flow during drought periods.

The Monocacy HUC has no Potomac flow entering the region from upstream, and consumptive demands for this HUC region are shown to be greater than the minimum historical low flow.

For the Monocacy HUC region, the USGS's *Monocacy at Jug Bridge, MD* gage flow record was examined. The minimum low flow shown in Table 6-1a for the Monocacy HUC was based on a flow that occurred in 1966 as measured at the USGS's *Monocacy at Jug Bridge, MD* gage. The flow data in 1966 were probably not representative of the natural flow that would have occurred absent human consumptive use in the basin. The low flow from the drought of 1930 is probably less influenced by upstream human consumptive use. The minimum flow for the Monocacy HUC

as calculated based on the 1930 drought is 29 mgd, which is only a little higher than estimates of consumptive use for the year 2000 (24 mgd) and smaller than forecasts of consumptive use in 2030 (33.5 mgd). (Note that the minimum flow for the Monocacy HUC as calculated based on the gage data measured during the 1999 drought was 30 mgd. Either the natural flows during the drought of 1999 were not as severe as the 1930 conditions, or actual consumptive demands as manifested during the 1999 drought were not as high as those calculated for the Monocacy HUC in Table 6-1a.) A comparison of calculated consumptive demand for the Monocacy HUC with the 1930 historical minimum streamflow indicates that upstream consumptive withdrawals are presently nearly equal to total low flow during drought periods, and are predicted to increase higher than the minimum 1930 historical streamflow by 2030.

For the remaining HUC regions, the forecasts of consumptive demand are less than the historical minimum and 7Q10 flows. Forecasts for the year 2000 are approximately 7 to 43 percent of the minimum flow, and approximately 5 to 22 percent of the 7Q10 flow for each HUC region. The forecasts of consumptive demand for the year 2030 are 8 to 56 percent of the minimum flow, and 5 to 29 percent of the 7Q10 flow for each HUC region.

B. Medium scale combined HUC region analysis

Cumulative consumptive demands on the Potomac River itself were evaluated throughout the basin through the medium scale analysis (combined HUC region analysis) and compared to Potomac River flow. The WMA demands were not considered in this analysis, but are included in Section VI. C below.

The streamflow data developed for the small scale individual HUC region analysis and documented in Appendix J were also used for the medium scale combined HUC region analysis.

Potomac flows from each HUC region were combined in the downstream direction using appropriate lagging factors. (Flow entering a HUC region takes 1-2 days to pass through it.) Combined flows were compared with the cumulative consumptive demand of all the upstream HUCs contributing to the flow. Flows were summarized using minimum flow and 7Q10 statistical parameters as in the procedure just described for the individual HUC analysis.

Historical Potomac River flow was assumed to be augmented by releases from Jennings Randolph and Savage River reservoirs for the maintenance of downstream water quality as has been the case for nearly 20 years, and likely to remain so in the future.

Figure 6-1 shows a schematic of the HUC regions, with directional arrows indicating flow direction. The North and South Branch HUC regions were treated as a single unit, with combined flow and combined cumulative consumptive demands calculated and compared as shown at point number 1 in Figure 6-1. Working in the downstream direction, the procedure was repeated. The combined flow from the North and South Branch HUCs was lagged 1 day and combined with flow from the Cacapon Town HUC region as shown at point number 2. The combined consumptive demand for the three HUC regions was compared with the combined flow.

The combined flow from the upstream three HUCs was lagged 2 days and combined with flow from the Conococheague-Opequon HUC region as shown at point 3. This combined flow was compared with the combined consumptive demand for the North Branch, South Branch, Cacapon Town, and Conococheague-Opequon HUCs. Similar procedures were repeated for all HUC regions. Results are presented in Table 6-2.

A more detailed description of how the individual HUC region flows were combined (lagged) is given in Appendix K, which also presents a discussion of flow validation.

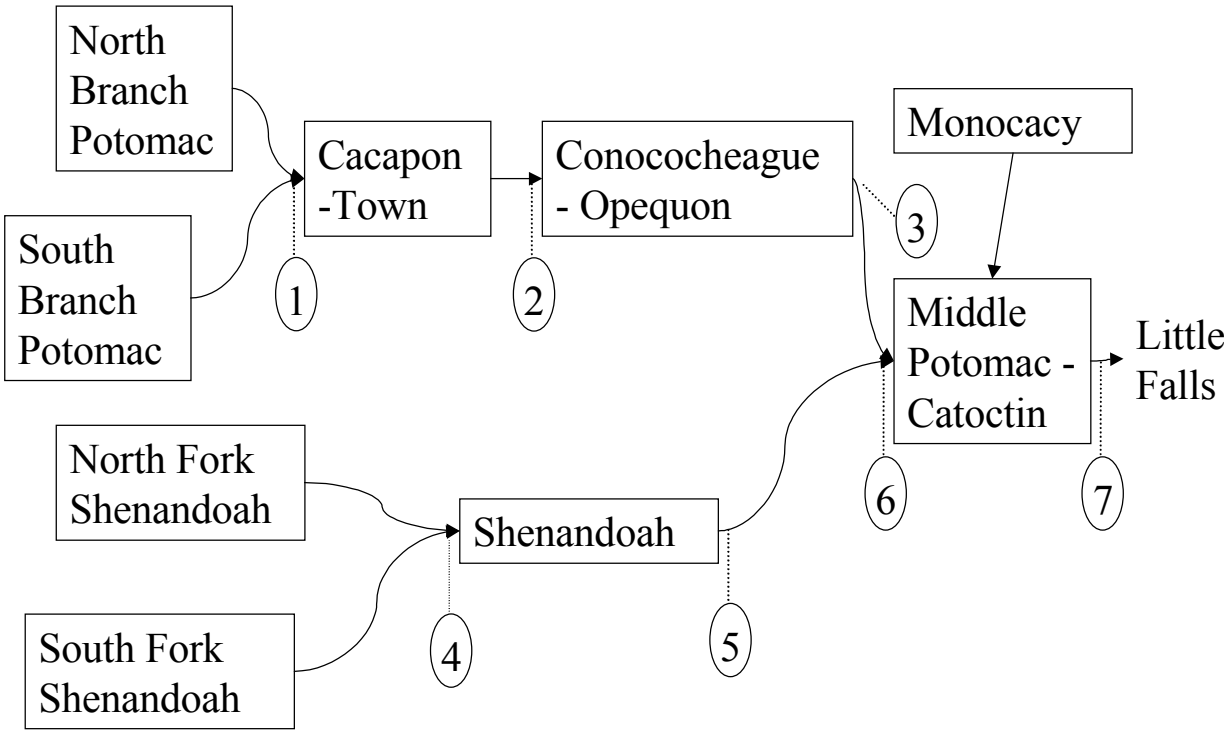

Figure 6-1: HUC flow diagram

Table 6-2: Simulated Potomac augmented flows and cumulative seasonal consumptive demands

Combined HUC areas (Numbers in parentheses are shown in Figure 6-1 and indicates point at which analysis was conducted).	7Q10, mgd (a)	Minimum flow, mgd (a)	Seasonal cumulative consumptive use, 2000, mgd (b,c)	Seasonal cumulative consumptive use, 2030, mgd (b,c)
(1) Confluence of South Branch and North Branch Potomac	163	136	20	20
(2) Downstream of South Branch and North Branch Potomac, and Cacapon-Town	210	168	22	23
(3) Downstream of South Branch and North Branch Potomac, Cacapon-Town, and Conococheague - Opequon	476	318	57	66
(4) Confluence of South Fork and North Fork Shenandoah	206	111	27	32
(5) Downstream of South Fork and North Fork Shenandoah and Shenandoah	233	125	33	40
(6)Downstream of South Branch and North Branch Potomac, Cacapon-Town, Conococheague - Opequon, South Fork and North Fork Shenandoah, Shenandoah	727	469	91	107
(7)Downstream of South Branch and North Branch Potomac, Cacapon-Town, Conococheague - Opequon, South Fork and North Fork Shenandoah, Shenandoah, Middle Potomac - Catoctin and Monocacy (d)	797	487	129	159

Notes:
(a) Flows are calculated as based on a regulated flow minimum of 78 mgd at Luke (in the North Branch HUC)
(b) Assuming hot and dry drought year conditions for the period June through August.
(c) Does not include 10.5 mgd consumptive use from Mount Storm
(d) Consumptive use shown for non-metro portion of HUC only.

Table 6-3 summarizes the cumulative demand as a percentage of minimum flow and of 7Q10 flow for each HUC confluence point described in Table 6-2 and shown in Figure 6-1.

Table 6-3: Cumulative demand as a percentage of minimum flow and of 7Q10 flow for each HUC confluence point.

HUC confluence point (a)	2000 demands, percentage of minimum flow	2030 demands, percentage of minimum flow	2000 demands, percentage 7Q10	2030 demands, percentage 7Q10
1	15%	15%	12%	13%
2	13%	14%	10%	11%
3	18%	21%	12%	14%
4	25%	29%	13%	16%
5	27%	32%	14%	17%
6	19%	23%	12%	15%
7	26%	33%	16%	20%

Notes: (a) HUC confluence points are delimited in Figure 6-1.

Tables 6-2 and 6-3 summarize cumulative demands upstream of the WMA and do not include those water supply demands withdrawn for the WMA area or releases from upstream reservoirs to support those demands.

Table 6-3 shows that the 2000 cumulative demands are estimated to vary between 13 and 27 percent of the minimum flow for the HUC confluence points. In 2030, cumulative demands are forecast to vary between 14 and 33 percent of the minimum flow. Table 6-3 also shows that the 2000 cumulative demands are estimated to vary between 10 and 16 percent of the 7Q10, and in 2030 are forecast to vary between 11 and 20 percent of the 7Q10.

In other words, current consumptive demand is about a quarter of the total flow in the free flowing Potomac during a repeat of the historical lowest flows. The consumptive demand is forecast to increase to up to a third of the historical low flow by 2030. Given flows that have a ten percent probability of occurring in any year, the current consumptive demand throughout the basin is less than a sixth of the flow at any point, and is forecast to be up to about a fifth of the flow in 2030.

When WMA demands are included, the flow versus demand comparison changes dramatically. WMA demands are already greater than the historical minimum flow in the Potomac River at Little Falls, which is why reservoir releases are made during times of low flow. Reservoir releases are made to augment the river for water supply and environmental flow recommendations. Increases in consumptive demand in the basin have an affect on reservoir storage and water supply reliability in the WMA. These effects are described in the following section.

C. Large scale basin analysis upstream of Little Falls

Cumulative consumptive demands for the Potomac basin upstream of the WMA were combined with current and forecast water supply withdrawals for the WMA and compared to historical river flow at Little Falls near Washington, D.C.

An important source of water use forecast information for the District of Columbia and all or parts of counties served by the large utilities in the Washington, D.C. metropolitan area is the *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Metro Study) (Hagen and Steiner, 2000). The Metro Study provides an extensive resource analysis at the basin scale. The resource analysis for the present study incorporates the method and tools used in the Metro Study. A description of the method and tools is included in Appendix L.

Appendix L describes the Washington metropolitan area water suppliers and service area, the system model that was developed for the resource assessment portion of the study as well as current CO-OP water supply operations. Several factors that can affect future resources were also incorporated into the system model and are describe in Appendix L. They include:

- Jennings Randolph release efficiency,

- the effects of siltation on reservoir storage over time,
- increasing return flows from wastewater treatment plants upstream of the Potomac water supply intakes and Occoquan Reservoir,
- the current recommended environmental flow rate for Little Falls,
- water quality releases from Jennings Randolph water quality storage, and
- modification of historic streamflow data to account for consumptive use.

This study includes the water resources and demands determined in the Metro Study for the Washington metropolitan area, and incorporates the findings of that study. In this case, as in some others, the forecasts had to be extended as part of the present study to the year 2030. Such extended forecasts are an extrapolation of prior trends, and could not be conducted with regard to economic considerations or capacity issues.

Year 2000 and 2020 forecasts were compared with the available resources for two alternatives: a *Baseline* scenario and a *Seasonal Consumptive Use* scenario. The *Baseline* scenario assumed the most likely growth forecast for the Washington metropolitan area, current levels of environmental flow requirements, current assumptions regarding conservation (i.e., effects of Federal Energy Policy Act of 1992), current effective water pricing rates, no effects of climate change on resources or demands, and implementation of voluntary and mandatory restrictions as documented in the Metro Study. The *Baseline* scenario did not consider the effects of upstream consumptive demands. The assumptions for the *Seasonal Consumptive Use* scenario were the same as those for the *Baseline* scenario but also included the effects of upstream consumptive demands. Seasonal consumptive demands were assumed to affect both historical stream flows as well as projected streamflow resources. Results of the analyses are provided in Table 6-4.

Table6-4: Forecast year and minimum combined Jennings Randolph and Little Seneca storage remaining and number of restriction years for *Baseline* and *Seasonal Consumptive Use* scenarios

Year	Scenario 1: *Baseline* (billion gallons)	Scenario 2: *Seasonal Consumptive Use* (billion gallons, number restrictions
2000	11.0 bg No restrictions	8.9 bg 2 voluntary restrictions no mandatory restrictions
2020	6.5 2 voluntary restrictions no mandatory restrictions	3.1 2 voluntary restrictions 1 mandatory restriction
2030	5.0 2 voluntary restrictions No mandatory restrictions	1.5 2 voluntary restrictions 3 mandatory restrictions

Table 6-4 shows that during a repetition of the worst drought of record (1930-1931), the minimum remaining water supply storage in Jennings Randolph and Little Seneca combined under the *Baseline* alternative would be 5.0 billion gallons (bg), given year 2030 demands. For the *Seasonal Consumptive Use* alternative, the minimum remaining water supply storage would be 1.5 bg given year 2030 demands. The net difference between the two scenarios is a reduction of 3.5 bg in remaining reservoir storage.

Table 6-4 also shows that the number of mandatory restrictions is projected to increase from zero to three over the adjusted 67-year period of record when consumptive demands are considered.

The magnitude, duration and frequency of low flows were examined for the Washington metropolitan area. The 1930-1931 drought was the longest drought in the historical record, and is the period in which modeled reservoir storage was most depleted given 2030 demands. The simulated flow for the *Seasonal Consumptive Use* alternative is quite variable over the roughly three and a half month period during which modeled releases were made (July 16, 1930 to November 3, 1930). The simulated flow downstream of Little Falls varied from between 110 and 1830 mgd and 164 mgd respectively. The simulated river flow did not remain constant at the 100 mgd recommended environmental flow-by target during the three and a half month release period in part because of the inefficiency of Jennings Randolph operations as discussed in Appendix L.

The frequency and duration of simulated flow is presented in Table 6-5. This table describes each year in the historical record for which releases would have been required given 2030 demands for both *Baseline* and *Seasonal Consumptive Use* alternatives . The total number of days in which releases would have been required for each year is also given.

Table 6-5: Years in historical record in which releases would have been required given 2030 demands, and number of days of releases for each year for *Baseline* and *Seasonal Consumptive Use* scenarios.

Simulation year	Number of days in which releases would have been made	
	Baseline alternative	*Seasonal Consumptive Use*
1930	72	88
1931	1	12
1932	36	45
1934	-	4
1941	-	6
1944	-	16
1954	-	6
1957	22	31
1959	1	10
1962	-	2
1963	32	57
1964	12	28
1965	19	34
1966	53	58
1969	-	5
1977	-	2

The number of days of releases shown in Table 6-5 may not be consecutive. For example, the 88 days in which modeled releases were required under 1930 flow conditions for the *Seasonal Consumptive Use* alternative took place over the course of 110 days.

Consumptive demands increase the frequency and duration of low flows in the Potomac River at

Little Falls, but because of reservoir regulation to meet environmental flow requirements, the magnitude of extreme low flows is not affected by increasing consumptive demands.

D. Ground water

The current work conservatively assumes that all withdrawals from groundwater are actually from the river; therefore, the maximum amount of demand possible is apparently required to be met by concurrent river flow. All consumptive demand was assumed to come from the river and its tributaries instantaneously, where in reality there would be a lag in the ground water consumptive use withdrawal in its effect on river flow. This conservative assumption is a major issue and may lead to on overestimate of impacts of demands on resources as calculated in the present study.

E. Small upstream reservoirs

The contribution to resources of small locally important upstream reservoirs was ignored in the present study. Although the duration and frequency of use and thus contribution of these reservoirs was not considered, these sources may provide a significant short term addition to overall resources. Their omission from the present study was a conservative assumption with regard to lagging demand compared with river flow, as it was for ground water.

F. Climate change effect on resources

A prior study of climate change, *Water Resources Management in the Potomac River Basin under Climate Uncertainty* (Steiner et al., 1997), examined several climate change scenarios and their effects on reservoir storage and Potomac River flow and Washington metropolitan area system demands for the year 2030. The study approach and results are summarized below.

Output from five General Circulation Models (GCMs) was examined. The five models selected were:

- Geophysical Fluid Dynamics Laboratory, new version (GFDL)
- Goddard Institute for Space Studies, version A (GISS-A)
- Goddard Institute for Space Studies, version B (GISS-B)
- United Kingdom Meteorological Office, Hadley Centre (UKMO)
- Max Planck Institute, Germany (MPI)

Complete data sets were obtained for all of these models through the National Center for Atmospheric Research. In general, the GCM scenarios predict a wide range of climatic variation rather than clearly representing any consistent future scenario. Some model results in fact predicted cooler and/or wetter summertime conditions.

A further source of uncertainty in this method was that the GCM outputs were in terms of average monthly precipitation and temperature. The outputs could only be used to generate projections on

similar statistics, that is, to project long term average values rather than trends or extremes. Precisely what is needed for the current study is a prediction of how extreme event (drought) flows might be affected by climate change.

There are numerous and substantial uncertainties associated with anticipated climate change, not least of which is the lack of any clear climate result for this region from the five different GCM model runs; therefore, no explicit climate change impacts were incorporated in the analysis of resources for the present study.

An analysis was conducted as part of the *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000) to determine the sensitivity of the metropolitan Washington water supply system to potential climate change. If climate change were to occur, demands could increase and streamflow resources could decrease relative to historical conditions. Resource sensitivity analysis showed that given a reduction in historical streamflow of 5 percent and a 9.5 percent increase in June through September Washington area water supply demands, the system of reservoirs could meet demands in 2020 but reserve storage would be nearly depleted.

It should be noted that across the board reductions in streamflow resources selected for the sensitivity analysis were not based on hydrology or general circulation models but were merely arbitrarily selected measures that have no basis in physical science. These reductions were used to alter the historical record so that changes in historical system resources could be quantifiably linked to changes in the system's ability to meet future demand. Explicit research has not been conducted to examine how extreme event hydrology (drought) might be affected by potential climate change. It remains an unanswered question of how much worse might have been the drought of 1930-1931 under the effects of potential climate change.

VII. Summary of Results

The population living and working in the Potomac River basin, from Washington, DC upstream to the boundary of the watershed, was estimated to increase by approximately 1,589,790 in the period from year 2000 to 2030. The population figures for the beginning and end of the period were estimated to be 5,076,750 and 6,666,540, respectively.

Total annual average demand for water supplies for all human uses in the Potomac River basin, from Washington, DC upstream to the boundary of the watershed, were forecast to increase from approximately 866 mgd to 1,083 mgd in the period from year 2000 to 2030.

Consumptive use in a hot dry year was estimated as approximately 122 million gallons per day (mgd) in 1995 , on average during the months of June, July and August. The most significant consumptive uses of water were the domestic (62.8 mgd), irrigation (18.1 mgd), and industrial (17.3 mgd) categories of water use. These three categories would have accounted for about 80 percent of the consumptive use in the basin during June through August given drought conditions in 1995.

Consumptive demand for the basin upstream of the Washington DC metropolitan area is expected to grow from 129 mgd in 2000 to 159 mgd in 2030 (a net change of 30 mgd over 30 years) during hot and dry conditions for the months of June through August.

A resource assessment was conducted to compare consumptive demands with Potomac River flow at several scales. Table 7-1 provides a summary of the resource assessment results. Several important assumptions were made regarding the resource analysis:

- Not considered in the resource analysis was that Maryland water users can be required to reduce or cease water use to maintain flows in streams. To meet flow requirements on water use permits, a reduction in use could be achieved by ceasing or reducing outdoor watering, thereby substantially reducing the consumptive use in a watershed.

- All withdrawals from groundwater are actually from the river. However, much of the groundwater withdrawn to meet peak demand will not have an immediate affect on streamflow, leading to possible over-estimates of consumptive use.

- No potential climate change impacts were incorporated in the analysis of resources for the present study.

- The contribution to resources of small locally important upstream reservoirs was ignored. Although the duration and frequency of use and thus contribution of these reservoirs was not considered, these sources may provide a significant short term addition to overall resources. Their omission from the present study was a conservative assumption with regard to lagging demand compared with river flow, as it was for ground water.

Table 7-1: Summary of resource assessment results

Scale	Conclusion
Individual HUCs	Consumptive withdrawals in some parts of the Middle Potomac HUC region appear to be nearly equal to total low flow during drought periods. The Monocacy HUC's consumptive withdrawals are presently nearly equal to total low flow during drought periods, and are predicted to increase higher than the minimum 1930 historical streamflow by 2030. For the remaining HUC regions, the estimates of consumptive demands for 2000 are approximately 7 to 43 percent of the minimum flow for each HUC. The estimates of consumptive demand for 2030 are 8 to 56 percent of the minimum flow
Regional (grouped HUCs)	Resources will be adequate to meet water supply demands in the Potomac River upstream of Washington DC in the year 2030. Withdrawals were calculated to be 13 to 27 percent of the minimum flow in 2000 and 14 to 33 percent of the minimum flow in 2030 for all groups evaluated. Withdrawals were calculated to be 10 to 16 percent of the 7Q10 flow in 2000 and 11 to 20 percent of the minimum flow in 2030.
Basin-wide (Potomac at DC)	Resources will be adequate to meet water supply demands and current environmental flow recommendations in the Potomac River upstream at Washington DC in the year 2030 under a repeat of the historical drought of record, but resources would be nearly depleted in this scenario. If climate change were to occur, demands could increase and streamflow resources could decrease relative to historical conditions. Resource sensitivity analysis shows that given a reduction in historical streamflow of 5 percent and a 9.5 percent increase in Washington area water supply demands, the system of reservoirs could meet demands in 2020 but reserve storage would be nearly depleted. Consumptive demands have an impact on long-term water supply resource availability at DC, decreasing the amount of remaining water supply in the reservoirs and increasing the frequency of voluntary and mandatory restrictions required to meet demands for the Washington metropolitan area in the year 2030. Consumptive demands increase the frequency and duration of low flows in the Potomac River at Little Falls; however, the release of water from upstream reservoirs to meet local environmental flow requirements limits the effect of the increased consumptive demand on the magnitude of extreme low flows.

VIII. Conclusions

A. Study conclusions

Cumulative consumptive demands for the Potomac basin upstream of the WMA were combined with current and forecast water supply withdrawals for the WMA and compared to historical river flow at Little Falls near Washington, D.C., which is downstream of all major Potomac River basin water supply intakes. For the Washington metropolitan area, resources will be adequate to meet demands in the year 2030 under a repeat of the historical drought of record but resources would be nearly depleted in this scenario. Consumptive demands have an impact on long-term water supply resource availability at DC, decreasing the amount of remaining water supply in the reservoirs in future years and increasing the frequency of voluntary and mandatory restrictions required so that demands can be met for the WMA. Consumptive demands increase the frequency and duration of low flows in the Potomac River at Little Falls, but because of reservoir regulation to meet environmental flow requirements, the magnitude of extreme low flows is not affected by increasing consumptive demands.

Cumulative demands on the Potomac River itself were evaluated throughout the basin through the medium scale analysis (grouped HUC region analysis). Resources will be adequate to meet water supply demands in the year 2030 in the Potomac River upstream of Washington DC. Consumptive demands throughout the basin upstream of DC are currently at most about a quarter of the total flow in the free flowing Potomac during a repeat of the historical lowest flows. The consumptive demand is forecast to increase to up to a third of the historic low flow by 2030. Given flows that have a ten percent probability of occurring in any year, the current consumptive demand throughout the basin is less than a sixth of the flow at any point, and is forecast to be up to about a fifth of the flow in 2030.

At the individual HUC scale, two of the seven HUC regions evaluated may not have enough flow to meet current and predicted consumptive demand during a repeat of the lowest historical minimum flow (Monocacy and Middle Potomac Catoctin). For the remaining individual HUC regions, estimates of consumptive demands range from approximately 7 to 43 percent of the minimum flow in 2000 and from 8 to 56 percent of the minimum daily flow in 2030.

This analysis did not attempt to identify potential problems at the local scale, i.e., for individual tributary streams in the headwaters of the Potomac.

The effect of potential climate change on resources was not explicitly considered in the present study. There are numerous and substantial uncertainties associated with anticipated climate change, not least of which is the lack of any clear climate result for this region from the five different global circulation models previously examined. However, resource sensitivity analysis for the Washington metropolitan area shows that given a reduction in historical streamflow of 5 percent and a 9.5 percent increase in Washington area water supply demands, the system of reservoirs could meet demands in 2020 but reserve storage would be nearly depleted.

B. Future work

Although the present study was expected to rely primarily on existing data and information, a significant amount of important new work was performed in the course of producing the results presented herein. During the study, several other potentially important areas of investigation were identified, but limitations on time and resources did not permit further work. Future effort spent on the following issues would lead to significant refinements in the forecast of water demand and the adequacy of resources to meet those demands in the future.

- Analyses of demands and resources within small watersheds (HUCs) would identify potential future resource availability problems at the local scale. In order to address the problems noted above for the Monocacy and Middle Potomac HUC regions, and to identify potential problems at the local scale, a forecast for each of the major components of seasonal demand (for the Potomac the major components are domestic, commercial, industrial, thermoelectric, livestock, and irrigation) would need to be identified spatially. GIS tools could be used to assist in combination with soil type, gage information, and areal adjustment could be used to identify 7Q10 and minimum historical flows at each withdrawal point. Cumulative upstream withdrawals could be accounted for using these spatial tools. The contribution to supply from small locally important upstream reservoirs would also be considered.

- Consumptive water use forecasts for the largest water using sector would be more confidently conducted if the assumption that outdoor domestic water use for the several housing types is the same throughout the basin as it is for the WMA could be tested.

- Future work might verify the USGS estimates of consumptive use for commercial, industrial, thermoelectric, livestock, and irrigation withdrawals in the basin, and resolve whether seasonal variations in consumptive demands for these categories of water use were significant.

- A more detailed consideration of ground water as a resource would provide useful refinements to the results.

- A thorough discussion of other issues (e.g. climate change, minimum instream flow requirements) impacting or potentially impacting demands and resources throughout the watershed would help integrate resources management issues for the Potomac River basin.

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