Water Supply Demands
and
Resources Analysis
in the
Potomac River Basin

Prepared for

The Maryland Department of the Environment

by

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Report No. 00 - 5

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here is consistent with that of others in the field, including the U.S. Geological Survey (USGS): "That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water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.

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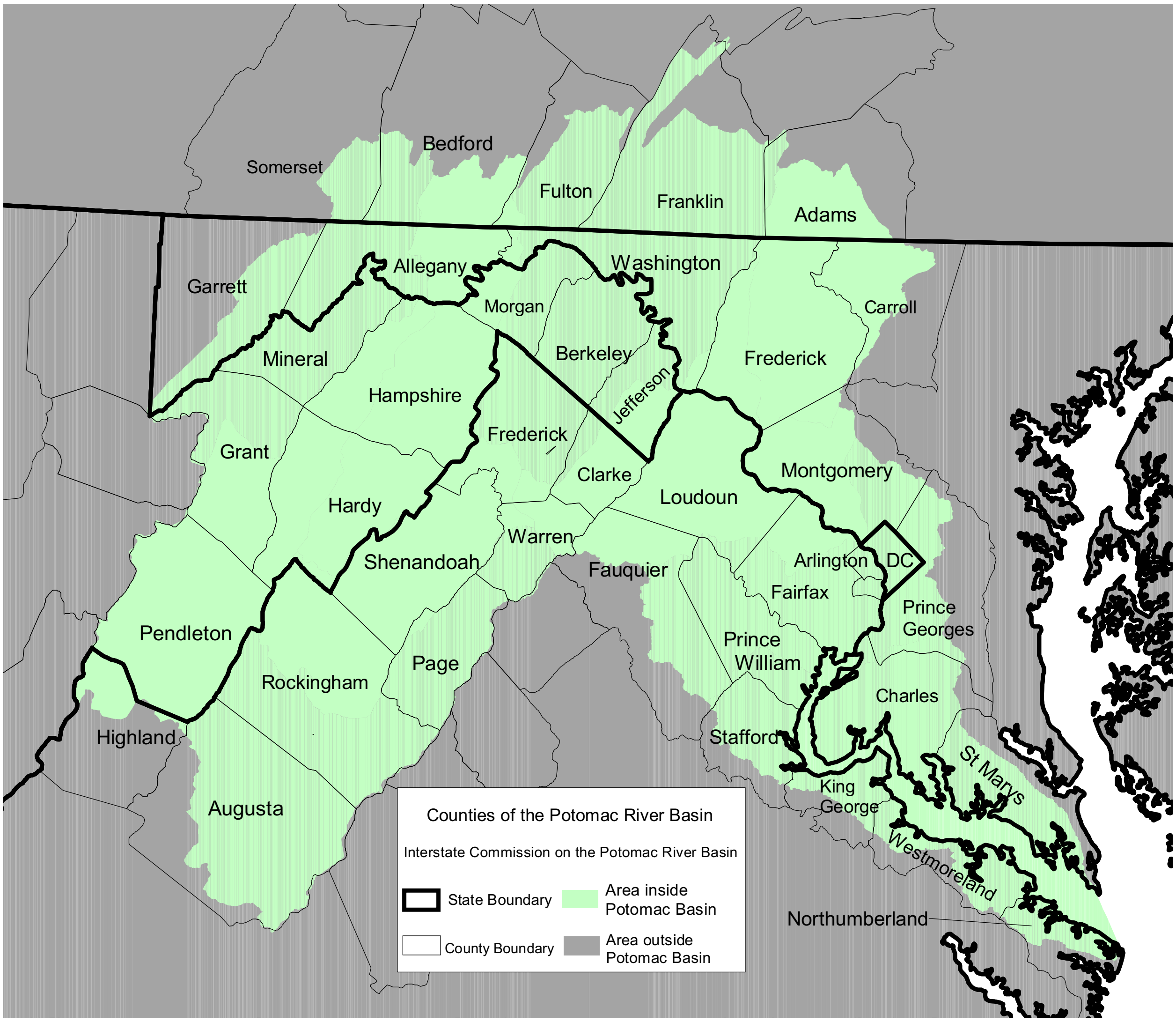

Figure ES - 1: Counties entirely or partially within the Potomac River basin

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.

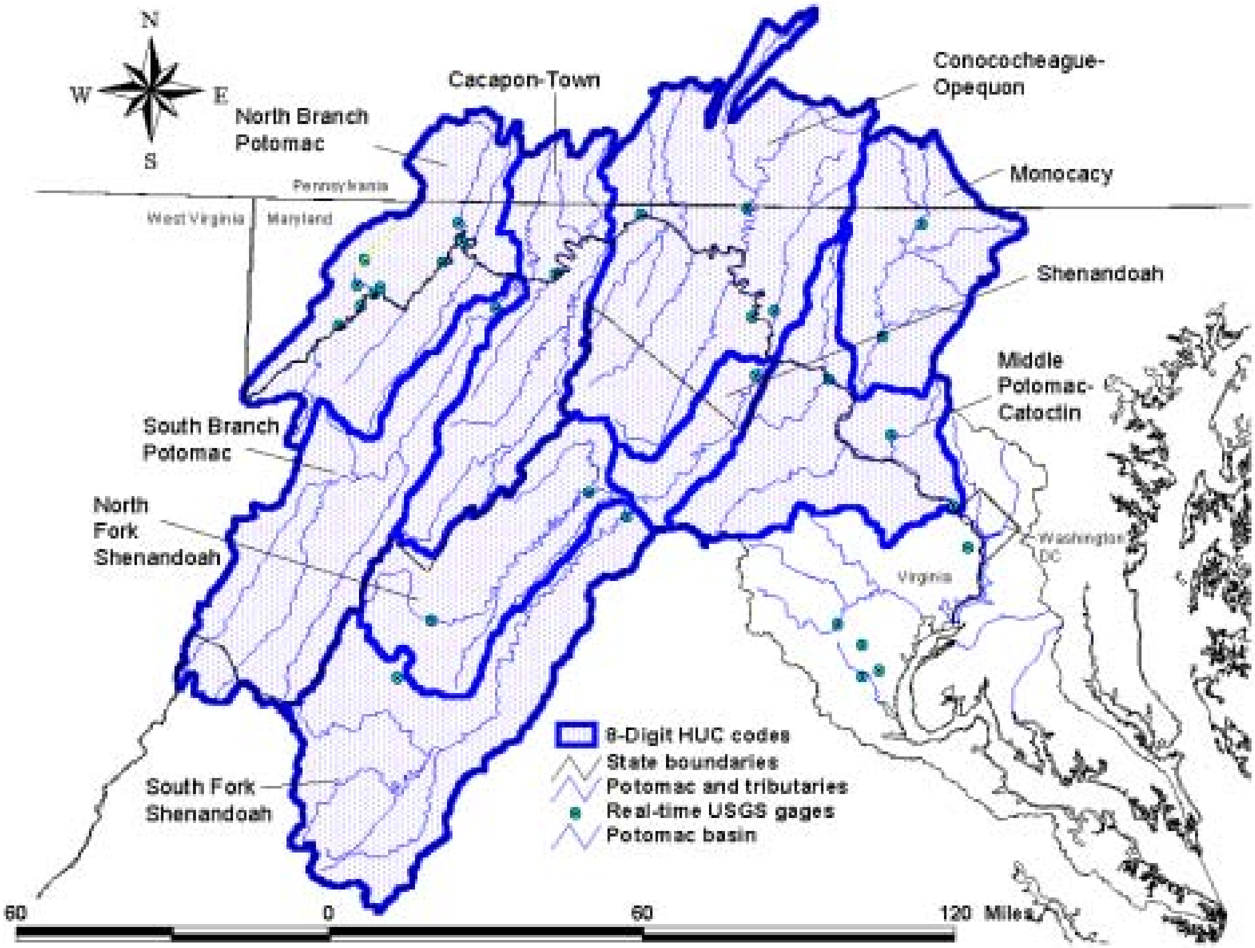

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Table ES - 1: Population, Total Water Use, and Consumptive Use: Non-tidal Potomac River Basin

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
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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.

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Table of Contents

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

List of Tables

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

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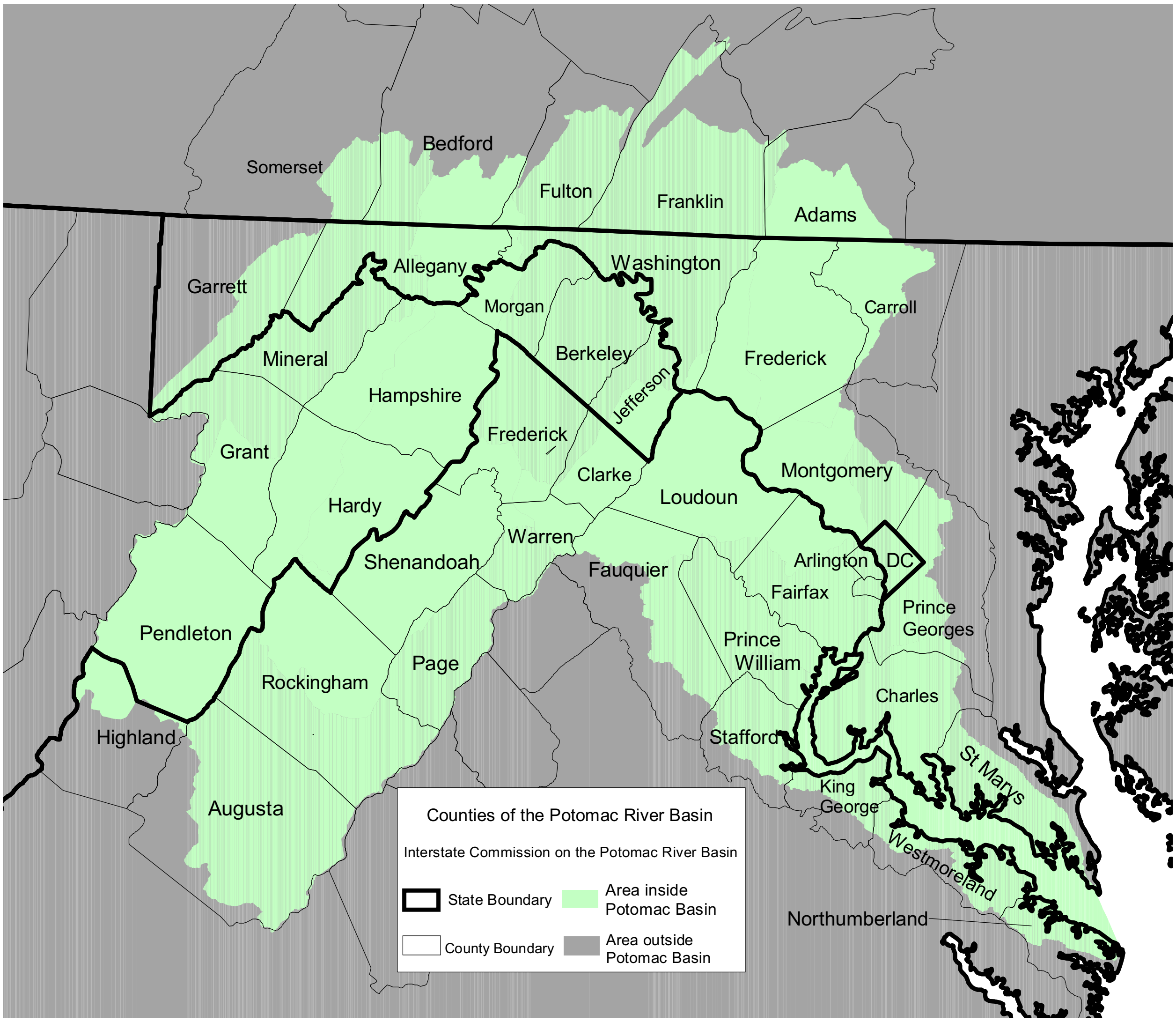

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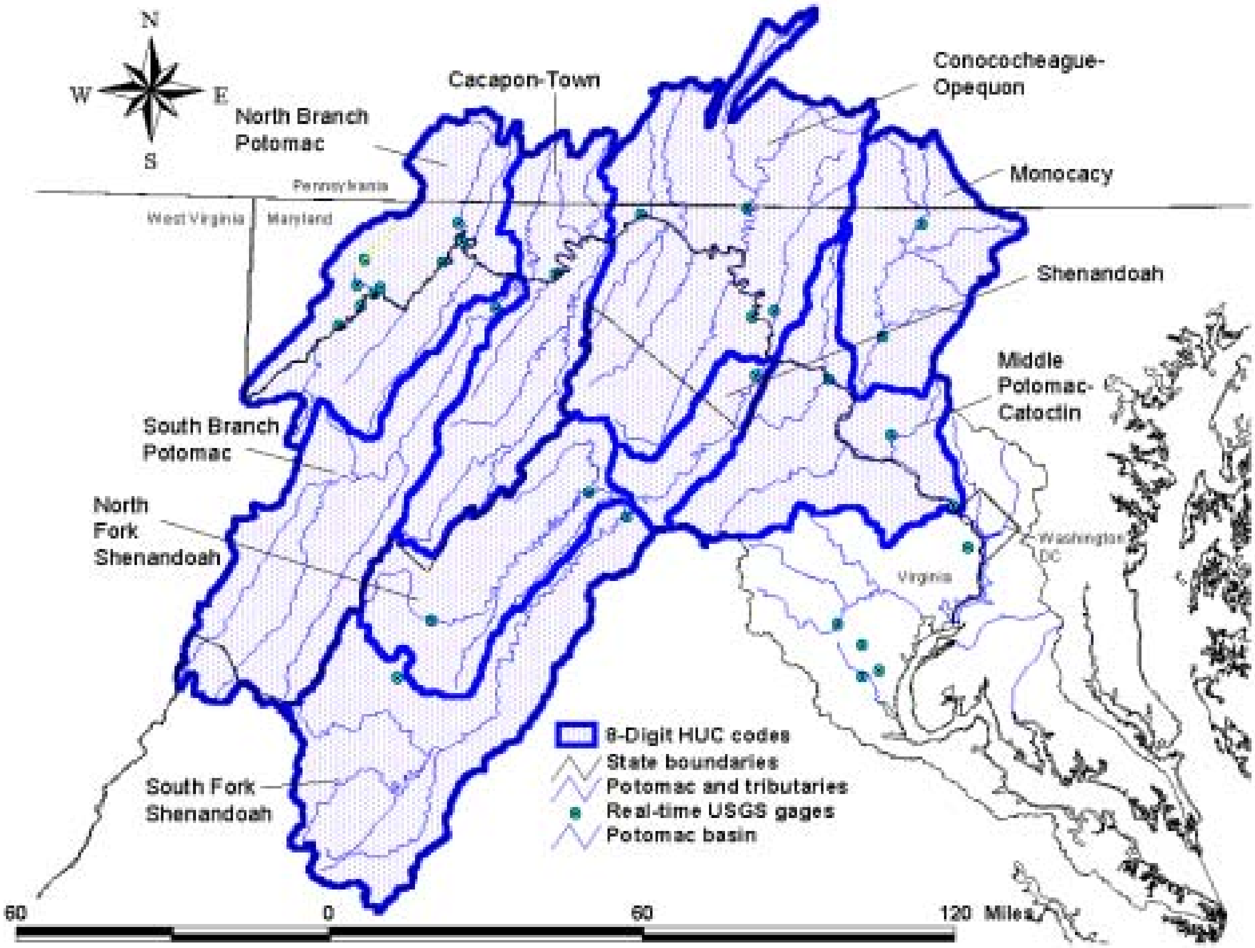

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3. Total use refers to water used for all purposes: domestic, commercial, industrial, agricultural, and unaccounted.
4. The consumptive use in the area served by the Washington, DC metropolitan area water utilities is not calculated or included in 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.

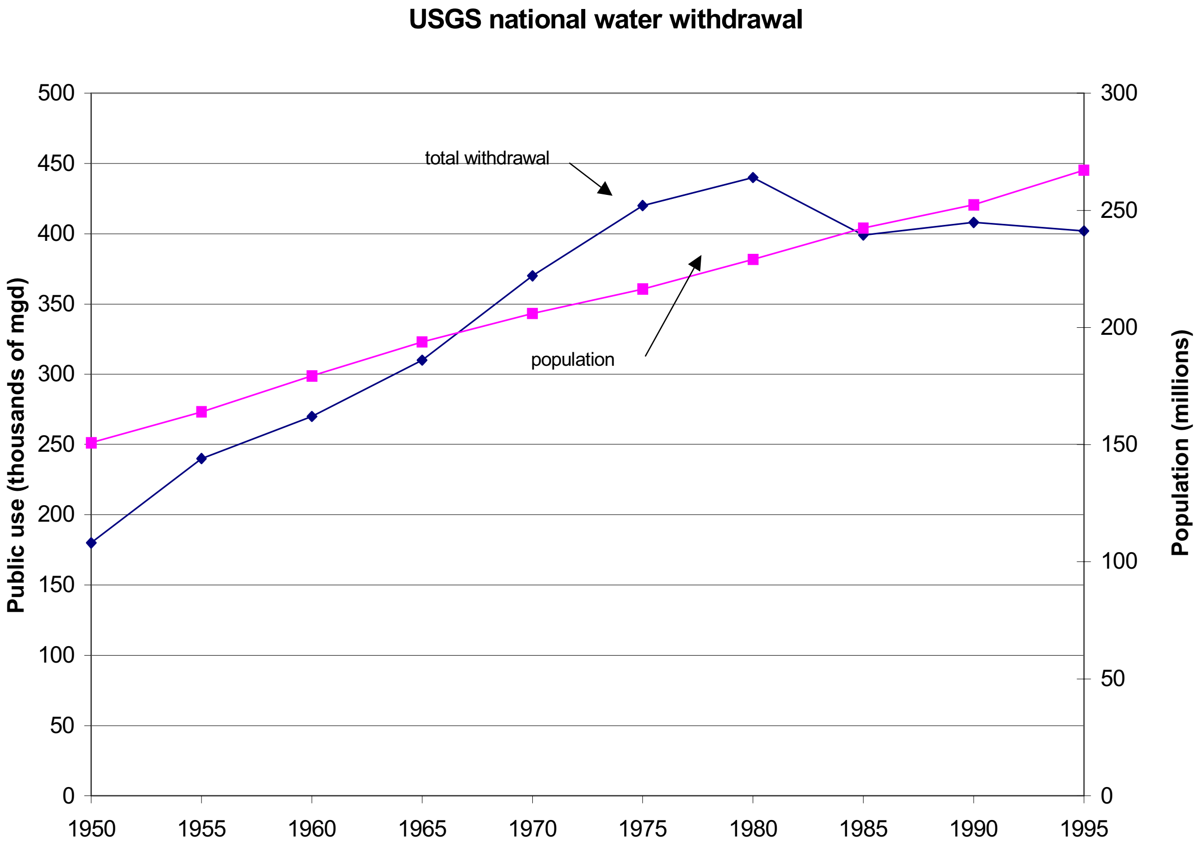

Figure 2-1: Trend in national water withdrawals and total US population

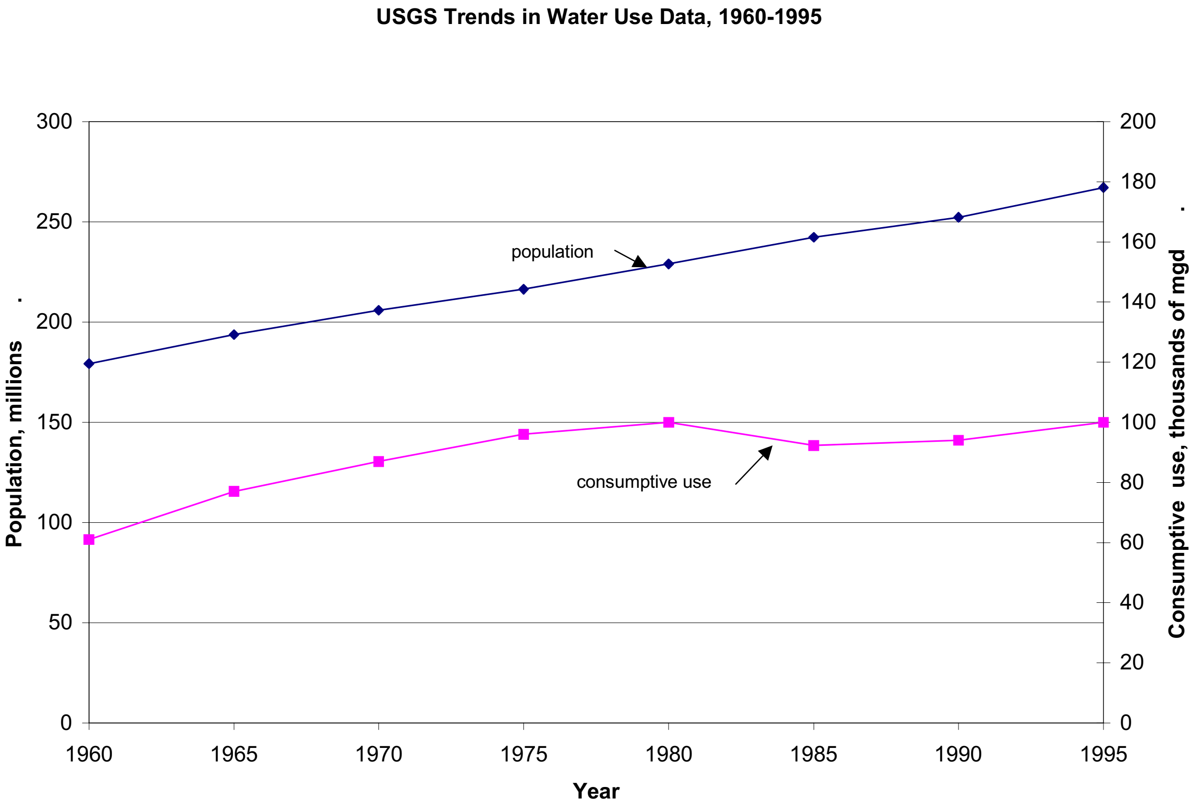

Figure 2-2: Trend in national consumptive water use and total US population

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.

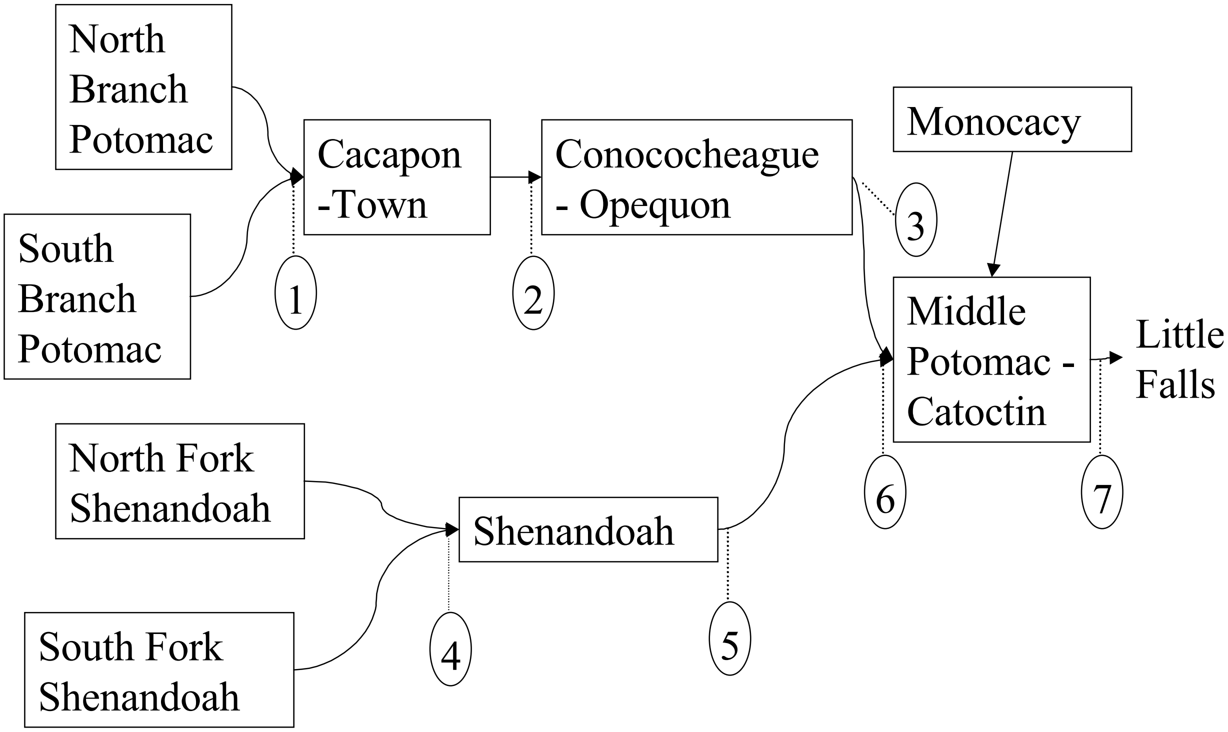

Figure 6-1: HUC flow diagram

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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MARYLAND

Allegany County, MD

Population

All of Allegany County is located fully within the Potomac River basin. The source of population estimates for the County for the base year of 1995 was 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 forecasts for the county for the years 2000, 2010, and 2020 were derived from information available from the Maryland Office of Planning, State Data Center (2000).

By projecting forecast trends another ten years for this study, it is estimated that the county population will be approximately 71,300 in the year 2030. Thus, the total population of Allegany County living in the Potomac River basin is forecast to decrease over the period 2000 to 2030 by 1,650, i.e. from 72,950 to 71,300. The proportions of the total population for the years 2000 through 2030, supplied by public systems and those that are self supplied, were derived by applying the ratio of population thus supplied derived from the U.S. Geological Survey information for the year 1995. These population data are presented in the summary table for Maryland, Table A - MD.

Water use

The source of water use estimates for the County for the base year of 1995 was derived from the U.S. Geological Survey information (USGS, 1995). This information provided water use data for residents supplied by public water systems as well as those who were self supplied. Due to the very small forecast change in population for the county for the period 2000 through 2030, water use forecasts for those years were derived by applying the rate of population change from the year 1995 to water supplied as derived from the USGS information for the year 1995.

The City of Cumberland, located in Allegany County, derives its water supply from sources in Bedford County, PA. The total water use in Allegany County is estimated to decrease over the period 2000 to 2030 by 1.5 mgd, i.e. from 52.2 mgd to 50.7 mgd, excluding agricultural water use. These water use and forecast data are presented in the summary table for Maryland, Table A - MD.

Carroll County, MD

Population

Approximately one half the area of Carroll County lies within the Potomac River basin. A significant portion of the population residing in that area is supplied by the City of Westminster public system which derives its supply from outside the Potomac basin. However, it is expected that a new reservoir will be developed in the Potomac basin in the near future to accommodate the city's growth. Therefore, in the year 2000 the population of Westminster was excluded from the analysis for this study; but the expected population growth for the city was included in the study for the years 2010 through 2030.

The county population supplied by water from the Potomac River basin was determined by analyzing census data (ESRI, 2000) in coordination with digital map overlays. For the years 2000 and 2010, the population of the county supplied by water from the Potomac River basin by public systems from surface or ground water sources was derived from Carroll County Master Plan for Water and Sewerage (1999). The populations thus derived were indexed to those available from the Maryland Office of Planning, State Data Center (2000) out to the year 2020.

By projecting forecast trends another ten years for this study, it is estimated that the county population supplied by public systems and that which is self supplied in the Potomac River basin portion of the county will be approximately 70,400 in the year 2030. Thus, the total population of Carroll County supplied by sources in the Potomac River basin is estimated to increase over the period 2000 to 2030 by 28,530, i.e. from 41,870 to 70,400 These population data are presented in the summary table for Maryland, Table A - MD.

Water use

Information concerning the amount of domestic water use estimates for the base year for the portions of the county in the Potomac River basin was derived from the Carroll County Master Plan for Water and Sewerage (1999). This information provided water use data for residents supplied by public water systems as well as those who were self supplied, and it formed the basis of forecasts for the county developed for the years 2000 through 2030. The water use forecasts for those years were developed in proportion to the increase in population during the same period, taking into account that the proportion of the total population supplied by public systems is expected to grow faster (due to the implementation of Maryland's Smart Growth policy) than those that are self supplied. Water use data for non-domestic uses was derived from the U.S. Geological Survey information (USGS, 1995), and adjusted by the percent of the population of the county living in the Potomac River basin.

The total water use in Carroll County is estimated to increase over the period 2000 to 2030 by 4.3 mgd, i.e. from 5.7 mgd to 10.0 mgd, excluding agricultural water use. These water use and forecast data are presented in the summary table for Maryland, Table A - MD.

Frederick County, MD

Population

All of Frederick County is located fully within the Potomac River basin. The source of population estimates for the County for the base year of 1995 was derived from the U.S. Geological Survey information (USGS, 1995). This information provided population data for residents supplied by public water systems as well as those who were self supplied. Population forecasts for the county for the years 2000, 2010, and 2020 were derived from information available from the Maryland Office of Planning, State Data Center (2000).

By projecting forecast trends another ten years for this study, it is estimated that the county population will be approximately 323,000 in the year 2030. Thus, the total population of Frederick County living in the Potomac River basin is estimated to increase over the period 2000 to 2030 by 129,400, i.e. from 193,600 to 323,000.

The proportion of the total population supplied by public systems is expected to grow faster (due to the implementation of Maryland's Smart Growth policy) than those that are self supplied. Trends related to this issue derived from the Frederick County Water and Sewerage Plan (1995) were applied to county total population data from the Maryland Office of Planning, State Data Center (2000). In this way, the population supplied by public systems and that which is self supplied were derived for the period 2000 through 2020. By projecting forecast trends another ten years for this study, data for the population supplied by public systems and that which is self supplied were derived for the year 2030. These population data are presented in the summary table for Maryland, Table A - MD.

Water use

Information concerning the amount of water use estimates for the base year for the county was derived from the U.S. Geological Survey information (USGS, 1995). This information provided water use data for residents supplied by public water systems as well as those who were self supplied, and it formed the basis of forecasts for the county developed for the years 2000 through 2030. The water use forecasts for those years were developed in proportion to the increase in population during the same period, taking into account that the proportion of the total population supplied by public systems is expected to grow faster (due to the implementation of Maryland's Smart Growth policy) than those that are self supplied.

The total water use in Frederick County is estimated to increase over the period 2000 to 2030 by 16.80 mgd, i.e. from 25.81 mgd to 42.61 mgd, excluding agricultural water use. These water use and forecast data are presented in the summary table for Maryland, Table A - MD.

Garrett County, MD

Population

Only a relatively small portion of Garrett county lies within the Potomac River basin. This land area takes the shape of a swath of land running parallel to the eastern border of the county, and is in the sub-drainages of the North Branch Potomac River, Savage River, and Georges Creek. The area is rural, rugged, and substantially occupied by state park and forest land or Jennings Randolph and Savage River reservoirs and their margins. The Garrett County Comprehensive Water and Sewer Master Plan (1997) contained information which indicates that 18.8 percent and 18.7 percent of the county population lived in the Potomac River basin portion of the county in the years 1990 and 2000, respectively. Due to the relatively rural nature of the area and small communities, only 17.7 percent and 19.7 percent of the Potomac basin population was served by public systems in the years 1990 and 2000, respectively. Maryland's Smart Growth policy will likely continue to favor the concentration of increasing population in the small communities, and other parts of the county which are presently more developed. Therefore, it is estimated that the percent of population living in the Potomac basin of the county in the future will be 18.5, 18.3 and 18.1 for the years 2010, 2020, and 2030 respectively. Population data for the years 2000 through 2020 was obtained from the Maryland Office of Planning, State Data Center (2000). By projecting forecast trends another ten years for this study, it is estimated that the county population supplied by public systems and that which is self supplied in the Potomac River basin portion of the county will be approximately 6,140 in the year 2030. Thus, the total population of Garrett County living in the Potomac River basin is estimated to increase over the period 2000 to 2030 by 690, i.e. from 5,450 to 6,140. These population data are presented in the summary table for Maryland, Table A - MD.

Water use

Communities supplied by public systems are almost entirely residential, with practically no commercial or industrial water use. The source of domestic water use estimates for the base year for the portions of the county in the Potomac River basin was derived from the Garrett County Comprehensive Water and Sewer Master Plan (1997). This information provided water use data for residents supplied by public water systems as well as those who were self supplied, and it formed the basis of forecasts for the county developed for the years 2000 through 2030. The water use forecasts for those years were developed in proportion to the increase in population during the same period. Water use data for non-domestic uses was derived from the U.S. Geological Survey information (USGS, 1995), and adjusted by the percent of the population of the county living in the Potomac River basin.

The total water use in Garrett County is estimated to increase over the period 2000 to 2030 by only 0.03 mgd, i.e. from 0.69 mgd to 0.72 mgd, excluding agricultural water use. These water use and forecast data are presented in the summary table for Maryland, Table A - MD.

Montgomery County, MD

Population

The population of Montgomery County served by public surface systems drawing water from the Potomac River consists of the customers of the Washington Suburban Sanitary Commission (WSSC) and City of Rockville. The town of Poolesville is the only significant public ground water system in the Potomac River basin portion of the county, and the remainder of the population is self supplied from wells. The Rockville, Poolesville and self supplied population data for the period 2000 - 2020 (shown in the Montgomery County Worksheet, Appendix B) was derived from Desjardin, et al. 1999 and digital map overlays.

In the year 2000 it is estimated (Hagen and Steiner, 2000, and Desjardin, et al. 1999) that the population of the areas served by the WSSC and Rockville is approximately 831,300. The population of the town of Poolesville (served by a ground water system) is estimated to be 3,700. The remaining population of the county is self supplied, with an estimated year 2000 population of 11,300. Thus, the total population of Montgomery County living in the Potomac River basin or served by WSSC with water drawn from the Potomac or Patuxent rivers is estimated to be approximately 846,300 in the year 2000. The population associated with the Commercial category of water use is the number of employees, and is not included in the total population for the county.

Population estimates for the year 2010 (from the same sources) for WSSC and Rockville, Poolesville, and self supplied are approximately 919,900, 3,800, and 11,100, respectively. Thus, the total population of the county living in the Potomac basin or potentially served by water from it is estimated to be approximately 934,800 in the year 2010.

Estimates for the year 2020 (from the same sources) for WSSC and Rockville, Poolesville, and self supplied are approximately 978,500, 3,800, and 10,500, respectively. Thus, the total population of the county living in the Potomac basin or potentially served by water from it is estimated to be approximately 992,800 in the year 2020.

By projecting forecast trends another ten years to 2030, it is estimated that the WSSC and Rockville, Poolesville, and self supplied populations will be approximately 1,008,000, 3,800, and 10,300, respectively. Thus, the total population of Montgomery County living in the Potomac basin or potentially served by water from it is estimated to be approximately 1,022,100 in the year 2030. These population data are presented in the summary table for Maryland, Table A - MD.

Water use
The major portion of Montgomery County population is served by the Washington Suburban Sanitary Commission (WSSC). The water use and forecast for the WSSC service area in the county for the present study to the year 2020 is based upon the recently completed *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000). That study considered detailed population and employee forecasts produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) and the expected effects of the *Energy Policy Act of 1992* (102D Congress, 1992) on future household consumption. All the commercial and industrial water use was converted to numbers of employees and water use per employee in order to use the Council of Governments' forecasts of employees. The forecast of demand for the WSSC service area in the present study to the year 2030 was developed by extending the trend established in the metropolitan area 20-year forecast. In the 30 year period from 2000 to 2030, the water use demand in the WSSC service area of the county is expected to grow by 20.5 mgd, i.e., from 88.8 mgd to 109.3 mgd.

The City of Rockville draws its water supply from the same source as does WSSC and returns its treated waste water effluent below the tidal limit. Therefore, the forecast for the city to the year 2020 was conducted in the *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000), and extended to the year 2030 in the same manner as that for the WSSC supplied portion of the county. In the 30 year period from 2000 to 2030, the water use demand in the City of Rockville is expected to grow by 0.4 mgd, i.e., from 5.3 mgd to 5.7 mgd. These forecasts of demand are combined with those for the WSSC served area of Montgomery County and presented as metro demands for Montgomery County in the demand summary table for Maryland (Table A - MD).

Prince George's County, MD

Population

Essentially all of the population of Prince George's County living in the Potomac River basin and receiving its water from the non-tidal portion of the river is supplied by the Washington Suburban Sanitary Commission (WSSC). In the year 2000 it is estimated (Hagen and Steiner, 2000, and Desjardin, et al. 1999) that the population of the area served by WSSC is approximately 747,700. The population associated with the Commercial category of water use is the number of employees, and is not included in the total population for the county.

The estimate for the year 2020 (from the same sources) is approximately 882,100. Interpolation of the estimates for the years 2000 and 2020, results in an estimated population for Prince George's County of approximately 814,900 in the year 2010.

By projecting forecast trends another ten years to 2030, it is estimated that the WSSC supplied population of the county will be 907,000 in the year 2030. These population data are presented in the summary table for Maryland, Table A - MD.

Water use

The Washington Suburban Sanitary Commission serves all of Prince George's County that is within the Potomac River basin. The water use and forecast for the WSSC service area in the county for the present study to the year 2020 is based upon the recently completed *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000). That study considered detailed population and employee forecasts produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) and the expected effects of the *Energy Policy Act of 1992* (102D Congress, 1992) on future household consumption. All the commercial and industrial water use was converted to numbers of employees and water use per employee in order to use the Council of Governments' forecasts of employees. The forecast of demand for the WSSC service area in the present study to the year 2030 was developed by extending the trend established in the metropolitan area 20-year forecast. In the 30 year period from 2000 to 2030, the water use demand in the WSSC service area of the county is expected to grow by 17.4 mgd, i.e., from 78.7 mgd to 96.1 mgd, excluding agricultural water use. These water use and forecast data are presented in the summary table for Maryland, Table A - MD.

Washington County, MD

Population

All of Washington County is located fully within the Potomac River basin. The source of population estimates for the County for the base year of 1995 was derived from the U.S. Geological Survey information (USGS, 1995). This information provided population data for residents supplied by public water systems as well as those who were self supplied. Population forecasts for the county for the years 2000, 2010, and 2020 were derived from information available from the Maryland Office of Planning, State Data Center (2000).

By projecting forecast trends another ten years for this study, it is estimated that the county population will be approximately 146,700 in the year 2030. Thus, the total population of Washington County living in the Potomac River basin is estimated to increase over the period 2000 to 2030 by 18,400, i.e. from 128,300 to 146,700.

The proportion of the total population supplied by public systems is expected to grow faster (due to the implementation of Maryland's Smart Growth policy) than those that are self supplied. Trends related to this issue derived from the Washington County Water and Sewerage Plan (1994) were applied to county total population data from the Maryland Office of Planning, State Data Center (2000). In this way, the population supplied by public systems and that which is self supplied were derived for the period 2000 through 2020. By projecting forecast trends another ten years for this study, data for the population supplied by public systems and that which is self supplied were derived for the year 2030. These population data are presented in the summary table for Maryland, Table A - MD.

Water use

The source of water use estimates for the county for the base year of 1995 was derived from the U.S. Geological Survey information (USGS, 1995). This information provided water use data for residents supplied by public water systems as well as those who were self supplied, and it formed the basis of forecasts for the county developed for the years 2000 through 2030. The water use forecasts for those years were developed in proportion to the increase in population during the same period.

The total water use in Washington County is estimated to increase over the period 2000 to 2030 by 5.1 mgd, i.e. from 48.7 mgd to 53.8 mgd, excluding agricultural water use. These water use and forecast data are presented in the summary table for Maryland, Table A - MD.

DISTRICT OF COLUMBIA

Population

All the population of Washington, D.C. is served by the District of Columbia Water and Sewer Authority with treated water purchased from the Washington Aqueduct Division of the U.S. Army Corps of Engineers (WA). The water is withdrawn from the non-tidal Potomac River at Great Falls (by gravity) and at Little Falls (by pumping). In the year 2000 it is estimated (Hagen and Steiner, 2000, and Desjardin, et al. 1999) that the population of the area served by WA is approximately 518,100.

The estimate for the year 2020 (from the same sources) is approximately 618,600. Interpolation of the estimates for the years 2000 and 2020, results in an estimated population for Washington, D.C. of approximately 568,300 in the year 2010.

By projecting forecast trends another ten years to 2030, it is estimated that the WA supplied population of the city will be 669,000 in the year 2030. These population data are presented in the water use and forecast summary table for District of Columbia, Table A - DC.

Water use

The nation's capital is served by the District of Columbia Water and Sewer Authority which is a wholesale customer for treated water of the Washington Aqueduct Division of the U.S. Army Corps of Engineers (WA). The water use and forecast for the city for the present study to the year 2020 is based upon the recently completed *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000). The metropolitan area 20-year forecast study considered detailed population and employee forecasts produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) and the expected effects of the *Energy Policy Act of 1992* (102D Congress, 1992) on future household consumption. All the commercial and industrial water use was converted to numbers of employees and water use per employee in order to use the Council of Governments' forecasts of employees. The forecast of demand for the District of Columbia in the present study to the year 2030 was developed by extending the trend established in the metropolitan area 20-year forecast. In the 30 year period from 2000 to 2030, the water use demand in the District of Columbia is expected to grow by 24.1 mgd, i.e., from 130.4 mgd to 154.5 mgd. These water use and forecast data are presented in the summary table for District of Columbia, Table A - DC.

PENNSYLVANIA

Adams County, PA

Population

Approximately half of the land area of Adams County (including the city of Gettysburg) lies in the Potomac River basin. The land is relatively flat with a predominance of agriculture. It is estimated that somewhat less than half of the population in this area is served by public water supply systems. The total population of the county, in the basin, is expected to grow from approximately 42,790 in the year 2000 to 51,650 in the year 2030.

Water use

Total water use for all categories is expected to increase from 8.35 mgd to 9.43 mgd during the forecast period, excluding agricultural water use. Relatively large industrial and agricultural uses exist in the self-supplied sector.

Bedford County, PA

Population

Approximately one third of the land area of Bedford County (with no large communities) lies in the Potomac River basin. The land is predominantly valley and ridge, with large areas of forest cover on the hillsides, and modest farms in the valleys. It is estimated that approximately one third of the population in this area is served by public water supply systems. The total population of the county, in the basin, is expected to grow from approximately 7,020 in the year 2000 to 7,900 in the year 2030.

Water use

Total water use for all categories is expected to increase only from 0.55 mgd to 0.59 mgd during the forecast period, excluding agricultural use. (Bedford County is the source of water supply for the City of Cumberland which is located in Allegany County, MD.)

Franklin County, PA

Population

Approximately three fourths of the land area of Franklin County (including the communities of Chambersburg, Waynesboro, Greencastle, and Mercersburg) lies in the Potomac River basin. The land is dominated by the broad valleys of the Conococheague and Antietam creeks and their tributaries. Agriculture and associated enterprises occupy most of the land of this county in the Potomac River basin. It is estimated that approximately 60 percent of the population in this area is served by public water supply systems. The total population of the county, in the basin, is expected to grow from approximately 115,800 in the year 2000 to 120,830 in the year 2030.

Water use

Commercial, industrial, and agricultural water use in Franklin County are relatively high in comparison with other Potomac River basin counties of the state. Total water use is expected to increase from 13.85 mgd to 14.01 mgd during the forecast period, excluding agricultural use.

Fulton County, PA

Population

Approximately three fourths of the land area of Fulton County (including numerous small communities) lies in the Potomac River basin. The land is dominated by valley and ridge topography. Forests and agriculture most of the land of this county in the Potomac River basin. It is estimated that approximately one fourth of the population in this area is served by public water supply systems. The total affected population of the county, in the basin, is expected to grow from approximately 11,920 in the year 2000 to 13,400 in the year 2030.

Water use

Total water use for all categories is expected to increase from 1.17 mgd to 1.23 mgd during the forecast period, excluding agricultural use.

Somerset County, PA

Population

Approximately one eighth of the land area of Somerset County (with no large communities) lies in the Potomac River basin. The land is dominated by mountainous terrain with large areas of forest cover on the hillsides, and modest farms in the valleys. It is estimated that approximately one half of the population in this area is served by public water supply systems. The total population of the county, in the basin, is expected to decrease from approximately 2,290 in the year 2000 to 2,040 in the year 2030.

Water use

Total water use is expected to decrease from 0.31 mgd to 0.27 mgd during the forecast period, excluding agricultural use.

VIRGINIA

Arlington County, VA

Population

Arlington County is adjacent to the District of Columbia, and is heavily urbanized. All the population of the county is served by wholesale purchase from the Washington Aqueduct Division of the U.S. Army Corps of Engineers (WA) with water drawn from the non-tidal Potomac River. In the year 2000 it is estimated (Hagen and Steiner, 2000, and Desjardin, et al. 1999) that the population of the area served by WA is approximately 189,300.

The estimate for the year 2020 (from the same sources) is approximately 210,200. Interpolation of the estimates for the years 2000 and 2020, results in an estimated population for Arlington County of approximately 199,800 in the year 2010.

By projecting forecast trends another ten years to 2030, it is estimated that the WA supplied population of the county will be 220,000 in the year 2030. These population data are presented in the summary table for Virginia, Table A - VA.

Water use

All of the population of Arlington County is served by the Arlington Department of Public Works which is a wholesale customer for treated water of the Washington Aqueduct Division of the U.S. Army Corps of Engineers (WA). The water use and forecast for the county for the present study to the year 2020 is based upon the recently completed *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000). Demand forecasts for the special areas of: the Pentagon, Arlington Cemetery, Fort Myer, and Ronald Reagan National Airport were calculated separately in the metropolitan area 20-year forecast, but are combined in the present study. The metropolitan area 20-year forecast study considered detailed population and employee forecasts produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) and the expected effects of the *Energy Policy Act of 1992* (102D Congress, 1992) on future household consumption. All the commercial and industrial water use was converted to numbers of employees and water use per employee in order to use the Council of Governments' forecasts of employees. The forecast of demand for Arlington County in the present study to the year 2030 was developed by extending the trend established in the metropolitan area 20-year forecast. In the 30 year period from 2000 to 2030, the water use demand in Arlington County is expected to grow by 7.9 mgd, i.e., from 27.9 mgd to 37.7 mgd, excluding agricultural use. These water use and forecast data are presented in the summary table for Virginia, Table A - VA.

Augusta County, VA

Population

Most of Augusta County lies within the non-tidal Potomac River basin at the headwaters of the Shenandoah River. Based on GIS overlays of 1990 Census tract information (ESRI, 2000) and the watershed boundary, it was determined that 96.3 percent of the county's population lived within the non-tidal Potomac River basin. Generally, for the Commonwealth of Virginia, population data and information are given for counties exclusive of independent cities. Therefore, population and water use data for the county and for the independent cities of Staunton and Waynesboro were combined for the present study. The population forecasts for the year 2000 and 2010 for the county and independent cities were obtained from the Weldon Cooper Center for Public Service at the University of Virginia. Population forecasts for whole states from 1995 through 2025 were obtained from *Population Projections: States: 1995 - 2025* (U.S. Bureau of the Census, 1997). The 2030 population for the state was estimated by extrapolating the U.S. Bureau of the Census data. Population figures for the county for the years 2020 and 2030 were developed for the present study by extending the trend of the county population for the years 2000 and 2010 as a percent of the state total population.

Water use
The populations of the county and of the independent cities of Staunton and Waynesboro supplied with water by community systems, and the number of other residents of the county who are self-supplied were obtained for the year 1995 from the USGS (USGS, 1995). The projections of domestic population supplied by community systems in the future years are based on the growth trend in population of the independent cities obtained from the Weldon Cooper Center. System and self-supplied commercial and industrial water uses are forecast to increase in proportion to system and self-supplied domestic population growth, respectively.

Clarke County, VA

Population
All of Clarke County lies within the non-tidal Potomac River basin near the down stream reaches of the Shenandoah River. Its relatively small population of approximately 13,500 in the year 2000 is forecast to grow to more than 16,500 by the year 2030.

Water use
The rural nature of the county is indicated by the fact that self-supplied water supplies will significantly exceed community system supplied water throughout the forecast period (2000 - 2030). Total water use demand is expected to stay below 2 mgd, excluding agricultural use.

Fairfax County, VA

Population
Fairfax County is located in northern Virginia as part of the Washington metropolitan area. The residents of the county receive their water supply from one of several sources, depending on where they live. In the year 2000 it is estimated (Hagen and Steiner, 2000, and Desjardin, et al. 1999) that the population of the areas served by the Fairfax County Water Authority (FCWA), either directly or wholesale through intermediate suppliers (Dulles, Fort Belvoir, Town of Herndon, Lorton, Virginia American Water Company - Alexandria) is approximately 916,300.

The population of the county served wholesale through intermediate suppliers by the Washington Aqueduct Division (WA) of the U.S. Army Corps of Engineers (Falls Church and Vienna) is approximately 147,000 (Hagen and Steiner, 2000 and Desjardin, et al. 1999). The information for the areas of the county supplied by FCWA and WA is labeled "metro" in the summary table for Virginia, Tables A - VA. The remaining population of the county is served by the City of Fairfax, or is self supplied, with estimated year 2000 populations of 40,000 and 10,900, respectively. The City of Fairfax and self supplied population data for the period 2000 - 2020 (shown in the Fairfax County Worksheet, Appendix B) was derived from Desjardin, et al. 1999 and digital map overlays. The total population for Fairfax County and independent cities therein is estimated to be approximately 1,114,200 in the year 2000.

Estimates of population for the year 2020 (from the same sources) are approximately 1,112,300 and 171,200 for FCWA and WA supplied areas, respectively; and 46,600 and 12,700 for the City of Fairfax and self supplied, respectively. Thus, the total population for Fairfax County and independent cities therein is estimated to be approximately 1,342,800 in the year 2020.

Interpolation of the estimates for the years 2000 and 2020, results in an estimated population for Fairfax County of approximately 1,228,500 in the year 2010.

By projecting forecast trends another ten years to 2030, it is estimated that the FCWA and WA supplied populations will be 1,141,000 and 173,000, respectively; and 47,000 and 13,000 for the City of Fairfax and self supplied, respectively. Thus, the total population for Fairfax County and independent cities therein is estimated to be approximately 1,374,000 in the year 2030. These population data are presented in the summary table for Virginia, Table A - VA.

Water use

The major portion of Fairfax County population is served by public supply systems. Most is served directly by the Fairfax County Water Authority (FCWA), and by wholesale supplies from FCWA to the Town of Herndon, Lorton, Fort Belvoir and Dulles Airport. Areas within the county served by other suppliers include: Alexandria, Falls Church, and the City of Fairfax. All of the population of the City of Alexandria is served by the Virginia American Water Company - Alexandria which is a wholesale customer for treated water of the Fairfax County Water Authority (FCWA). All the population of Falls Church and Vienna is served by wholesale purchase from the Washington Aqueduct Division of the U.S. Army Corps of Engineers (WA) with water drawn from the non-tidal Potomac River. The water use and forecast for the FCWA and WA service areas in the county for the present study to the year 2020 is based upon the recently completed *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000). That study considered detailed population and employee forecasts produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) and the expected effects of the *Energy Policy Act of 1992* (102D Congress, 1992) on future household consumption. All the commercial and industrial water use was converted to numbers of employees and water use per employee in order to use the Council of Governments' forecasts of employees. The portions of

Fairfax County which are not served directly or wholesale by FCWA and WA (i.e., not included in the metropolitan area 20-year forecast study) are the City of Fairfax which has its own surface supply, and several areas where the population is self supplied by wells. The forecast of demand for the various service areas in the county for the present study to the year 2030 was developed by extending the trend established in those areas through the year 2020. In the 30 year period from 2000 to 2030, the water use demand in Fairfax County is expected to grow by 29.4 mgd, i.e., from 136.1 mgd to 165.5 mgd. These water use and forecast data are presented in the summary table for Virginia, Table A - VA.

Fauquier County, VA

Population

Only a very small portion of Fauquier County is located in the non-tidal portion of the Potomac River basin, west of the Washington metropolitan area. However, its resident population and their water use are included for the purposes of this study. That area-apportioned population is estimated to grow from just under 5,000 to just over 6,000 during the forecast period.

Water use

Total water use is estimated to grow from 0.47 mgd to 0.59 mgd, excluding agricultural use.

Frederick County, VA

Population

All of Frederick County lies within the non-tidal Potomac River basin near the down stream end of the Shenandoah River. More than a third of the population of Frederick County resides in the independent city of Winchester. The population forecasts for the year 2000 and 2010 for the county and the City of Winchester were obtained from the Weldon Cooper Center for Public Service at the University of Virginia. Population forecasts for whole states from 1995 through 2025 were obtained from *Population Projections: States: 1995 - 2025* (U.S. Bureau of the Census, 1997). The 2030 population for the state was estimated by extrapolating the U.S. Bureau of the Census data. Population figures for the county for the years 2020 and 2030 were developed for the present study by extending the trend of the county population for the years 2000 and 2010 as a percent of the state total population, resulting in a significant increase from 80,300 to 104,720 over the forecast period.

Water use

Total water use is estimated to grow from 11.0 mgd to 14.3 mgd, excluding agricultural use.

Highland County, VA

Population

Only a very small portion of Highland County is located in the non-tidal portion of the Potomac River basin at the headwaters of the South Branch Potomac River. The land is high in elevation, forested, and sparsely populated. However, its resident population and their water use are included for the purposes of this study. That area-apportioned population is estimated to grow only from approximately 500 to 580.

Water use
Total water use is estimated to grow only from 1.09 mgd to 1.17 mgd where industrial use accounts for a significant portion.

Loudoun County, VA

Population
All of Loudoun County lies within the non-tidal Potomac River basin and is a transition from urban to rural land uses as distances increase away from the Washington metropolitan area. Southeastern portions of the county are served by the Loudoun County Sanitation Authority (LCSA) with wholesale purchases from the Fairfax County Water Authority (FCWA) with water drawn from the Occoquan Reservoir or the non-tidal Potomac River, and purchases limited to 7 mgd from the City of Fairfax which draws its water from Goose Creek (a tributary to the non-tidal Potomac River). Estimates of population forecasts to the year 2020 for those areas are from Hagen and Steiner, 2000; and Desjardin, et al. 1999 and labeled as metropolitan, "metro" in the water use and forecast summary tables for Virginia (Table A - VA). The remainder of the county receives water from the Leesburg community system or from self- supplied ground water sources in the non tidal Potomac River basin. The Leesburg and self supplied population data for the period 2000 - 2020 (shown in the Loudoun County Worksheet, Appendix B) was derived from Desjardin, et al. 1999 and digital map overlays.

In the year 2000 it is estimated (Hagen and Steiner, 2000; and Desjardin, et al. 1999) that the population of the areas served by the LCSA is approximately 94,000. The population of the town of Leesburg (served by a ground water and/or non-tidal Potomac River system) is estimated to be 29,300. The remaining population of the county is self supplied, with an estimated year 2000 population of 38,800. Thus, the total population of Loudoun County is estimated to be approximately 162,200 in the year 2000.

Population estimates for the year 2010 for the LCSA, Leesburg, and self supplied sources are approximately 170,600, 45,200, and 55,900, respectively. Thus, the total population of the county is estimated to be approximately 271,700 in the year 2010.

Estimates for the year 2020 for the LCSA, Leesburg, and self supplied sources are approximately 247,200, 60,500, and 61,900, respectively. Thus, the total population of the county is estimated to be approximately 369,600 in the year 2020.

By projecting forecast trends another ten years to 2030, it is estimated that the LCSA, Leesburg, and self supplied sources are approximately 315,000, 70,000, and 67,000, respectively. Thus, the total population of the county is estimated to be approximately 452,000 in the year 2030. These population data are presented in the summary table for Virginia, Table A - VA.

Water use

The southeastern portion of Loudoun County is served by the Loudoun County Sanitation Authority (LCSA) which is a wholesale customer of the Fairfax County Water Authority (FCWA) and the City of Fairfax. The water use and forecast for the LCSA service area in the county for the present study to the year 2020 is based upon the recently completed *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000). The metropolitan area 20-year forecast study considered detailed population and employee forecasts produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) and the expected effects of the *Energy Policy Act of 1992* (102D Congress, 1992) on future household consumption. All the commercial and industrial water use was converted to numbers of employees and water use per employee in order to use the Council of Governments' forecasts of employees. The forecast of demand for the portion of Loudoun County supplied by LCSA in the present study to the year 2030 was developed by extending the trend established in the metropolitan area 20-year forecast. In the 30 year period from 2000 to 2030, the water use demand in the portion of Loudoun County supplied by LCSA is expected to grow by 23.4 mgd, i.e., from 9.8 mgd to 33.2 mgd. The water use demand in the portion of Loudoun County that depends on the Leesburg system and that is self supplied is expected to increase from 6.96 to 14.46 mgd. These water use and forecast data are presented in the summary table for Virginia, Table A - VA.

Page County, VA

Population

All of Page County lies within the non-tidal Potomac River basin located in the middle reaches of the Shenandoah River valley. Although there are no officially independent cities in the county, the population served by community systems is approximately 1.5 times the number of people who are self supplied. Its total population of approximately 23,690 in the year 2000 is forecast to grow to 26,680 by the year 2030.

Water use

Total water use for all categories is expected to increase from 2.12 mgd from system-supplied sources and 1.95 mgd from self-supplied sources to 2.69 mgd and 2.16 mgd, respectively, not including agricultural use.

Prince William County, VA

Population

Although Prince William County lies in the Potomac River basin, it is entirely down stream of the non-tidal Potomac. However, much of its population is supplied through wholesale purchases by the Prince William County Service Authority and the Virginia American Water Company - Dale City by water from the Fairfax County Water Authority (FCWA) and by the cities of Manassas and Manassas Park, which share the Occoquan watershed – a water resource which is used conjunctively with the non-tidal Potomac River. Therefore, the combined population of areas served through wholesale suppliers by FCWA will be included in the present study as they were in the metropolitan area study (Hagen and Steiner, 2000) and indicated as "metro" in the summary table for Virginia, Table A - VA. The populations of Manassas and Manassas Park will also be included in the present study in the category of public supply systems. Data for these cities for the period 2000 - 2020 (shown in the Prince William County Worksheet, Appendix B) was derived from Desjardin, et al. 1999 and digital map overlays.

In the year 2000 it is estimated that the population of the areas served by the FCWA is 227,300 and that served by Manassas and Manassas Park is approximately 43,200. Thus, the total population of Prince William County served by sources used in conjunction with the non-tidal Potomac River is estimated to be approximately 270,500 in the year 2000.

Population estimates for the year 2010 (from the same sources) served by FCWA and Manassas and Manassas Park are approximately 282,600 and 45,400, respectively. Thus, the total population of the county served for the purposes of this study is estimated to be approximately 328,000 in the year 2010.

Estimates for the year 2020 (from the same sources) for the FCWA and Manassas and Manassas Park served populations are approximately 337,900 and 46,000, respectively. Thus, the total population of the county served for the purposes of this study is estimated to be approximately 383,900 in the year 2020.

By projecting forecast trends another ten years to 2030, it is estimated that the FCWA and Manassas and Manassas Park served populations will be approximately 388,000 and 46,000, respectively. There is no self-supplied population in Prince William County drawing water from the non-tidal portion of the Potomac River basin. Thus, the total population of Prince William County forecast to be served for the purposes of this study is estimated to be approximately 434,000 in the year 2030. These population data are presented in the summary table for Virginia, Table A - VA.

Water use

Large portions of the population of Prince William County are served by the Prince William County Service Authority which is a wholesale customer of the Fairfax County Water Authority (FCWA). The population of Dale City, within the county, is served by the Virginia American Water Company - Dale City which is also a wholesale customer for treated water of FCWA and is included in the forecasts designated as metropolitan, "metro" in the summary table for Virginia, Table A - VA. Although the vast majority of water supplied is derived from surface sources, a small amount (2 mgd) is from wells. Although these wells are not located in the non-tidal portion of the Potomac River basin, they may affect the surface water resource of the Occoquan Watershed, and thus they are included in the analyses for the present study. The cities of Manassas and Manassas Park draw their water from Lake Manassas which is situated in the watershed which is tributary to the Occoquan Reservoir. The water use and forecast for the FCWA wholesale service area in the county for the present study to the year 2020 is based upon the recently completed *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000). The metropolitan area 20-year forecast study considered detailed population and employee forecasts produced by the Metropolitan Washington Council of Governments (Desjardin, et al. 1999) and the expected effects of the *Energy Policy Act of 1992* (102D Congress, 1992) on future household consumption. All the commercial and industrial water use was converted to numbers of employees and water use per employee in order to use the Council of Governments' forecasts of employees. The forecast of demand for Prince William County in the present study to the year 2030 was developed by extending the trend established in the metropolitan area 20-year forecast. In the 30 year period from 2000 to 2030, the water use demand in Prince William County is expected to grow by 18.1 mgd, i.e., from 28.8 mgd to 46.9 mgd (including the demands of the cities of Manassas and Manassas Park). These water use and forecast data are presented in the summary table for Virginia, Table A - VA.

Rockingham County, VA

Population

All of Rockingham County lies within the non-tidal Potomac River basin, spanning the middle Shenandoah River valley from east to west. More than a third of the population of Frederick County resides in the independent city of Harrisonburg. The population forecasts for the year 2000 and 2010 for the county and the City of Harrisonburg were obtained from the Weldon Cooper Center for Public Service at the University of Virginia. Population forecasts for whole states from 1995 through 2025 were obtained from *Population Projections: States: 1995 - 2025* (U.S. Bureau of the Census, 1997). The 2030 population for the state was estimated by extrapolating the U.S. Bureau of the Census data. Population figures for the county for the years 2020 and 2030 were developed for the present study by extending the trend of the county population for the years 2000 and 2010 as a percent of the state total population, resulting in a significant increase from 102,190 to 129,690 over the forecast period.

Water use

Due to the relative large present population of the county being served by community systems in the City of Harrisonburg and other towns, that sector of demand is expected to increase significantly (13.10 mgd to 17.63 mgd) compared with self-supplied amounts (12.95 mgd to 15.13 mgd), excluding agricultural use. However, large commercial and industrial uses exist in both system-supplied and self-supplied categories.

Shenandoah County, VA

Population

All of Shenandoah County lies within the non-tidal Potomac River basin located in the middle reaches of the Shenandoah River valley. The population served by community systems is slightly more than the number of people who are self supplied. Its total population of approximately 37,600 in the year 2000 is forecast to grow to 47,920 by the year 2030.

Water use

Total water use for all categories is expected to increase from 2.94 mgd from system-supplied sources and 3.45 mgd from self-supplied sources to 4.01 mgd and 3.98 mgd, respectively, and excluding agricultural use. Relatively large commercial and industrial uses exist in both system-supplied and self-supplied categories.

Warren County, VA

Population

All of Warren County lies within the non-tidal Potomac River basin located in the middle reaches of the Shenandoah River valley. The population served by community systems is slightly more than the number of people who are self supplied. Its total population of approximately 32,000 in the year 2000 is forecast to grow to 42,740 by the year 2030.

Water use

Total water use for all categories is expected to increase from 2.18 mgd from system-supplied sources and 1.48 mgd from self-supplied sources to 3.13 mgd and 1.78 mgd, respectively, and excluding agricultural use. Relatively small commercial and industrial uses exist in both system-supplied and self-supplied categories.

WEST VIRGINIA

Berkeley County, WV

Population

All of Berkeley County lies within the non-tidal Potomac River basin located in the middle of the eastern panhandle of the state. The population of the county which is served by community systems is approximately twice the number of people who are self-supplied. Its total population of approximately 72,000 in the year 2000 is forecast to grow to 99,730 by the year 2030.

Water use

Total water use for all categories is expected to increase from 13.52 mgd to 18.14 mgd during the forecast period, excluding agricultural use. Significant industrial uses exist in both system-supplied and (particularly) self-supplied sectors.

Grant County, WV

Population

All of Grant County lies within the non-tidal Potomac River basin located at the headwaters of the orth Branch Potomac River. The population of the county which is served by community systems is more than twice the number of people who are self-supplied. Its total population of approximately 11,750 in the year 2000 is forecast to grow to 15,180 by the year 2030.

Water use

Total water use for all categories is expected to increase from 6.71 mgd to 8.52 mgd during the forecast period, excluding agricultural use. Relatively large commercial and industrial uses exist in the self-supplied sector.

Hampshire County, WV

Population

All of Hampshire County lies within the non-tidal Potomac River basin located at the confluence of the South Branch and the North Branch rivers. The population served by community systems is less than half the number of people who are self-supplied. The total population of the county is expected to increase from approximately 19,600 in the year 2000 to 26,100 by the year 2030.

Water use

Total water use for all categories is expected to increase from 12.49 mgd to 14.47 mgd during the forecast period, excluding agricultural use. Relatively large industrial uses exist in the self-supplied sector.

Hardy County, WV

Population

All of Hardy County lies within the non-tidal Potomac River basin located in the middle of the South Branch Potomac River valley. The population served by community systems approximately half the number of people who are self supplied. The county’s total population of approximately 12,100 in the year 2000 is forecast to grow to 14,910 by the year 2030.

Water use

Total water use for all categories is expected to increase from 7.99 mgd to 9.33 mgd during the forecast period, excluding agricultural use. Relatively large industrial uses exist in the self-supplied sector.

Jefferson County, WV

Population

All of Jefferson County lies within the non-tidal Potomac River basin located at the eastern tip of the eastern panhandle and at the confluence of the Shenandoah and Potomac rivers. The population served by community systems is expected to grow from being approximately the same as those who are self-supplied in the year 2000 to 1.5 times the self-supplied by the year 2030. The county's total population of approximately 42,120 in the year 2000 is forecast to grow to 55,290 by the year 2030.

Water use

Total water use for all categories is expected to increase from 8.60 mgd to 10.45 mgd during the forecast period, excluding agricultural use. Relatively large commercial and industrial uses exist in the self-supplied sector.

Mineral County, WV

Population

All of Mineral County lies within the non-tidal Potomac River basin located adjacent to the North Branch Potomac River. The population served by community systems is approximately twice the number of people who are self supplied. The county's total population of approximately 27,810 in the year 2000 is forecast to grow to 31,860 by the year 2030.

Water use

Total water use for all categories is expected to increase from 3.17 mgd to 3.50 mgd during the forecast period, excluding agricultural use. Relatively small commercial and industrial uses exist in both system-supplied and self-supplied sectors.

Morgan County, WV

Population

All of Morgan County lies within the non-tidal Potomac River basin located adjacent to the Potomac River, just down stream of the confluence of the North Branch and South Branch rivers. The population served by community systems is only approximately one third to one half the number of people who are self supplied. The county's total population of approximately 13,970 in the year 2000 is forecast to grow to 17,910 by the year 2030.

Water use

Total water use for all categories is expected to increase from 2.56 mgd to 2.97 mgd during the forecast period, excluding agricultural use. Relatively small commercial and industrial uses exist in both system-supplied and self-supplied sectors.

Pendleton County, WV

Population

All of Berkeley County lies within the non-tidal Potomac River basin located at the headwaters of the South Branch Potomac River. The population served by community systems approximately one half the number of people who are self supplied. The county's total population of approximately 8,200 in the year 2000 is forecast to grow to 9,380 by the year 2030.

Water use

Total water use for all categories is expected to increase from 2.54 mgd to 2.71 mgd during the forecast period, excluding agricultural use. Relatively small commercial and industrial uses exist in both system-supplied and self-supplied categories.

Appendix E. Effects of the *Energy Policy Act of 1992* on projected WMA water use.

Typical water use inside the home

The American Water Works Association (AWWA), in a cooperative project with EPA and the Bureau of Reclamation, maintains the *WaterWiser* website, which is a source of a vast array of water efficiency references, books, surveys, and other information. The *WaterWiser* website reports typical water use inside the home. The typical resident of a single family home with no conservation measures installed consumes 72.5 gallons of water per day (Figure E-1). This figure represents indoor use only and does not include outdoor use. AWWA reports that the highest uses of water in the home are for toilet flushing at 20.1 gallons per capita per day (gpcpd), clothes washers at 15.1 gpcpd, and showers at 12.6 gpcpd. These three water uses comprise a total of 66% of the water used in the home.

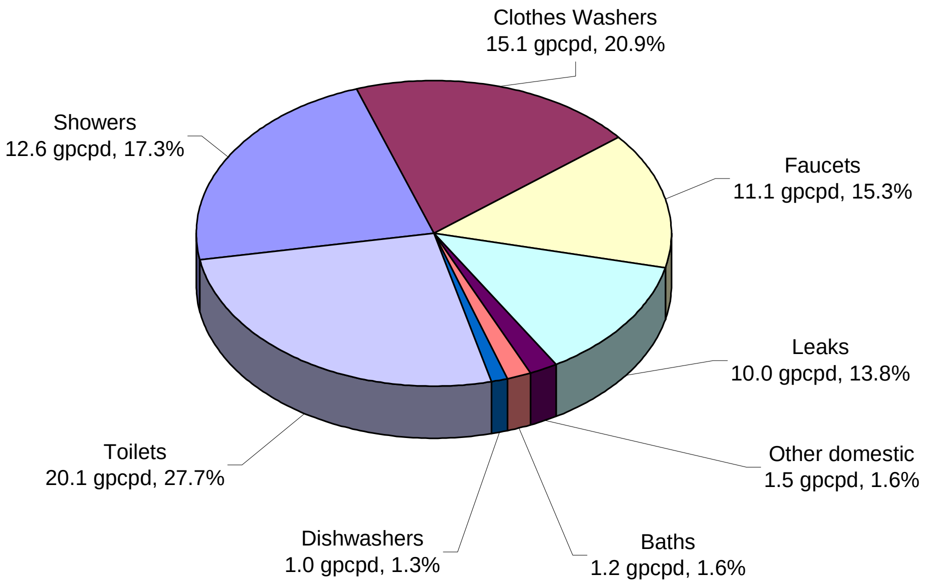

Figure E-1: Typical per capita water use inside the single family home, without conservation measures (source: American Water Works Association "WaterWiser")

Assessing the effects of the Energy Policy Act of 1992 – low flush toilets

The Energy Policy Act requires that all showerheads and toilets manufactured in the US after January 1, 1994 conform to specified flow efficiency standards. Assessing the impact of these standards on future per household water use is vital for assessing 2020 demands. The American Water Works Association Research Foundation's (AWWARF) *Residential End Uses of Water* study is a comprehensive source of information to determine the effects of the Energy Policy Act. This study provides specific data on the end uses of water in the home from a representative sample of residential homes and is the most comprehensive ever undertaken for assessing indoor water uses (Mayer et al., 1997). Flow measurements from 1,188 homes in North America were taken from 12 study sites and 14 utilities around the country during the period May, 1996 through March, 1998. The homes were chosen using random sampling of billing databases. Two weeks of data was collected during each of the summer and winter periods. Water meter readings were recorded in 10-second intervals using electronic data loggers. The recorded timing and flow rates of all water-using events were analyzed in detail, so as to permit identification and classification of water using events (Mayer et al. 1999). Over 1.9 million end use events were identified and segregated.

The water savings from installation of ultra low flush (ULF) toilets due to remodeling and from new construction for the period 2000 through 2020 was estimated for the WMA based on the results of the AWWARF study. It was assumed that the toilet replacement rate and flushing rates in multi-family homes in the WMA followed the same model as that for the single family homes.

AWWARF study results were used to determine the per household toilet water use in houses with and without low flush toilets. The mean toilet flush volume for the entire AWWARF study group was 3.48 gpf. Approximately 13.9% of flushes were with volumes per flush of less than two gallons, averaging 1.63 gallons per flush (Dziegielewski et al., 1999). The average volume per flush on the remaining 86.1 percent of flushes was calculated to be 3.78 gallons per flush. Newer, post-1994 housing stock and housing stock with remodeled bathrooms in the WMA were assumed to have a water use of 1.63 gallon per flush. Older, pre-1994 housing stock in the WMA was assumed to have a water use of 3.78 gallon per flush.

The average number of flush counts per household per day was 12.4 in the AWWARF study. The WMA household average size is smaller than the average household size of the 12 study sites in the AWWARF study, which means the WMA average number of flush counts per household will be different than that of the AWWARF study and should be adjusted. The average number of residents per household for the AWWARF study group was 2.71. In 1998, the WMA CO-OP utilities served a population of 3,628,513 people living in 1,393,791 single family and multi-family households, for a total of 2.60 people per household. (Approximately 62% of the total homes in the WMA CO-OP service area are single family dwellings with the remainder multi-family dwellings.) The average number of toilet flushes per household in the WMA was therefore assumed to be the ratio of 2.6 over 2.71 times 12.4, or 11.9 flushes per household per day.

The net toilet use is calculated as average number of flush counts times the mean toilet flush volume. The water demand for toilet flushing in pre-1994 housing stock in the WMA was assumed to be 11.9 flushes times 3.78 gpf, for a total water use of 45.0 gallons per household. The water demand for toilet flushing in houses with remodeled bathrooms and in housing stock built after 1994 was assumed to be 11.9 flushes times 1.63 gpf, for a total water use of 19.4 gallons per household.

The hypothesis that low flush toilets are susceptible to double flushing (and lower water savings) was debunked in the AWWARF study. The average number of flushes per capita per day for the ULF homes and non-ULF homes in the study were not statistically different, indicating that residents of homes which exclusively use ULF toilets are not flushing more frequently than residents of homes without any ULF toilets. (Mayer et al., 1999)

An estimate was made of the number of WMA households in the CO-OP service area that have low flush toilets already in place by the year 2000. Two key assumptions were made: 1) that all houses built after 1994 incorporate ULF toilets, and 2) that 2% of the original 1994 housing stock in the WMA CO-OP service area is remodeled each year with ULF toilets.[1] Table E-1 shows the calculation of the percentage of housing with low flow toilets in the CO-OP service area. The percentage of housing stock in the WMA with low flush toilets was estimated to be 17% at the end of 1999 and 67% at the end of 2020.

Table E-1: Percentage of housing with low-flow toilets in the CO-OP service area

Year	Portion of original 1994 housing stock with remodeled toilets (begin of year)	Portion of original 1994 housing stock remodeled with low flush toilets per year	Total number of 1994 original housing stock with low flush toilets (end of year)	New households with low flush toilets installed per year[a]	Total number of households with low flush toilets (end of year)	Total housing stock in CO-OP service area.	Percentage of total housing stock with low flush toilets (end of year)
1990	0	0	0	0	0	1,260,800	
1991	0	0	0	0	0	1,274,099	
1992	0	0	0	0	0	1,287,398	
1993	0	0	0	0	0	1,300,697	0%
1994	0	26,280	26,280	13,299	39,579	1,313,996	3%
1995	26,280	26,280	52,560	13,299	79,158	1,327,296	6%
1996	52,560	26,280	78,840	13,299	118,737	1,340,595	9%
1997	78,840	26,280	105,120	13,299	158,316	1,353,894	12%
1998	105,120	26,280	131,400	13,299	197,895	1,367,193	14%
1999	131,400	26,280	157,680	13,299	237,474	1,380,492	17%
2000	157,680	26,280	183,960	18,662	282,416	1,393,791	20%
2001	183,960	26,280	210,239	18,662	327,359	1,412,453	23%
2002	210,239	26,280	236,519	18,662	372,301	1,431,116	26%
2003	236,519	26,280	262,799	18,662	417,243	1,449,778	29%
2004	262,799	26,280	289,079	18,662	462,185	1,468,440	31%
2005	289,079	26,280	315,359	18,662	507,127	1,487,102	34%

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[1] The assumption was made that the toilet replacement rate in existing housing stock would be 2 percent per year. This replacement rate really amounts to little more than a reasonable guess, as precise data documenting replacement rates of toilets in existing housing stock is hard to get for a particular area. Presumably, the replacement rate would be a function of the age of existing housing stock. However, a professional in the conservation field suggests that this value is probably quite reasonable (Bill Davis, Planning and Management Consultants, personal communication, February 9, 2000).

Year	Portion of original 1994 housing stock with remodeled toilets (begin of year)	Portion of original 1994 housing stock remodeled with low flush toilets per year	Total number of 1994 original housing stock with low flush toilets (end of year)	New households with low flush toilets installed per year[a]	Total number of households with low flush toilets (end of year)	Total housing stock in CO-OP service area.	Percentage of total housing stock with low flush toilets (end of year)
2006	315,359	26,280	341,639	18,662	552,069	1,505,764	37%
2007	341,639	26,280	367,919	18,662	597,011	1,524,427	39%
2008	367,919	26,280	394,199	18,662	641,953	1,543,089	42%
2009	394,199	26,280	420,479	18,662	686,895	1,561,751	44%
2010	420,479	26,280	446,759	18,662	731,838	1,580,413	46%
2011	446,759	26,280	473,039	18,662	776,780	1,599,075	49%
2012	473,039	26,280	499,319	18,662	821,722	1,617,737	51%
2013	499,319	26,280	525,599	18,662	866,664	1,636,400	53%
2014	525,599	26,280	551,879	18,662	911,606	1,655,062	55%
2015	551,879	26,280	578,158	18,662	956,548	1,673,724	57%
2016	578,158	26,280	604,438	18,662	1,001,490	1,692,386	59%
2017	604,438	26,280	630,718	18,662	1,046,432	1,711,048	61%
2018	630,718	26,280	656,998	18,662	1,091,375	1,729,711	63%
2019	656,998	26,280	683,278	18,662	1,136,317	1,748,373	65%
2020	683,278	26,280	709,558	18,662	1,181,259	1,767,035	67%

Note: [a] The number of new houses estimated for the WMA CO-OP service area using figures from the 1995 water demand study (Mullusky et al., 1996) and from data compiled for the current study.

Using the information provided in Table E-1, the average water demand per household for toilet flushing of all housing stock in the WMA can be calculated assuming a rate of 45.0 gallons per household without low flush toilets and 19.4 gallons per household for those households with low-flush toilets. The overall average WMA water demand per household for toilet flushing in the year 2000 is thus calculated to be 40.1 gallons per household. The overall average per household water demand for toilet flushing of all housing stock in the WMA in the year 2020 is calculated to be 27.9 gallons per household. Table E-2 summarizes the expected overall per household average water demand in the WMA for toilet flushing for the period 2000 to 2020.

Table E-2: Per household WMA water use for flushing, 2000-2020

Year	Number of households with low flush toilets in use, mid-year	Total households	Percentage of total households with low flush toilets in use, mid-year	Per household WMA water use for flushing, gallons
2000	259,945	1,393,791	18.7%	40.1
2005	484,656	1,487,102	32.6%	36.5
2010	709,367	1,580,413	44.9%	33.3
2015	934,077	1,673,724	55.8%	30.4
2020	1,158,788	1,767,035	65.6%	27.9

Assessing the effects of the Energy Policy Act of 1992 – low flow showerheads

The potential water savings from converting showerheads in existing housing stock to low-flow showerheads can also be calculated from the data collected in the AWWARF study. Average daily use for showering was measured at 30.8 gallons per household (Dziegielewski et al., 1999). The average daily frequency of showering was 1.80 showers per household per day, or 0.7 showers per person per day. Average duration of showers was 7.95 minutes, with an average flow of 2.19 gallons per minute. Nearly three-fourths of the study's showering events were already at rates less than the standard of 2.5 gpm established by the Federal Energy Policy act. The authors conclude that the saturation of low-flow showerheads is relatively high and that often showers are throttled below their maximum rated flows (Dziegielewski et al., 1999).

Nonetheless, the potential savings for the WMA can be calculated on a per household basis. The WMA is assumed to have approximately the same distribution of showerhead flow rates as the cities in the AWWARF study. Table E-3 shows the potential savings by replacing all non-compliant showerheads with 2.5 gpm showerheads by the year 2020. (A 100% rate of retrofit and remodeling is assumed for non-compliant, older showerheads.) The resulting calculation shows that the current average daily use for showering is about 31.1 gallons per household per day, as compared to a predicted 2020 use of 27.6 gallons per household per day.

Table E-3: Calculation of current and future water use for showering as based on effects of Energy Policy Act of 1992

	Current (2000) scenario			2020 scenario		
Shower flow range (gallons per minute)	Shower flow used for calculation purposes (gallons per minute)	Percent of all showering events (Dziegielewski et al., 1999)	Water use normalized to household (gallons)	Shower flow used for calculation purposes (gallons per minute)	Percent of all showering events	Water used normalized to household (gallons)
0.5 or less	0.5	0.9	0.1	0.5	0.9	0.1
0.5 to 1	0.75	4.8	0.5	0.75	4.8	0.5
1 to 1.5	1.25	16.2	2.9	1.25	16.2	2.9
1.5 to 2	1.75	28.7	7.2	1.75	28.7	7.2
2 to 2.5	2.25	22	7.1	2.25	22	7.1
2.5 to 3	2.75	11.2	4.4	2.5	27.4	9.8
3 to 3.5	3.25	6.4	3.0	0	0	0.0
3.5 to 4	3.75	4.3	2.3	0	0	0.0
4 to 4.5	4.25	2.4	1.5	0	0	0.0
4.5 to 5	4.75	1.5	1.0	0	0	0.0
More than 5.0	5.25	1.6	1.2	0	0	0.0
Total per household average water use			31.1			27.6

Total water savings in the WMA

To summarize, the effects of the *Energy Policy Act of 1992* (102D Congress) are estimated as follows for application in the 2020 WMA and are based on AWWARF's *Residential End Uses of Water* study. The current average daily use for toilet flushing was calculated as 40.1 gallons per household per day, as compared to a predicted 2020 use of 27.9 gallons per household per day for a net reduction of 12.2 gallons per household per day. The current average daily use for showering was calculated as 31.1 gallons per household per day, as compared to a predicted 2020 use of 27.6 gallons per household per day for a net reduction of 3.5 gallons per household per day. **The total per household reduction in demand due to showerhead and toilet retrofitting is thus expected to drop by 12.2 + 3.5 = 15.7 gallons per household per day.**

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Appendix F: Chesapeake Bay Program population estimates by HUC - method

The following summary provides an overview of the method by which the Chesapeake Bay Program developed an estimate of population forecast by HUC. The summary can also be found on the Chesapeake Bay Program website at http://www.chesapeakebay.net/info/method.htm.

Population Estimates & Projections - Methodology

POPULATION ESTIMATE DATA

The Bureau of the Census provides annual population estimates based on the 1990 U.S. Census for 1990 to 1995. The results of the projections are published on the Census Bureau's World Wide Web home page (http://www.census.gov/). The annual estimates are produced in conjunction with the Federal-State Cooperative Program for Population Estimates, and are aggregated by county for each state in the Chesapeake Bay watershed. Documentation and methodology on the Census population estimate data is attached at the end of this report.

POPULATION PROJECTION DATA

All states in the Chesapeake Bay watershed, with the exception of Pennsylvania, used a

cohort-component methodology for projecting their state population by county. The methods are similar, but not identical. For example, Virginia projects population in ten year intervals, rather than five. The Virginia data was manipulated to yield five year increments by using a linear interpolation technique. The formulas used to calculate the 2005 & 2015 population were:

Population 2005 = (Population 2000 + Population 2010) / 2
Population 2015 = (Population 2010 + Population 2020) / 2

In addition, New York's projections are based on the 1980 U.S. Census, rather than the 1990 Census. Also, New York's projections stop at projection year 2010. The New York data was extrapolated to 2015 and 2020 using linear extrapolation formulas:

Population 2015 = Population 2010 + (Population 2010 - Population 2005) and
Population 2020 = Population 2015 + (Population 2015 - Population 2010)

West Virginia uses two series to model two scenarios. Series A "indicate that West Virginia's population decline has almost bottomed out," and that "The population level will be stable over the next 30 years at the present level of 1.8 million people" (Isserman, et. al., 1992). Series M considers the most recent migration rates which "have severe implications for the future of West Virginia" (Isserman, et. al., 1992). For the purposes of projecting populations within the Chesapeake Bay watershed, the most recent migration trend in West Virginia has been towards migration into the Bay watershed. The series M scenario produces slightly higher population numbers for the West Virginia portion of the watershed due to the recent migration trend towards

Bay watershed counties. For that reason, the series M projections were chosen for estimating the West Virginia portion of the watershed.

METHODOLOGY FOR COUNTY & STATE PROJECTIONS

Once the Census Bureau estimates and state projections were assembled, a database was constructed containing the 1990 - 1995 population estimates from the Census Bureau and the 2000, 2005, 2010, 2015, and 2020 population projections from the states agencies.

Next, the percentage of each county within the Chesapeake Bay watershed was determined. Previous efforts at compiling population for the basin focused on the percentage of county area within the Chesapeake Bay. For example, the assumption was made that, if 25 percent of the counties area was in the basin, then 25 percent of the counties population was in the basin. While this method provided a general idea of population within the basin, it did not account for the distribution of the population within each county.

A new approach, using 1990 block centroids, was developed to get a better handle on the county-based population distribution. Census blocks are the smallest area for which the Census Bureau regularly collects population data. Using nearly 300,000 census block centroids for the watershed, an accurate estimate of the population living in the watershed was obtained for each county. In other words, for each county, the total population, as well as an accurate estimate of county population within the basin was known.

From this data, the percentage of each counties population living within the Chesapeake Bay watershed was determined. For example, the 1990 Census population of New Castle county Delaware was 441,946, using detailed block centroids, the population living within the watershed was estimated at 3,902. The percentage of 1990 New Castle county population living in the watershed was 0.88%. (Using the area-based method, the results would have been quite misleading: 14.5% of New Castle county's area is in the watershed, 14.5% of the 1990 population would have estimated 64,082 of New Castle's residents living in the watershed).

Next, the assumption was made that the population within each county will grow homogeneously, and that the ratio of county residents in the watershed to the total county population would remain constant. Following this assumption, the percentage of each county's 1990 population living in the watershed would remain the same. Having the population estimates and projections for each county to 2020 allowed for calculation of the population per county in the watershed. In the New Castle county example, the 2000 population was projected to be 490,665, of which 4,329, or 0.883%, were assumed to be living in the Chesapeake Bay watershed.

The percentage of population living in the watershed was determined for each county with residents in the Chesapeake Bay watershed. These percentages were applied to the Census-based population estimates for 1990 - 1995, as well as the 2000, 2005, 2010, 2015, and 2020 state-based population projections.

The results of the county-based analysis were summed to determine the estimated population in the Chesapeake Bay watershed by state.

METHODOLOGY FOR MODELING SEGMENT PROJECTIONS

A process similar to the method used to determine the watershed population was used to calculate population estimates by modeling segment. Each modeling segment was treated as a separate entity, and the percentage of each county within the modeling segment was determined. The Census block centroids were used to determine an accurate 1990 population by county within the modeling segment. This population was compared to the total county population, and a ratio of segment population by county to total population by county was developed for the modeling segment. These ratios were then applied to the 1991 - 1995 Census-based population estimates, as well as the 2000, 2005, 2010, 2015, and 2020 state-based population projections to determine the segment population in each of those years.

In addition to the population estimates & projections required for the state & county analysis, the modeling effort required a back projection to 1985 so that it would be compatible with 1985 land cover data. To accomplish this, the 1980 Census population figures by county were used. The 1980 population by modeling segment was calculated using the same percentage used for the projections. From the 1980 and 1990 population by modeling segment data, the 1985 population by modeling segment was calculated using the following formula:

$$\text{Population 1985} = (\text{Population 1980} + \text{Population 1990}) / 2$$

For more information, contact the Chesapeake Bay Program Office, 410 Severn Avenue, Suite 109, Annapolis, MD 21403, Tel: (800) YOUR-BAY, Fax: (410) 267-5777.

Appendix H

Calculation of domestic consumptive water use for the Potomac River basin

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

Summary

Estimates of current and future domestic consumptive water use for the Potomac River basin were made based on population forecasts and as extrapolated from single family water use data for the Washington metropolitan area (WMA).

The WMA single family outdoor water use was calculated for a drought year and was based on a series of conservative assumptions that erred on the side of larger estimates of outdoor water use. For example, all single family domestic outdoor water use was assumed to be consumptive. Outdoor water use data were obtained for a hot, dry year (1999). The calculated outdoor water use for the WMA was compared to values obtained from the literature and found to be similar 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 (Mayer et al., 1999, Linaweaver et al. 1966). The single family outdoor use based on the WMA was applied to forecasts of the number of households in the basin to calculate forecasts of domestic outdoor water use by month.

The average annual domestic consumptive water use estimated for the basin was compared to the basin's domestic consumptive water use as derived from USGS Water Use Data (USGS, 1998). The USGS-based estimate was approximately 40 percent of the value of the domestic consumptive use as calculated based on the WMA outdoor single family water use.

Calculation of single family outdoor (consumptive) use, Washington metropolitan area

Daily water use data for the Washington metropolitan area (WMA) are available from the *Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (2020 Study) (Hagen and Steiner, 2000). The WMA comprises a served population of approximately 3.6 million residents. Water use data from the 2020 Study were used in the present study to develop estimates of single family outdoor water use in the WMA.

The 2020 Study included data from which estimates could be made of the single family, multi-family, and employee water uses in the WMA as shown in Table H-1. The single-family water use in the WMA accounted for 45.2 percent of the total water used by the three categories followed by multi-family use at 27.8 percent and employee water use at 27 percent. Total unaccounted water was distributed according to these percentage among the three categories to determine total average annual water use by category, including unaccounted water, as presented in the last column of Table H-1.

Table H-1: Year 2000 estimated annual WMA water use by user category

	Year 2000 calculated water use, mgd	Percentage of water use to total by category, including unaccounted water	Year 2000 total water use by category, including unaccounted water,mgd
Single-family use	176.5	45.2%	216.6
Multi-family use	108.4	27.8%	133.0
Employee water use	105.3	27.0%	129.2
Unaccounted water	88.7	NA	NA

Net single family water use for the WMA during the drought year of 1999 was determined on a daily basis by the following method. Estimated total water use for employee and multi-family water use categories (133.0 and 129.2 mgd, respectively) was subtracted from actual 1999 daily production data to determine a net single-family water use for each day. This calculation assumes that multi-family and employee water use remains constant throughout the year. This assumption is conservative in that it assumes all of the seasonal increase in water production for the WMA is attributed to the single family category. Figure H-1 shows the resulting calculated single family water use for the WMA, where outdoor water use varies considerably, with water use peaking in the summer months of June and July.

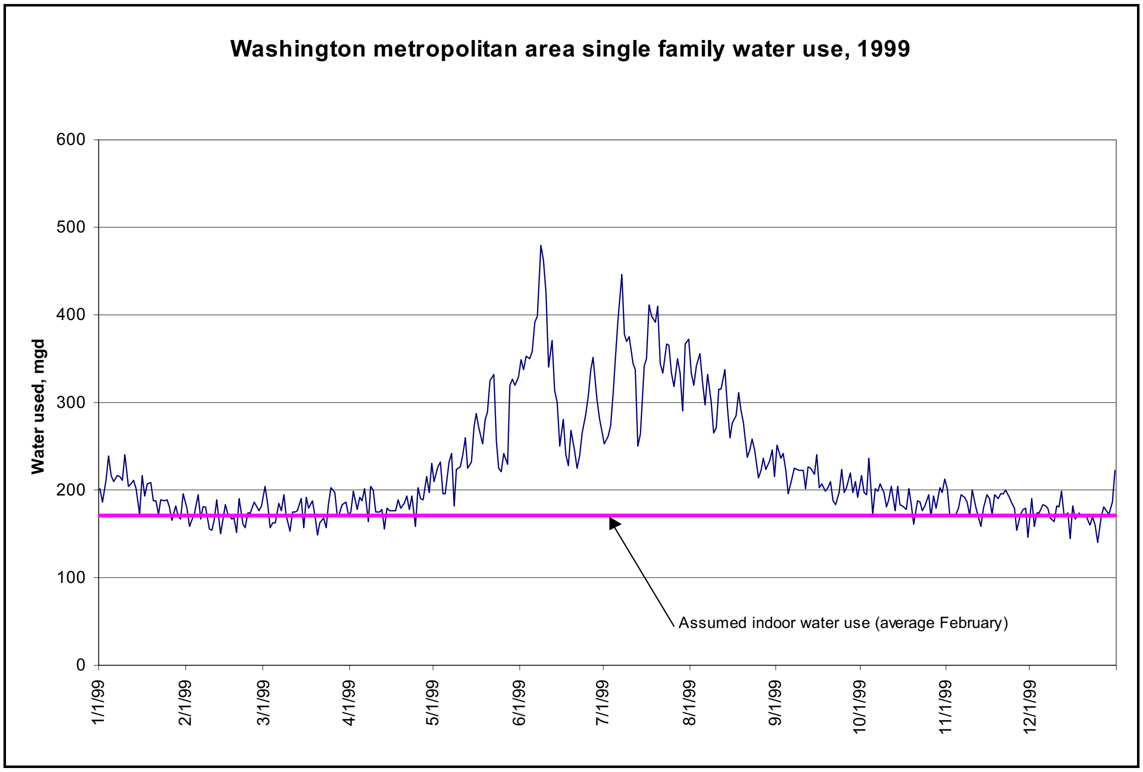

Figure H-1: Calculated WMA single family water use, 1999

The American Water Works Association Research Foundation's (AWWARF's) *Residential End Uses of Water* (End Use Study; Mayer et al., 1999) confirms that residential domestic indoor water use does not change significantly from summer to winter. If it is assumed that outdoor water use in the winter months is minimal, the difference in wintertime and summertime water use is a fair measure of total outdoor water use. For the Potomac basin, the assumption that wintertime water use contains little or no outdoor component is probably a reasonable approximation because the area does not have a hot or dry winter climate. An average of the lowest month's water use is thus a fair approximation of indoor water use for the single family category in the WMA. In 1999, the lowest month occurred in February. The February average single family use for the WMA extended throughout the calendar year is shown in Figure H-1.

The total WMA indoor and outdoor single family water use per household was calculated as follows. Any water use higher than the February average water use was assumed to be due to outdoor uses. Outdoor water use was calculated for each day in 1999. Total outdoor water use for 1999 was thus calculated to be 20.0 billion gallons for the single family households in the metro region. The indoor use was 62.6 billion gallons. Given a total number of single family households of 880,000 in the metro area, the net per household indoor and outdoor water use was calculated. The total outdoor water use for single family households was approximately 22.7 thousand gallons per home for 1999, with an indoor use in 1999 of approximately 71.1 thousand gallons per home.

Note that mandatory water restrictions were implemented on August 11, 1999 for the Maryland portion of the WMA. Maryland comprises approximately 35 percent of the total WMA water demand. The mandatory water restrictions were called late in the drought and were followed in late August with extensive hurricane related precipitation which effectively ended the drought. Because the mandatory water restrictions would only have been in place for approximately two weeks of the hot and dry period, and because they only affected about 35 percent of the study area, the mandatory water restrictions were assumed to have a negligible effect on the total of the WMA outdoor water demands.

Comparison to values from literature

Residential End Uses of Water

The AWWARF End Use Study is a recent source of information on the end uses of water in the home. The End Use Study is the most comprehensive ever undertaken for assessing U.S. indoor water uses by single family households (Mayer et al., 1999). Flow measurements from 1,188 homes in North America were taken from 12 study sites and 14 utilities around the country during the period May, 1996 through March, 1998. The recorded timing and flow rates of all water-using events were analyzed in detail, so as to permit identification and classification of each water using event such as toilet flushing, laundry washing, or outdoor irrigation. Over 1.9 million end use events were identified and segregated.

The End Use Study confirms a well established relationship between climate and outdoor water use. Predictably, the highest percentages of outdoor water use occurred in hot, dry climates. For example, the outdoor water use in Phoenix, AZ accounted for 70 percent of the total annual water use per single family home. In contrast, outdoor water use in Cambridge, Ontario (near Detroit, MI) accounted for 9.9 percent of the total annual water use per single family home. Other factors can influence single family water outdoor use including lot size, family income, water price, irrigation method, landscape type, landscape quality, swimming pools, and non-irrigation outdoor water uses. Unfortunately, the study sites in the End Use Study did not include a location in the mid-Atlantic area, so there were no data for outdoor domestic water use directly applicable to the Potomac River basin.

Residential Water Use Research Project reports

A five year long study of residential water use was conducted at the Johns Hopkins University sponsored by the (then) Federal Housing Administration in the early sixties. It was a national study, using data from several dozen selected residential areas. A landmark paper, Howe and Linaweaver (1967) was published, but this paper does not develop Middle Atlantic or Northeast models, instead dividing the data east and west of the 100th meridian. A table from one of the study reports, the *Residential Water Use , Report V, Phase 2* (Linaweaver et al. 1966) was provided by a member of the present study's Technical Advisory Committee, yielding some data for residential indoor and outdoor water use in the mid-Atlantic region. Some caution should be used in application of these data, since 1) data for the study were collected in 1963, and 2) the study areas are not typical of present-day conditions, as they were newly built suburbs with very high irrigation loads consistent with establishing newly planted lawns and shrubs. The study focus was on outdoor water use and its relationship to lot size. (As expected, outdoor water use was strongly correlated to lot size.) The outdoor water use varied from 8 to 39 percent of the annual average domestic use, with the larger outdoor water use percentage correlating to larger lot sizes.

Table H-2 shows how these calculated values compare to measured water consumption for the 14 study sites from the AWWARF's End Use Study and to the measured water consumption of the four study sites presented in one of the Linaweaver reports (1967). Note that the WMA values are calculated for a drought year.

Table H-2 shows that the WMA has about the same indoor water use as the sites profiled in the End Use Study, and has an outdoor water use that is similar to Tampa, Seattle, and two sites in Ontario. As might be expected, the outdoor water use for more arid regions in Denver, California and Arizona was higher than the outdoor water use in the WMA.

Table H-2: Annual indoor, outdoor, and total single family home residential use for the WMA as compared to other sites.

Location	Outdoor Annual Use (kgal/home)	Indoor Annual Use (kgal/home)	Total Annual Use (kgal/home)	Outdoor use, percentage of total
Results calculated by ICPRB, drought year				
Washington metropolitan area	22.7	71.1	93.8	24%
Data from AWWARF End Use Study				
Waterloo, Ontario	7.8	67.7	75.5	10%
Cambridge, Ontario	7.8	71.2	79	10%
Tampa, Fl	30.5	56.1	86.6	35%
Lompoc, CA	43.5	62.1	105.6	41%
Seattle, WA	21.7	54.1	75.8	29%
Eugene, OR	48.8	65.1	113.9	43%
Denver, CO	104.7	61.9	166.6	63%
Walnut Valley, CA	114.8	76.3	191.1	60%
Boulder, CO	73.6	54.4	128	58%
Tempe, AZ	100.3	65.2	165.5	61%
Las Virgenes, CA	213.2	70.9	284.1	75%
Scottsdale, AZ	156.5	60.1	216.6	72%
Phoenix, AZ	161.9	70.8	232.7	70%
San Diego, CA	99.3	55.3	154.6	64%
Data from Linaweaver study				
Donnybrook Apts. (net lot size, 1,100 ft^2)	4.4	52.6	56.94	8%
Country Club Park (net lot size 7,000 ft^2)	14.6	68.3	82.9	18%
Pine Valley (net lot size, 7,600 square feet)	17.9	78.1	96.0	19%
Hampton (net lot size, 28,000 square feet)	47.5	73.7	121.2	39%

The Country Club Park and Pine Valley sites profiled in the Linaweaver study are the two sites with lot sizes most closely approximating typical lot sizes in a metropolitan area at 7,000 square feet. The outdoor water use value calculated for the WMA is slightly higher than that calculated for these two sites. This was an unexpected result, given that the Linaweaver study sites were located in newly developed suburbs and one might have expected a higher per household water use because of a higher irrigation demand for new landscaping. However, the higher WMA water use than that of the Country Club Park and Pine Valley sites may be due to the fact that the WMA outdoor water use was calculated for a drought year. The outdoor use calculated for the WMA is significantly higher than the Donnybrook site, with its small lot sizes averaging only 1,100 square feet. The Hampton outdoor water use was significantly higher than the WMA outdoor water use, but the average lot size at the Hampton site, at 28,000 square feet, was much bigger than typical metropolitan lot sizes.

The WMA single family outdoor water use was based on a series of conservative assumptions that erred on the side of larger estimates of outdoor water use. The calculated outdoor water use for the WMA was similar to or slightly higher than measurements of outdoor single family water use for nearby mid-Atlantic study cities and for cities with non-arid climates, which is consistent with the WMA outdoor single family water use being calculated using data from a drought year.

Calculation of 1999 domestic consumptive use, Potomac basin

Estimates of 1999 domestic consumptive water use for the Potomac basin were made based on household (population) forecasts and extrapolated from single family water use data for the Washington metropolitan area (WMA).

The conservative assumption was made that no single family outdoor water use would be returned to the river and was thus considered entirely consumptive. All outdoor water use was assumed to be lost to evapotranspiration.

The outdoor water use calculated for the WMA was assumed to apply to all households throughout the Potomac basin. This assumption may not be ideal, given differences in demographic and household characteristics between the metro area and the more rural areas of the basin. Future study to examine the validity of this assumption might involve a site specific study to develop single family outdoor water use data for individual homes and one or more of the smaller towns in the basin, preferably using data for a recent drought year.

The monthly variation in consumptive demand was considered adequate for the purpose of the present study, but no consideration was given to peak daily or peak weekly consumptive demands. For a resource evaluation at the smaller subwatershed scale, this assumption may not be most appropriate. This scale is more appropriate in a resource analysis for cumulative consumptive demand through the basin, and is best for cumulative demand at the basin scale. Differences in the timing of peak daily or weekly consumptive demands for different jurisdictions will be offsetting in a downstream direction through the basin, given differences in basin wide travel times. Additionally, 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 long 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 appropriate.

The number of single family households in the Potomac basin, not including the WMA, was estimated using geographic information system (GIS) ArcView™ tools to aggregate US Census Bureau household information by census tract. Housing estimates were obtained for 1990. Census updates of population for 1999 were obtained. The ratio of 1999 to 1990 population was multiplied by the number of 1990 households to develop estimates of 1999 households.
Table H-3 shows the number of single family households estimated in the Potomac basin upstream of the WMA, and does not include those households served by the major metropolitan area water suppliers. Note that single family attached dwellings (townhouses) were counted in the single family household category in Table H-3. The table also presents the number of apartment units and mobile homes in the basin.

Table H-3: 1999 households in the Potomac basin by state, excluding the WMA

	Single family households	Apartment household units	Mobile homes
Virginia	138,114	27,343	13,436
West Virginia	65,118	9,013	17,308
Pennsylvania	46,571	8,703	7,829
Maryland	131,009	33,078	6,568
Totals	380,812	78,137	45,141

Source: US Census

Outdoor water use for the apartment and mobile home categories was assumed to be approximately 20 percent of the single family use. The 20 percent value was the ratio of the average annual Donnybrook Apartments outdoor water use (Linaweaver et al. 1966) to that of the average annual single family water WMA outdoor water use. The comparison is not perfect because of the age of the Linaweaver study, the high irrigation loads of the newly developed Linaweaver subject area, and the WMA outdoor use was calculated for a drought year but not in the Linaweaver study. Further work could examine actual water use for the apartment and mobile home categories of dwellings in the basin to determine the accuracy of this assumption. However, the total numbers of these two categories of dwellings is only 24 percent of the total households in the basin, so changes in the per unit water use estimate for these category of dwellings will likely have a relatively smaller impact on changes in the estimate of consumptive water use.

The calculated WMA single family outdoor water use is summarized by month in terms of average gallons per household per day as shown in column 2 of Table H-4. Monthly per household water use was multiplied by the number of single family households in the basin to yield an estimate of the basin's single family outdoor water use in each month (column 3). Monthly single family outdoor water use, adjusted by a factor of 0.2, was multiplied by the number of apartment and mobile homes in the basin to yield an estimate of the basin's apartment and mobile home outdoor water use in each month (column 4). The calculated total 1999 domestic outdoor water use for the basin is shown in the last column of Table H-4.

Table H-4: Calculated 1999 Potomac basin consumptive domestic water use

	1999 WMA single family outdoor water use, gallons per household per day	Basin single family outdoor use, millions of gallons per day (a)	Basin apartment and mobile home outdoor water use, millions gallons per day (a)	Total 1999 domestic outdoor water use for basin, millions of gallons per day (a,c)
January	7.2(b)	2(b)	0	2(b)
February	5.9	2	0	2
March	9.5	4	0	4
April	18.3	7	0	7
May	94.7	36	2	38
June	169.0	64	4	69
July	196.9	75	5	80
August	123.3	47	3	50
September	47.4	18	1	19
October	23.7	9	1	10
November	13.6	5	0	5
December	7.2	3	0	3

Notes:
(a) Basin demand is calculated for those households upstream of Little Falls excluding the WMA
(b) January value adjusted to represent assumed effect of water main breakage.
(c) Totals may not appear correct due to rounding errors

Seasonal variation in outdoor water use is evident in Table H-4. The average 1999 WMA single family outdoor water use in June through August was 163 gallons per day but close to zero for December through March. The total 1999 domestic outdoor water use for the basin is calculated to increase from nearly zero mgd in February to 80 mgd in July. The calculated total 1999 domestic outdoor water use for the basin averaged 24 mgd for January through December and averaged 66 mgd for the period June through August. Note that the domestic outdoor monthly demand is based on the outdoor water use during 1999, and could possibly change given different weather conditions.

Comparison to USGS estimates of domestic consumptive use

Consumptive water use was summarized for the Potomac basin (upstream of Little Falls and not including the WMA) as based on USGS 1995 Water Use Data (USGS, 1998). Consumptive use for the domestic category of water use as based on USGS Water Use Data was calculated to be on average 9.5 mgd for 1995, the most recent year for which data were available. The 9.5 mgd is about 40 percent of the domestic outdoor water use of 24 mgd calculated for the basin, based on WMA outdoor water use. The relatively large difference in the two numbers, and the large uncertainty associated with both estimates of domestic consumptive use, suggests that a conservative approach would be to use the larger number to estimate domestic consumptive use (assuming all outdoor use is consumptive) as was implemented in the present study.

Forecast of future domestic consumptive use

Estimates of future domestic consumptive use were developed based on forecasts of single family households, apartments, and mobile homes, which in turn were based on ratios of current population to population forecasts. The more conservative WMA-based estimate of per household outdoor use was used to develop the forecast rather than the USGS-based consumptive use estimate.

Population estimates for Hydrologic Unit Code[1] (HUC) regions in the Potomac basin were compiled from information supplied by the Chesapeake Bay Program (Chesapeake Bay Program, 2000). A detailed summary of population estimates by HUC for each forecast year is provided in the main body of the report. The number of single family households in each HUC region was estimated based on the percentage of each HUC region's population to the total basin population for each year. For example, the Middle Potomac-Catoctin HUC region has 8 percent of the total basin population, so the total number of single family households in that HUC region was assumed to be 8 percent of the total households in the basin. A similar algorithm was used to develop estimates of the number of apartments and mobile homes. Table H-5 shows the estimated number of single family households for each HUC region.

Table H-5: Forecast of single family households in the Potomac basin by HUC region, excluding the WMA

	2000	2010	2020	2030
South Branch Potomac	8,927	9,233	9,501	9,794
North Branch Potomac	32,608	32,738	32,835	32,954
Cacapon-Town	6,956	7,435	7,830	8,282
Conococheague-Opequon	127,487	138,694	148,060	158,654
South Fork Shenandoah	64,181	67,817	71,531	75,193
North Fork Shenandoah	18,763	20,325	21,887	23,449
Shenandoah	14,407	16,319	17,997	19,830
Middle Potomac-Catoctin (c)	30,057	35,833	40,630	46,079
Monocacy	77,414	91,022	99,959	112,010
Totals	380,800	419,416	450,230	486,245

Forecasts of average June through August daily domestic consumptive water demand by HUC region and for the basin were developed, assuming a repeat of hot and dry conditions and that all outdoor water use is consumptive. The forecast for single family consumptive demand was developed by multiplying the numbers of single family households by the average June through August WMA single family outdoor water use of 163 gallons per household per day. A forecast

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[1] A Hydrologic Unit Code refers to a USGS designated natural drainage basin or hydrologic area. There are 8 HUC regions in the Potomac Basin upstream of the Washington DC area. The USGS provides its water use data by HUC region.

of daily domestic consumptive water demand for apartments and mobile homes for each HUC was developed by multiplying the numbers of apartments and mobile homes for each HUC by the WMA household water use of 163 gallons per household per day and by a factor of 0.2. Table H-6 summarizes average June through August consumptive domestic use by HUC watershed, excluding metro-Washington use, estimated for hot and dry years (mgd). The forecasts in Table H-6 combine estimates of consumptive use for the single family, apartment, and mobile home categories.

Table H-6: Average summertime (June through August) consumptive domestic use by HUC watershed, excluding metro-Washington use, assuming a hot, dry year (mgd)

	1995	2000	2010	2020	2030
South Branch Potomac	1.5	1.5	1.6	1.6	1.7
North Branch Potomac	5.6	5.7	5.7	5.7	5.7
Cacapon-Town	1.2	1.2	1.3	1.4	1.4
Conococheague-Opequon	21.2	22.1	24.1	25.7	27.5
South Fork Shenandoah	10.8	11.1	11.8	12.4	13.1
North Fork Shenandoah	3.1	3.3	3.5	3.8	4.1
Shenandoah	2.3	2.5	2.8	3.1	3.4
Middle Potomac-Catoctin	4.7	5.2	6.2	7.1	8.0
Monocacy	12.3	13.4	15.8	17.4	19.4
Totals	**62.8**	**66.1**	**72.8**	**78.2**	**84.4**

Table H-6 shows that average June through July domestic water use for the portion of the basin upstream of the WMA is forecast to grow from approximately 66 mgd in 2000 to 84 mgd in 2030, assuming a repeat of a hot and dry year.

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Appendix I

Calculation of irrigation consumptive use for the Potomac basin

Appendix I: Calculation of irrigation consumptive use for the Potomac basin

Summary

Estimates of current and future agricultural irrigation consumptive water use for the Potomac basin were made based on the USGS 1995 base estimate of irrigation water use (USGS, 1998) adjusted by forecasts of eastern U.S. percentage increase in irrigated acres (Brown, 2000).

The forecast of average annual Potomac basin irrigation water use was multiplied by coefficients to represent the growing season for a dry year. Irrigation consumptive demand was calculated for a drought year and was based on a series of conservative assumptions. For example, all irrigation water use was assumed to be consumptive.

Calculation of annual average irrigation consumptive use, Potomac basin, dry years

The conservative assumption was made that no water withdrawn for irrigation would be returned to the river and was thus considered entirely consumptive. (All irrigation water use was assumed to be lost to evapotranspiration.)

Irrigation water use for the basin was obtained from the US Geological Survey (USGS, 1998) for the year 1995. The 1995 average annual use in the basin upstream of the Washington metropolitan area (WMA) for irrigation was calculated to be 5.2 mgd.

There is variability in consumptive agricultural irrigation water use from one year to the next, with more extreme water uses for irrigation during the hotter and drier years. Irrigation consumptive use during such drought periods is approximately 65 to 70 percent greater than average year consumptive use (Patrick Hammond, Maryland Department of the Environment, personal communication, August 12, 2000).

The USGS data for 1995 represents data from a dry summer growing season, but 1995 was not an extremely dry year. The 1995 irrigation demand was probably greater than an average year, but probably not as much as the 65 to 70 percent greater than average year demand. To determine expected irrigation water use during times of extreme drought, as based on the 1995 data, the 70 percent estimate was halved. An increase of 35 percent was applied to the 1995 USGS irrigation consumptive use to arrive at an estimate of dry year irrigation demands resulting in 7.0 mgd (5.2 multiplied by 1.35) averaged over the whole year.

Calculation of monthly irrigation consumptive use, Potomac basin, dry years

The growing season in the Potomac basin occurs from April through September, but significant irrigation takes place from June through August. At other times of the year, irrigation withdrawals are zero or insignificant, with the possible exception of September irrigation for corn crops (Patrick Hammond, Maryland Department of the Environment, personal communication, August 12, 2000). The Potomac basin growing season was confirmed using published tables of growing season for various crops based on mean temperature (Natural Resource Conservation Service, 1993).

The Blaney-Criddle method was used to evaluate net consumptive demand for the region by month as a function of temperature, length of day, crop type, and available moisture (Natural Resource Conservation Service, 1993). Figure I-1 shows the net inches of consumptive demand for a crop type of deciduous orchards, significant in the Potomac River basin. Figure I-1 shows the net water that would be used by a crop when an ample water supply is available. Figure I-1 was used as the basis for calculating the distribution of monthly irrigation water use for the Potomac basin during the growing season given an annual average use of 7.0 mgd and assuming no irrigation use outside of the growing season as shown in Table I-1.

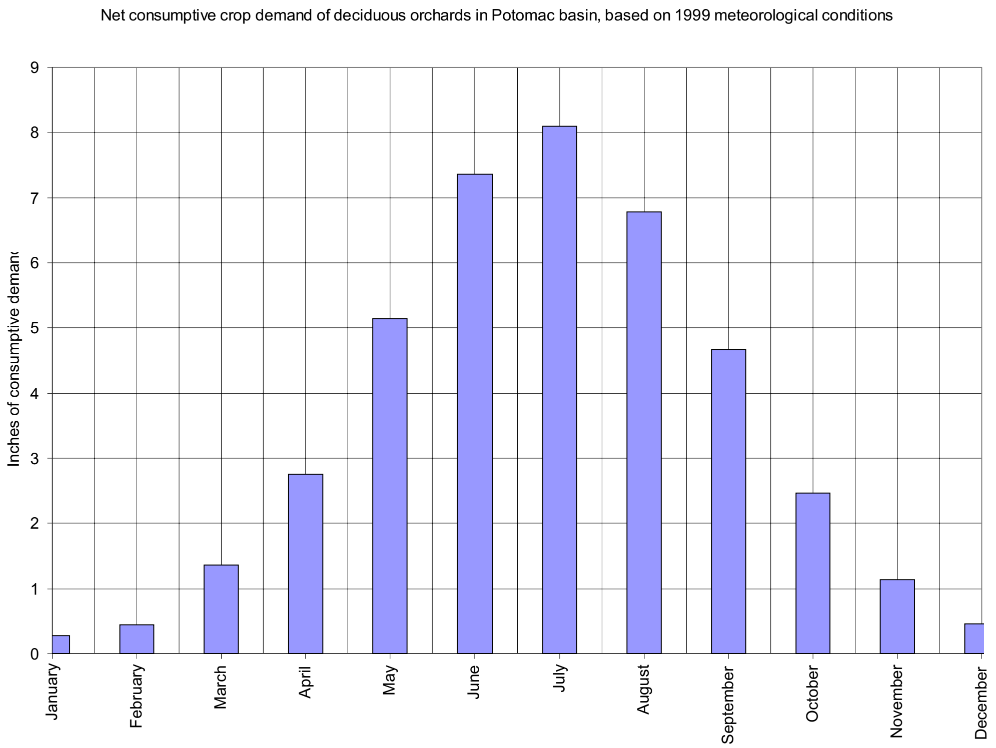

Figure I-1: Net consumptive demand for deciduous orchards in Potomac basin based on 1999 meteorological conditions

Table I-1: Estimated 1995 levels of consumptive irrigation water use by month for the Potomac basin assuming hot and dry conditions.

	Irrigation water use by month, mgd
January	0
February	0
March	0
April	6.6
May	12.4
June	17.8
July	19.5
August	16.4
September	11.3
October	0
November	0
December	0

Table I-1 shows that the peak irrigation is estimated to occur in June, July and August and averages 17.9 mgd during these months. No irrigation was assumed to take place outside of the April through September growing season. (The average irrigation value for the year from Table I-1 is 7.0 mgd.) The ratio of average June through August irrigation as compared to the average annual value is 2.6 (equals 17.9 divided by 7.0). The annual average irrigation water use for a dry year of 7.0 mgd was multiplied by a factor of 2.6 to develop an estimate of average June through August dry year irrigation water use, for a base year of 1995.

Forecast of monthly irrigation consumptive use, Potomac basin, dry years

Estimates of future irrigation consumptive water use for the Potomac basin were made based on the June through August calculated irrigation demand in hot and dry years adjusted by forecasts of eastern U.S. percentage increase in irrigated acres (Brown, 2000). Table I-2 shows the forecast of millions of acres irrigated in the eastern U.S.

Table I-2: Forecast of irrigated acres.

	Million acres irrigated, eastern US	Percentage change from 1995
1995	11.3	0
2000	12.6	12
2010	14.3	26
2020	15.4	36
2030	16.4	45

Source: Brown, 2000.

USGS also tracks irrigated acreage at a smaller scale, in Water Resources Regions, of which there are 18 in the conterminous U.S. Trends in irrigation use specific to the New England Water Resources Region (USGS; 1972, 1977, 1983, 1988, and 1998) were examined as shown in Figure I-2. The Potomac basin is included in the New England Water Resources Region.

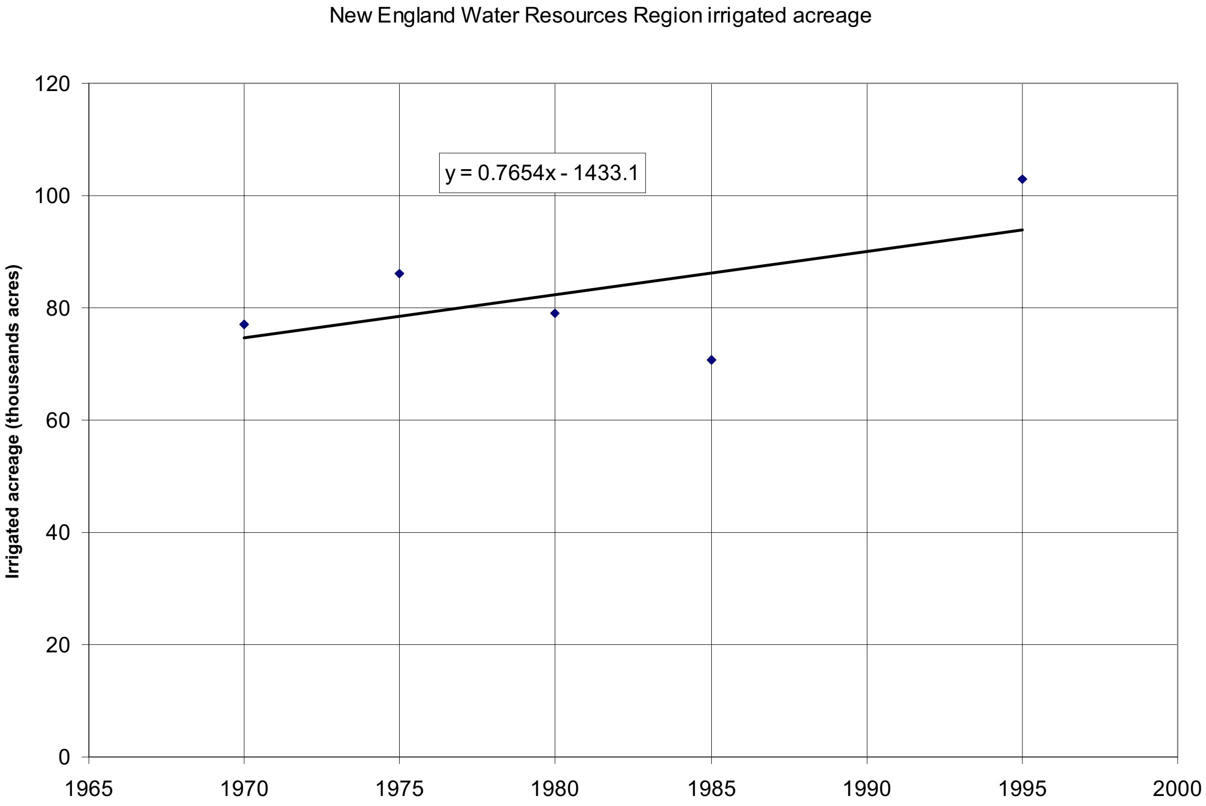

Figure I-2: New England Water Resources Region irrigated acreage

Figure I-2 shows an increasing trend in irrigated acreage for the New England Water Resources Region. However, the variability in irrigated acreage from year to year is great, so trend analysis of this limited data set was considered less accurate than trends determined for the broader eastern U.S. data. The eastern national trend resulted in higher estimates of irrigated water use, with an increase of irrigated acreage of 45 percent from 1995 to 2030, as opposed to a projection in irrigated acreage of 28 percent based on a trend analysis using the New England Water Resources Region. Therefore, the more conservative eastern national trend analysis was used to estimate future irrigated acreage for the Potomac basin.

The percentage changes from 1995 irrigated acreage for the eastern U.S. were used to develop estimates of irrigated acreage for future years for the Potomac basin. Because the recent trend in eastern withdrawals per acre has been constant (Brown, 2000), future irrigation water use in the

Potomac was projected to increase directly as a proportion of eastern acres irrigated.

Forecasts of average June through August daily irrigation consumptive water demand by HUC region and for the basin were developed, assuming a repeat of hot and dry conditions and that all irrigation water use is consumptive as shown in Table I-3.

Table I-3: Average summertime (June through August) consumptive irrigation use by HUC watershed, excluding metro-Washington use, assuming a hot, dry year (mgd)

	1995	2000	2010	2020	2030
South Branch Potomac	0.0	0.0	0.0	0.0	0.0
North Branch Potomac	0.3	0.4	0.4	0.5	0.5
Cacapon-Town	0.1	0.1	0.1	0.1	0.1
Conococheague-Opequon	4.8	5.3	6.0	6.5	6.9
South Fork Shenandoah	1.8	2.0	2.3	2.5	2.7
North Fork Shenandoah	1.4	1.6	1.8	1.9	2.1
Shenandoah	0.4	0.4	0.5	0.5	0.6
Middle Potomac-Catoctin	3.4	3.8	4.3	4.6	4.9
Monocacy	5.9	6.5	7.4	8.0	8.5
Totals	**18.1**	**20.1**	**22.8**	**24.5**	**26.2**

Table I-3 shows that average June through July consumptive irrigation water use for the portion of the basin upstream of the WMA is forecast to grow from approximately 20 mgd in 2000 to 26 mgd in 2030, assuming a repeat of a hot and dry year.

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Appendix J

Streamflow derivation by HUC

Appendix J: Streamflow derivation by HUC

North Branch Potomac HUC

The area of the North Branch Potomac HUC is 1,345 square miles. Regulation by Jennings Randolph and Savage reservoirs has changed the flow characteristics of the North Branch. The COE manages the river to maintain a minimum flow at Luke, MD, of 120 cfs (78 mgd). A conservative estimate was made of the flow that would have occurred over the historical record given the current status of river regulation per the following method. The minimum flow of 78 mgd was assumed at Luke, and area adjustment was applied to that flow contributed by the intervening drainage area between Luke and the downstream end of the HUC. The drainage area of the watershed at Luke is 405.8 square miles. The drainage area between Luke and the downstream end of the North Branch Potomac HUC is 939 square miles. Two USGS gages were used for the area adjustment over the period 10/1/1929 through 9/30/1999: George's Creek at Franklin, with a drainage area of 72.4 square miles, and Wills Creek near Cumberland, with a drainage area of 247 square miles. Both gages are located in the intervening drainage area. The area adjustment factor applied to combined George's Creek and Will1s Creek flows was 2.94 [938.9/(72.4+247)]. The area adjusted flow was added to the minimum assumed flow of 78 mgd in order to simulate the HUC flow for the North Branch.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 111 mgd. The total consumptive use for the North Branch HUC in 1995 is calculated to be 19.7 mgd. Note that much of the consumption (10.5 mgd) is evaporation from a thermoelectric plant that is upstream of Jennings Randolph (Mt. Storm). Therefore, the portion of the consumptive demand that is thermoelectric should be subtracted from the total consumptive demand before a comparison of consumptive demand with the 7Q10. The historical simulated minimum flow for the North Branch HUC is 99 mgd, assuming current policies for reservoir flow augmentation throughout the historical record.

South Branch Potomac HUC

The area of the South Branch Potomac HUC is 1,481.5 square miles. The USGS's *South Branch Potomac River Near Springfield* gage in West Virginia is in the South Branch Potomac HUC and has been operational from 1928 through the present. The gage has a drainage area of 1,471 square miles. Historical streamflow data was obtained for the period 8/8/1928 through 9/30/1998. An area adjustment factor of 1.007 (1,481.5 divided by 1,471) was applied to the gaged flow in order to simulate HUC flow for the South Branch.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 48 mgd. The total consumptive use for the South Branch HUC in 1995 was calculated to be 4.6 mgd. The historical simulated minimum flow for the South Branch HUC is 33 mgd.

Cacapon Town HUC

The area of the Cacapon Town HUC is 1,206 square miles. The USGS's *Cacapon River Near Great Cacapon,* gage in West Virginia is in the Cacapon Town HUC and was operational from 1922 through 1995. The gage had a drainage area of 677 square miles. Historical streamflow data was obtained for the period 12/12/1922 through 9/30/1995. An area adjustment factor of 1.78 (1,206 divided by 677) was applied to the gaged flow in order to simulate HUC flow for the Cacapon Town HUC.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 44 mgd. The total consumptive use for the Cacapon Town HUC in 1995 was calculated to be 0.9 mgd. The historical simulated minimum flow for the Cacapon Town HUC is 29 mgd.

Conococheague Opequon HUC

The area of the Conococheague Opequon HUC is 2,281 square miles. The USGS's *Antietam Creek near Sharpsburg* and *Conococheague Creek at Fairview* gages in Maryland are both in the Conococheague Opequon HUC and have been operational since 1928. The gages have a combined drainage area of 775 square miles. Historical streamflow data was obtained for the period 10/1/1929 through 9/30/1999. An area adjustment factor of 2.94 (2,281 divided by 775) was applied to the gaged flow in order to simulate flow for the Conococheague Opequon HUC.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 249 mgd. The total consumptive use for the Conococheague Opequon HUC in 1995 was calculated to be 12.2 mgd. The historical simulated minimum flow for the Conococheague Opequon HUC is 148 mgd.

North Fork Shenandoah HUC

The area of the North Fork Shenandoah HUC is 1,044 square miles. The USGS's *Shenandoah River at Millville* gage in West Virginia is in the Shenandoah River Valley outside of the North Fork HUC and has been operational from 1928 through the present. The gage has a drainage area of 3,040 square miles. Historical streamflow data was obtained for the period 10/1/1929 through 9/30/1998. An area adjustment factor of 0.34 (1,044 divided by 3,040) was applied to the gaged flow in order to simulate HUC flow for the North Fork Shenandoah HUC.

EPA's DFLOW was used to calculate the 7Q10 for the HUC, which was equal to 81 mgd. The total consumptive use for the North Fork Shenandoah HUC in 1995 was calculated to be 4.6 mgd. The historical simulated minimum flow for the North Fork Shenandoah HUC is 43 mgd.

South Fork Shenandoah HUC

The area of the South Fork Shenandoah HUC is1,660 square miles. The USGS's *Shenandoah River at Millville* gage in West Virginia is in the Shenandoah River Valley outside of the South Fork HUC and has been operational from 1928 through the present. The gage has a drainage area of 3,040 square miles. Historical streamflow data was obtained for the period 10/1/1929 through 9/30/1998. An area adjustment factor of 0.55 (1,660 divided by 3,040) was applied to the gaged flow in order to simulate HUC flow for the South Fork Shenandoah HUC.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 128 mgd. The total consumptive use for the South Fork Shenandoah HUC in 1995 was calculated to be 7.5 mgd. The historical simulated minimum flow for the South Fork Shenandoah HUC is 68 mgd.

Shenandoah HUC

The area of the Shenandoah HUC is352 square miles. The USGS's *Shenandoah River at Millville* gage in West Virginia is in the Shenandoah River Valley inside of the Shenandoah HUC and has been operational from 1928 through the present. The gage has a drainage area of 3,040 square miles. Historical streamflow data was obtained for the period 10/1/1929 through 9/30/1998. An area adjustment factor of 0.12 (352 divided by 3,040) was applied to the gaged flow in order to simulate HUC flow for the Shenandoah HUC.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 27 mgd. The total consumptive use for the South Fork Shenandoah HUC in 1995 was calculated to be 3.3 mgd. The historical simulated minimum flow for the Shenandoah HUC is 14 mgd.

Monocacy HUC

The area of the Monocacy HUC is 986 square miles. The USGS's *Monocacy River at Jug Bridge near Frederick* gage in Maryland is in the Monocacy HUC and has been operational from since 1929. The gage has a drainage area of 817 square miles. Historical streamflow data was obtained for the period 10/1/1929 through 9/30/1999. An area adjustment factor of 1.21 (986 divided by 817) was applied to the gaged flow in order to simulate HUC flow for the Monocacy HUC.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 41 mgd. The total consumptive use for the Monocacy HUC in 1995 was calculated to be 7.4 mgd. The historical simulated minimum flow for the Monocacy HUC is 14 mgd.

Middle Potomac Catoctin HUC

The area of the Middle Potomac Catoctin HUC is 1,227 square miles. The USGS's *Goose Creek near Leesburg, VA* gage is in the Middle Potomac Catoctin HUC and has been operational from since 1930. The gage has a drainage area of 332 square miles. Historical streamflow data was obtained for the period 1/1/1930 through 9/30/1999. An area adjustment factor of 3.70 (1,127 divided by 332) was applied to the gaged flow in order to simulate HUC flow for the Middle Potomac Catoctin HUC.

EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 4 mgd. The total consumptive use for the Middle Potomac Catoctin HUC in 1995 was calculated to be 13.8 mgd. The historical simulated minimum flow for the Middle Potomac Catoctin HUC is 1 mgd.

Appendix K

Streamflow derivation and validation for medium scale resource analysis

Appendix K: Streamflow derivation and validation for medium scale resource analysis

Potomac flow and cumulative demands downstream of North Branch HUC

Potomac flow downstream of the North Branch HUC was determined as described in the section above for the North Branch, "Stream Flow Data by HUC." EPA's DFLOW program was used to calculate the 7Q10 for the HUC, which is equal to 111 mgd. The total consumptive use for the North Branch HUC in 1995 is calculated to be 9.2 mgd. (excluding the 10.5 mgd attributable to Mt. Storm) The historical simulated minimum flow for the North Branch HUC is 99 mgd, assuming current policies for reservoir flow augmentation throughout the historical record.

Potomac flow and cumulative demands downstream of South Branch HUC

The combined flow on the Potomac below the confluence of the North Branch and South Branch HUCs was calculated by combining the simulated flows for both HUCs. The period of record for the combined flow was 10/1/1929 through 9/30/1998. EPA's DFLOW was used to calculate a 7Q10 of 163 mgd. The North Branch and South Branch 1995 combined upstream consumptive demand was 13.7 mgd (excluding the 10.5 mgd attributable to Mt. Storm). The simulated minimum flow was calculated to be 136 mgd.

Potomac flow and cumulative demands downstream of Cacapon Town HUC

The combined flow on the Potomac below the confluence of the North Branch, South Branch, and Cacapon Town HUCs was calculated by combining the simulated flows for each HUC, (with a day's lag on the combined North Branch and South Branch flow). The dataset included the period from 10/1/29 through 9/30/1995. EPA's DFLOW was used to calculate a 7Q10 of 210 mgd. The combined upstream consumptive demand in 1995 was 14.6 mgd (not counting 10.5 mgd attributable to Mt. Storm). The simulated minimum flow for the combined flow was calculated to be 168 mgd.

Potomac flow and cumulative demands downstream of Conococheague Opequon HUC

The combined flow on the Potomac below the confluence of the North Branch, South Branch, Cacapon Town and Conococheague Opequon HUCs was calculated by combining the simulated flows for each HUC, (with a net 3-day lag on the combined North Branch and South Branch flow, a net two-day lag on the Cacapon Town, and no lag for the Conococheague flow). The dataset included the period from 10/1/1929 through 9/30/1995. EPA's DFLOW was used to calculate a 7Q10 of 476 mgd. The combined upstream consumptive demand in 1995 was calculated to be 26.8 mgd (not counting 10.5 mgd attributable to Mt. Storm). The simulated minimum flow for the combined flow was calculated to be 318 mgd.

Potomac flow and cumulative demands downstream of Shenandoah HUC

The North Fork and South Fork Shenandoah HUCs do not directly augment the Potomac. The net Shenandoah flow was calculated by adding the flows for the three Shenandoah HUCs (with a 1 day lag on the North Fork and South Fork Shenandoah HUCs.) This combined Shenandoah flow was added to the flows calculated for upstream Potomac HUCs, with a net 3-day lag on the combined North Branch and South Branch HUC flow, a net 2-day lag on the Cacapon Town HUC flow, and no lag on the Conococheague Opequon HUC flow. The dataset included the period from 10/1/1929 through 9/30/1995. EPA's DFLOW was used to calculate a 7Q10 of 727 mgd. The combined upstream consumptive demand in 1995 was calculated to be 42.2 mgd (not counting 10.5 mgd attributable to Mt. Storm). The simulated minimum flow for the combined flow was calculated to be 469 mgd.

Potomac flow and cumulative demands downstream of Monocacy HUC

The combined flow on the Potomac below its confluence with the Monocacy HUC was calculated by adding the simulated flows for each upstream HUC, with a net 5-day lag on the combined North Branch and South Branch flow, a net 4-day lag on the Cacapon Town, and a net 2-day lag for the Conococheague Occoquan and Shenandoah HUC flows. The dataset included the period from 10/1/1929 through 9/30/1995. EPA's DFLOW was used to calculate a 7Q10 of 781 mgd. The combined upstream consumptive demand in 1995 was calculated to be 49.6 mgd (not counting 10.5 mgd attributable to Mt. Storm). The simulated minimum flow for the combined flow was calculated to be 484 mgd.

Potomac flow downstream of Middle Potomac Catoctin HUC

The combined flow of the Potomac below its confluence with the Middle Potomac-Catoctin HUC was calculated by adding the simulated flows for each upstream HUC, with a net 7-day lag on the combined North Branch and South Branch flow, a net 6-day lag on the Cacapon Town, a net 4-day lag for the Conococheague Occoquan and Shenandoah HUC flows, and a net 2-day lag on the Monocacy HUC flow. The dataset included the period from 1/1/1930 through 9/30/1995. EPA's DFLOW was used to calculate a 7Q10 of 797 mgd. The combined upstream consumptive demand in 1995 was calculated to be 55.8 mgd (excluding 10.5 mgd attributable to Mt. Storm).

A comparison was made between the simulated flow dataset and the actual flows for the period 1982 through 1995 to determine the validity of the method used for simulating low flows. The results of the comparison are shown in Table K-1.

Table K-1: Comparison of simulated flow dataset and actual Potomac flows, 1982-1995

	7Q10, mgd	7Q5, mgd	7Q2, mgd
Simulated Little Falls flow (a)	970	1,060	1,276

Little Falls actual flow (b)	926	1,028	1,262
Difference	44	32	14

Notes:
(a) Based on upstream HUC flows
(b) Gaged flow at Little Falls adjusted to include metro Washington withdrawals

Table K-1 shows that the 7Q10 flow for the period 1982 through 1995 for the simulated Little Falls flow was 970 mgd. The 7Q10 flow for the Little Falls actual (gaged) flow was 926 mgd. The lower actual flow raises a concern: there is approximately 44 mgd less water during 7Q10 flow than is predicted by the simulated flow data set. For the low flows that would occur at higher probabilities (7Q5 and 7Q2, i.e., low flows that would occur at a 20% and 50% likelihood in any given year) the difference is less.

For average flows and low flows during ordinary years (1982) the simulated flow matches well with actual gaged flows. For low flows during the more extreme dry years (1986) the simulated summertime flows are higher than the actual gaged flows.

One possible explanation could be the magnitude and timing of agricultural and municipal consumptive water uses. During extreme low flows such as would occur at a 10 percent likelihood in any given year (the so called 10-year recurrence interval) weather conditions are typically drier and hotter. One might expect consumptive uses during these hot dry months to be higher than the annual average consumptive use. Higher consumptive uses could explain why actual gaged flow was lower than the simulated flow dataset during the more extreme low flow periods.

Note that at the highest flow rates, the area adjustment method does not predict the timing or magnitude of peak flows. This result is expected and is not a problem since it is low flow periods that are of concern for this study.

The simulated minimum flow downstream of the Middle Potomac-Catoctin HUC was calculated to be 487 mgd. This simulated minimum flow can be compared to the actual minimum flow that occurred September 10, 1966. In 1966, Jennings Randolph was not yet on line. The simulated flow record, which included current rates of reservoir flow releases, was adjusted to represent that 1966 flow without Jennings Randolph augmentation releases. The minimum simulated flow was calculated to be 417 mgd. This flow is 29 mgd higher (7.5%) than the actual minimum flow that occurred. The difference might be attributable to consumptive use in 1966 that was not reflected in the simulated flow dataset or to errors introduced through the development of the simulated flow record.

Appendix L

Large scale basin resource analysis: method and tools

Appendix L: Large scale basin resource analysis: method and tools

This appendix 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 including:

- 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.

Water suppliers and service area

The majority (approximately 90 percent) of the 3.6 million people in the Washington metropolitan area's (WMA's) population relies on water furnished by three agencies, the "CO-OP utilities:"

- The Washington Aqueduct Division of the U.S. Army Corps of Engineers (Aqueduct) serving the District of Columbia and portions of Virginia.
- The Fairfax County Water Authority (FCWA) serving parts of northern Virginia.
- The Washington Suburban Sanitary Commission (WSSC) serving the Maryland suburbs.

These agencies supply treated water either directly to customers or through wholesale suppliers.

Water supplies from the Patuxent reservoirs in Maryland and the Occoquan reservoirs in Virginia are also included in the study because of their conjunctive use with supplies from the non-tidal Potomac. These resources are used by FCWA and WSSC. The Patuxent and Occoquan/Manassas reservoirs are currently used at approximately their sustainable yields. Therefore, all future increases in demand in the distribution areas jointly served by them and the non-tidal Potomac River will likely be accommodated by increased withdrawals from the non-tidal Potomac River.

Model description

A daily system simulation model was developed that captures the daily operating rules of the system of reservoirs, fluctuating daily and seasonal demands, 67 years of historical flows, and that provides outputs of daily reservoir volumes given current and future demands (The Potomac

System River and Reservoir Model, PSRRM). PRSSM simulates the WMA water supply system and emulates CO-OP system reservoir operations as described below. Demands in PRSSM are modeled to incorporate seasonal and daily variability in flows. PRSSM is run in a continuous mode through the 67 years of deterministic historical reservoir inflow and Potomac River flow records on a daily time step. The drought of 1930-31 is the longest drought included in the historic record, and is noteworthy for lasting from the summer through the fall and winter of 1930-1931.

The system model can be compared to an accounting procedure, tracking reservoir inflows and reservoir releases in order to calculate daily reservoir storage throughout the historical record. PRSSM can thus be used to determine how the current system of reservoirs and the Potomac River would respond to current or future demands given the current operating rules and the historical record of streamflow. The model reports the storage remaining in each reservoir and the Potomac flow at Little Falls before and after withdrawals for each day in the historical record. PRSSM functions as both an operations and planning model, and has been used to develop more efficient operating rules for the WMA system of reservoirs.

Reservoir operations

During periods of low flow, the Occoquan and Patuxent reservoirs are used at their maximum sustainable withdrawal rates. Reservoir response curves have been developed for the Occoquan and Patuxent reservoir systems that allow managers to determine the maximum sustainable and safe withdrawal rate (Hagen and Steiner, 2000). The response curves were used in the drought of 1999 and allowed managers to fully utilize the reservoirs in the early stages of the drought while maintaining adequate reserve storage. Managers understood that the "cost" of fully utilizing the reservoirs during the drought was to incur a 1 percent chance that withdrawals would have to be reduced during the winter, when the free flowing Potomac is able to more than meet demands. Reservoir rule curves based on the reservoir response curves were developed and incorporated into PRSSM.

Jennings Randolph and Little Seneca reservoirs are used to augment low flows in the Potomac River. Jennings Randolph and Little Seneca releases are made when predicted demands plus environmental flow requirements are greater than predicted Potomac flow. Because Jennings Randolph Reservoir is some 200 miles upriver, releases must be made approximately nine days in advance to allow for travel time downstream. The operations procedure for a Jennings Randolph release is to determine how much water, if any, to release from Jennings Randolph Reservoir in order to meet anticipated demands nine days in the future. The Little Seneca Reservoir, less than a day's travel time from metropolitan intakes, is used in conjunction with Randolph so that releases made from the latter can be more conservative. If the Jennings Randolph release is too small (because of lower than expected river flow or higher than expected demands), a release can be made from the smaller, closer reservoir to make up for any temporary shortfalls that become apparent as Jennings Randolph water travels to the intakes. These operations were incorporated into PRSSM.

To determine the Jennings Randolph release, streamflow throughout the watershed is monitored. The USGS's real-time flow data are invaluable in obtaining a snapshot of flow conditions and for evaluating flow trends. For example, up to 17 USGS graphs depicting gage readings of Potomac and tributary streamflow were printed each day during the drought of 1999. Flow regressions for major tributary flows were developed to estimate streamflow recessions. Forecasts of major tributary flows, based on the tributary flow regressions, were used to develop forecasts of Potomac flow at Washington in 9 days time.

Jennings Randolph and Little Seneca efficiency of operations

Due to fluctuations in short-term demand and in flow forecasting, not all water released from Jennings Randolph can be captured at the intakes. River flows might be greater than predicted or demands might be less, in which case water in excess of the environmental flow recommendations flows past the intakes. The Jennings Randolph release is thus less than 100 percent "efficient" from a water supply perspective. Thus, an appropriate algorithm was developed for the Jennings Randolph release in PRSSM that simulates Jennings Randolph inefficiency. Future Potomac flow was considered unknown for each model timestep, and was estimated based on the algorithm used during actual operations. That is, flow regressions were incorporated into the model and used to estimate streamflow recessions which in turn were used to forecast Potomac flow 9 days beyond the current model timestep. In model runs as in real life operations, the flow downstream of Little Falls could be in excess of the environmental flow recommendation. Thus, the PRSSM approximates the real-life inefficiency that might be expected of Jennings Randolph releases during periods of low flow.

The travel time of a Jennings Randolph release takes 9 days when the release is large (on the order of at least 100 to 200 mgd) and travels as a "wave," a condition called unsteady flow by hydraulic engineers. For a small release less than approximately 100 mgd, the water travels downstream as a particle, and would take approximately 20 days to arrive at DC during periods of low flow. Thus, the Jennings Randolph release in both real operations and as modeled in PRSSM calls for an initial day's release of 200 mgd whenever the forecast of demands is greater than the forecast of river flow 9 days hence. The large release is made to quickly get the water to the intakes as a "wave." Subsequent day's releases are at least 100 mgd whenever the forecast of 9-day demands is greater than the forecast of river flow 9 days hence. Little Seneca is assumed in model runs to be 100% efficient.

Effects of sedimentation on reservoir storage

Reservoir storage was assumed to decrease over time due to the effects of reservoir sedimentation. Table L-1 shows the current and projected reservoir storage for the system reservoirs. Sedimentation rates were determined using the most recently available bathymetric surveys. Current reservoir storage was compared to original estimates of reservoir storage to determine storage loss over time. ICPRB reports 98-3, 98-4a, 98-5, and 99-3 show the calculations of reservoir sedimentation for the system reservoirs. The changes in reservoir storage were incorporated into the system model as a function of forecast year.

Table L-1: Effects of sedimentation on system reservoir storage

	Usable capacity in year 2000, mg	Usable capacity in year 2020, mg
Occoquan	7,988	7,188
Patuxent	10,200	9,720
Little Seneca	3,860	3,560
Jennings Randolph water supply	13,360	12,968
Jennings Randolph water quality	16,623	16,135

Effects of increased treated wastewater return flow

Several waste-water treatment plants (WWTPs) serving the WMA discharge treated effluent upstream of the metro area water intakes, both in the Potomac River and upstream of Occoquan Reservoir. These discharges were estimated for future years and incorporated into PRSSM as available for future use. The facilities considered for this analysis include WSSC's Seneca WWTP, Loudoun County Sanitation Authority's planned Broad Run WWTP, and the Upper Occoquan Sewage Authority's (UOSA's) WWTP. Table L-2 shows the current and projected WWTP return flows for these three facilities. The increases in treated wastewater return flow were incorporated into PRSSM as a function of forecast year.

Table L-2: Current and projected WWTP return flows for the WMA

	2000 return flows, mgd	2020 return flows, mgd	2050 return flows, mgd
Loudoun County Broad Run WWTP	0	11	29
Seneca WWTP	6	22	26
UOSA WWTP	25	42	67
Totals	31	75	122

Environmental flow recommendations

The current environmental flow recommendations for the WMA were used for the resource analysis. The recommendations are based on a 1981 study (MD DNR, 1981). The flow recommendations include a 300 mgd minimum daily flow downstream of Great Falls and a 100 mgd minimum daily flow downstream of Little Falls.

Jennings Randolph water quality release

Jennings Randolph has a total of 30 billion gallons of water quality and water supply storage, of which 13.4 are allocated for water supply storage and 16.6 are allocated for water quality storage. Further storage is allocated for flood control (11.8 bg). The CO-OP water utilities have agreed to share the cost of the water supply storage portion of Jennings Randolph, and control the release of the 13.4 bg water supply portion of the storage through ICPRB. The US Army Corps of Engineers (COE) manages the water quality storage in Jennings Randolph as well as nearby Savage Reservoir, and makes releases from water quality storage for flow management every day of the year.

Regulation for water quality management at Jennings Randolph is to use as much of the available water quality storage as needed every year to produce the greatest possible improvement in water quality downstream in the North Branch Potomac. Joint regulation with nearby Savage River Dam is used to assist in meeting this goal. The release rule for water quality is based on the expected inflow rate and the volume of remaining storage in the lake. The idea is to maximize the minimum flow from the reservoir without running out of water.

However, when a request for a water supply release is made by ICPRB on behalf of the utilities, the Jennings Randolph release from water quality may be reduced by the COE to the minimum release of 120 cubic feet per second (cfs; 78 mgd). This can be the case even when in the days prior to a water supply release, the water quality release may have been higher than 120 cfs. In the summer of 1999, water quality releases dropped from about 160 cfs (103 mgd) to 120 cfs at the beginning of the first water supply release.

Modeling analysis shows that the 120 cfs release can be maintained throughout the historical streamflow record, even in the event of a multi-year drought.

Therefore, it can be appropriately and conservatively assumed that future water quality releases are simply equal to 120 cfs during a water supply release. This assumption greatly simplifies the programming involved in the simulation model PRSSM. This model assumes that only 120 cfs is being releases from the two reservoirs for water quality at all times, and that any deficit would have to be made up by water from water supply storage.

Modification of historic streamflow data to account for consumptive demand

Total June through August consumptive use in the Potomac basin upstream of the metropolitan water supply intakes for 2000 was estimated to be 129 mgd, excluding the consumptive thermoelectric use upstream of Jennings Randolph Reservoir in the North Branch. Projected consumptive use in the basin is forecast to increase by 30 mgd from 2000 to 2030, or approximately 1 mgd per day.

Stream flow resources were modified in the computer simulation model PRSSM to account for present and expected consumptive demands. The historical streamflow data was adjusted to represent those flows that would have occurred given current patterns of consumptive use. The 129 mgd consumptive demand was subtracted from 1929 historical flow in June, July and August to account for current levels of seasonal consumptive demand. Implicitly, it was assumed that actual consumptive use in 1929 was zero and that the 1929 historical streamflow record had to be adjusted by the full 129 mgd to represent current consumptive use patterns. No adjustment was made to the historical streamflow record for 1997. For years between 1929 and 1997, the historical streamflow record was adjusted by subtracting an amount that varied linearly from 129 mgd in 1929 to zero mgd in 1997. A further adjustment to streamflow resources was made to account for projected consumptive use. When projected year 2020 demands were modeled, all years of streamflow resources were decreased by an additional 20 mgd in the months of June, July and August.