

# Appendix B – Water Withdrawals and Consumptive Use in the Potomac River Basin

---

Prepared for

The Nature Conservancy and the U.S. Army Corps of Engineers

By

Interstate Commission on the Potomac River Basin

51 Monroe Street, Suite PE-08

Rockville, MD 20850

March 2012

Water is the driver of Nature.

- Leonardo da Vinci

When the well's dry, we know the worth of water.

- Benjamin Franklin (1706-1790), Poor Richard's Almanac, 1746

## Table of Contents

Table of Figures .....	iii
Table of Tables.....	iv
List of Abbreviations.....	v
Executive Summary.....	ES-1
1 Introduction .....	1
2 Water Consumption in the Potomac River Basin .....	4
2.1 Study Area .....	4
2.2 Current Water Use .....	4
3 Withdrawal and Consumptive Use Projections by Water Use Sector .....	11
3.1 USGS Water Withdrawal Estimates .....	12
3.2 Water Use Sectors .....	13
3.3 Developing Water Withdrawal Forecasts .....	14
3.3.1 Base Scenario .....	14
3.4 Estimating Consumptive Use Fraction of Water Withdrawal.....	26
4 Apportioning Water Withdrawals to the River-Segment Spatial Scale and Monthly Time Scale	28
4.1 Developing Water Use Projections at the River-Segment Scale .....	28
4.2 Developing Consumptive Use Projections at the Point Scale.....	30
4.3 Quantifying Withdrawals by Source Type — Groundwater and Surface Water.....	30
4.4 Inter-basin Transfers and Water Conveyance.....	31
5 Future Water Withdrawal and Consumptive Use Scenarios .....	32
5.1 High Domestic and Public Supply Scenario .....	33
5.2 Medium Domestic and Public Supply Scenario.....	36
5.3 Low Domestic and Public Supply Scenario .....	37
5.4 Power Sector Scenario.....	38
5.4.1 Power Plant Technology and Water Use.....	40
5.4.2 Scenario Options.....	41
5.4.3 Withdrawal Projection and Consumptive Use Projections .....	42
5.4.4 Results.....	42
5.5 Climate Change Scenario .....	43
5.5.1 Climate Change Effects .....	43
5.5.2 Climate Change Effects on Water Demand .....	46
5.5.3 Summary of Climate Change Scenario Adjustments.....	54
5.5.4 Climate Change Scenario Results .....	55
5.6 Drought Scenario .....	57
5.6.1 Domestic and Public Supply .....	57
5.6.2 Power Sector.....	63
5.6.3 Agriculture Sector .....	64
5.6.4 Consumptive Use.....	65
5.6.5 Results.....	65
6 Analysis of Water Consumption by Watershed .....	67

7	Conclusion.....	69
8	Comparison of Results to Previous Studies .....	71
8.1	MDE Wollman Report (2008) .....	71
8.2	ICPRB Section for Cooperative Operations on the Potomac Studies.....	71
8.2.1	Washington Metropolitan Area Water Supply Reliability 2010 Study .....	71
8.2.2	2000 Water Supply Demands and Resources Analysis in the Potomac River Basin ....	79
	References.....	88
	Supplemental Tables.....	93

## Table of Figures

Figure 1. Percent change in Potomac River basin population from 2010 to 2030.....	5
Figure 2. Agricultural land use change by county between 2002 and 2030.....	6
Figure 3. Forest loss between 2002 and 2030.....	7
Figure 4. Infill redevelopment between 2002 and 2030.....	8
Figure 5. Urban land use change between 2002 and 2030.....	9
Figure 6. Projected number of animals in the Potomac River basin in 2010. ....	10
Figure 7. Drainage to gage sites on the Potomac River and location of withdrawal points.....	11
Figure 8. Annual change in water withdrawal per person between 2000 and 2005.....	16
Figure 9. Ratio of irrigated to total row-crop land, using USDA-FRIS data .....	20
Figure 10. Projected withdrawal and irrigated acres of crop land in Frederick County, Maryland. ....	21
Figure 11. Animal units per agricultural land area by FIPS code from 1982 through 2010.....	23
Figure 12. Water withdrawal and consumptive use by sector in 2005 and 2030.....	34
Figure 13. Water withdrawal by sector for surface and groundwater.....	35
Figure 14. Domestic and public supply withdrawal and consumptive use in the medium DP scenario.....	37
Figure 15. Domestic and public supply withdrawal and consumptive use in the low DP scenario....	38
Figure 16. Power sector causal link model.....	39
Figure 17. IPCC Scenarios (Pachauri et al. 2007).....	45
Figure 18. Monthly withdrawal as a percent of annual withdrawal for each state .....	47
Figure 19. Percent of total water withdrawal by sector on a monthly time scale for each basin state. ....	48
Figure 20. Irrigation and climate change causal links.....	50
Figure 21. Thermo-electric power and climate change causal links.....	52
Figure 22. Domestic and public supply and climate change causal links.....	53
Figure 23. Comprehensive causal links diagram for the climate change scenario.....	55
Figure 24. Withdrawal and consumptive use in the climate change scenario for 2030.....	56
Figure 25. Combined water production at WMA suppliers and precipitation for drought years 1999 and 2002.....	59
Figure 26. Water production at WMA suppliers and temperature for drought years 1999 and 2002.....	60
Figure 27. Monthly average temperature in 1930 and 2005.....	61
Figure 28. Difference in temperature between 2005 and 1930 (1930-2005/2005).....	62
Figure 29. Historical drought coverage.....	63
Figure 30. Drought recurrence interval and irrigation withdrawal (Jarrett 2007).....	64
Figure 31. Causal link diagram for the drought scenario.....	65
Figure 32. Drainage area flow diagram.....	68
Figure 33. Map of the Potomac River basin, showing WMA water supply system resources and areas served by the WMA water suppliers.....	73
Figure 34. Average annual, summertime, wintertime, and peak day water use for the Washington, D.C., metropolitan area from 1990 through 2008.....	75
Figure 35. Portion of the basin that drains to Little Falls by sub-watershed (HUC8).....	80

## Table of Tables

Table 1. Water Use Sectors and abbreviations .....	14
Table 2. The average of irrigated to agricultural land for each Potomac basin state, calculated from USDA-NASS data. ....	19
Table 3. Data sources and rate used to project future withdrawal amounts.....	25
Table 4. Consumptive use fraction of total water withdrawal (Shaffer and Runkle 2007). ....	26
Table 5. Water withdrawal data resolution.....	28
Table 6. Sector reclassification of state and USGS data. ....	29
Table 7. Summary of assumptions for future water withdrawal and consumptive use scenarios. ....	33
Table 8. Averaged county rates of change in water withdrawal amounts by sector. ....	36
Table 9. Comparison of domestic and public supply scenario results for 2030.....	38
Table 10. Change in withdrawal between the medium DP scenario with open-loop cooling and the power scenario with closed-loop cooling and CO <sub>2</sub> capture technology. ....	42
Table 11. Comparison of 2030 power sector withdrawals under base conditions (high DP and medium DP scenarios) and in the power scenario, with and without the new plant. ....	43
Table 12. Fraction of irrigated land to all crop land under climate change assumptions.....	50
Table 13. Literature summary of water demand changes due to climate change.....	53
Table 14. Summary of sector adjustments for the climate change scenario. ....	54
Table 15. Comparison of 2030 withdrawals and consumptive use in the CC and high DP scenarios... ..	57
Table 16. Comparison of drought and medium DP scenario results. ....	66
Table 17. Withdrawal and consumptive use by drainage area to Potomac River gage sites (MGD). 67	
Table 18. Reported 2005 withdrawal data from the Middle Potomac Watershed Assessment and CO-OP studies. ....	76
Table 19. Middle Potomac and CO-OP study forecasts for 2010 and 2030 .....	76
Table 20. Comparison of CO-OP and Middle Potomac Watershed Assessment methods for estimating future water demand. ....	77
Table 21. Per capita water use estimates for the public supply sector and combined public supply and domestic self-served sectors. ....	78
Table 22. Results from Steiner et al. (2000) for forecasts of average consumptive use in June through August of a hot and dry year by HUC (in Steiner et al, pg. 6). ....	82
Table 23. Comparison of the methods used to create future withdrawal and consumptive use forecasts in the MPWA and CO-OP studies. ....	84
Table 24. Estimated average June through August consumptive use (MGD) for the initial year in the CO-OP and MPWA studies. ....	85
Table 25. Estimated 1995 HD average June through August consumptive use (MGD) by sector in the CO-OP study. ....	86
Table 26. Estimated 2005 HD average June through August consumptive use (MGD) by sector in the MPWA. ....	86
Table 27. Estimated average June through August consumptive use (MGD) in 2030 in the CO-OP and MPWA studies. ....	87
Table 28. Change in average consumptive use rates between the initial study year and 2030 in the CO-OP and MPWA studies. ....	87

## List of Abbreviations

AG	Agriculture sector
CBP	Chesapeake Bay Program
CU	Consumptive use
CO-OP	ICPRB Section for Cooperative Water Supply Operations on the Potomac
D.C.	District of Columbia
DP	Domestic and Public Supply sector
DP1	Low domestic and public supply scenario
DP2	Medium domestic and public supply scenario
EPRI	Electric Power Research Institute
FIPS	Federal Information Processing Standards
FRIS	Farm and Ranchland Information Survey
GW	Groundwater
HD	Hot and Dry Scenario
HSPF	Hydrological Simulation Program-Fortran
HUC	Hydrologic Unite Code
ICPRB	Interstate Commission on the Potomac River Basin
IN	Industry sector
IR	Irrigation sector
IPCC	Intergovernmental Panel on Climate Change
LI	Livestock sector
MDE	Maryland Department of the Environment
MGD	Million Gallons per Day
MI	Mining sector
MPRWA	Middle Potomac River Watershed Assessment
NASS	National Agricultural Statistics Service
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PO	Power Sector
SRES	IPCC Special Report on Emission Scenarios
SW	Surface water
USDA	United States Department of Agriculture
US-EIA	United States Energy Information Administration
USGS	United States Geological Society
WAD	Washington Aqueduct
WD	Withdrawal
WMA	Washington Metropolitan Area
WSM	Watershed Model
WSSC	Washington Suburban Sanitary Commission

## Executive Summary

This study aims to provide a range of future withdrawal and consumptive use scenarios to inform analysis of flow alteration-ecology relationships in the Potomac River basin for the Middle Potomac River Watershed Assessment (MPRWA). To this end, water withdrawals and consumptive use were projected in five-year intervals through 2030, using 2005 as the base year for analysis and projecting across the entire Potomac River basin by county. Acknowledging that the past does not predict the future, six scenarios were developed that project withdrawals and consumptive use under various conditions.

The six scenarios represent a range of potential future water use conditions. One scenario represents the base conditions as they are understood today and makes no changes to these conditions in future years. Two scenarios adjust the per capita withdrawal rate for domestic and public supply. The other three scenarios consider water and consumptive use under drought conditions, likely climate changes, and advances in power generation technology.

Data from U.S. Geological Survey (USGS) and state withdrawal databases from 2005 along with assumptions about consumptive use and demand projections served as the basis for these estimates.

Ground water and surface water withdrawals were estimated for the following sectors:

- domestic and public supply (DP),
- mining (MI),
- thermo-electric power (PO),
- industry (IN),
- livestock (LV), and
- irrigation (IR).

This analysis is based solely on documented withdrawal locations and rates. None of the data sets used in this analysis included data on the conveyance of water. Therefore, water withdrawn in a given county was assumed to have been both consumed and discharged in that same county. To have calculated where water was withdrawn, conveyed, and ultimately discharged, additional data would have been required that was not readily available.

The Interstate Commission on the Potomac River Basin (ICPRB) performed a similar study in 2000 (Hagen et al. 2000). The 2000 ICPRB study and the present study had different purposes and therefore the methods used for the two studies were different. When comparing the 2000 ICPRB study with the medium or low domestic and public supply scenarios in the current study, however, the results are comparable.

In this study, the rates of change in the withdrawal forecasts were less than 1.5 percent for the power, industry, and mining sectors. The rates of change for the irrigation, livestock, and domestic and public water supply sectors were controlled by population and land use projections. Domestic and public water supply was also controlled by the projected increase in water withdrawal per

person. This increase in withdrawal per person was a continuation of the trend from 2000 to 2005 into the future.

When comparing the sectors, most water is withdrawn by the power sector, but most water is consumptively used by the domestic and public supply sector. This relationship was true for all years and scenarios. The scenarios clearly show that the per person withdrawal rate makes a sizeable difference.

The power sector is the largest growth sector in consumptive use. Regulatory forcing will result in cleaner air and protect against organism entrapment. Those regulations also will result in increased power use, and therefore water withdrawal, to fuel the new technology. The power sector will also grow because of population increases.

The drought scenario showed a 17 percent increase in withdrawals. The increase in withdrawals occurs in the summer months when streamflow is low. Climate change is an important consideration in any analysis of future trends. In this study, climate change had little impact on water use. However, climate change is anticipated to have a significant impact on water quality due to greater intensity storms, increased erosivity, sediment delivery and associated phosphorus.

The results of this study indicate that there will be impacts to the water resources in this region if future growth and water use continue along the same trend. Impacts to the Potomac River from water demand likely can be ameliorated by management and policy options.

# 1 Introduction

The characteristics of flow patterns in river systems directly affect ecological health. For instance, some plant and animal reproductive cycles are tied directly to seasonal flooding, such as frogs needing vernal pools filled by floods or a dry river preventing fish migration. Changes to the existing flow characteristics can change the variety of plants and animals in a watershed as well as the overall health of the system.

Understanding the relationship between flows and ecological health informs policy and management decisions that can have both immediate and long-term impacts on a river system. Decisions about how land is used or water withdraw regulations have individual and cumulative effects on river ecology. Furthermore, having a sense of future flow characteristics is essential to understanding future ecological conditions.

Inherent in predicting future flows is knowing how much water is currently being withdrawn in a watershed and the portion of that withdrawal which is used consumptively. Once withdrawal and consumptive use data are gathered they can be used in watershed models to simulate flow time series for different scenarios.

Water withdrawals represent the human demand for water, whether it comes from a stream or a well, or if it is used as drinking water or for manufacturing. Withdrawals can vary in amount, timing, use, and location, among other factors.

Consumptive use is “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” (Kenney et al. 2009). Knowing how much water is consumptively used in a basin is critically important for understanding flow characteristics as it represents the amount of water that is no longer available for use.

This study aims to provide a variety of future withdrawal and consumptive use scenarios to inform analysis of flow alteration-ecology relationships in the Potomac River basin for the Middle Potomac River Watershed Assessment (MPRWA). To this end, water withdrawals and consumptive use were projected in five-year intervals through 2030, using 2005 as the basis for analysis. Acknowledging that the past does not predict the future, six scenarios were developed that project withdrawals and consumptive use under various conditions.

The six scenarios represent a variety of potential future water use conditions. One scenario represents the base conditions as they are understood today and makes no changes to these conditions in future years. Two scenarios adjust the per capita withdrawal rate for domestic and public supply. The other three scenarios consider water and consumptive use under drought conditions, likely climate changes, and advances in power generation technology.

These six scenarios were used as an input to the Chesapeake Bay Program’s Watershed Model-HSPF (WSM) that was used to develop hypothetical flows that were then used to develop flow-alteration

ecology relationships. For more information on how the scenarios were used, refer to Section 4 – Hydrologic Modeling in the project’s main report.

The limitations in this study are similar to those that most water use studies confront. Nonetheless, they are iterated as a reminder of the need to strive for better data for future studies. Every effort has been made to balance best-available data with the most appropriate data for this study.

The data used in this study was the best-available at the time the study was prepared. There are missing data and incomplete data sets. Some datasets were not at the same scale as other datasets used in the forecasting and analysis. Indubitably, better data will become available in the future, and new technologies may be developed that change the forecasts for the water use sectors. New technology or improved efficiencies in current technologies will likely diminish the rates of change over time.

The data presented in this study are derived from withdrawals at particular points. The study focus is on demand, which drives withdrawals. The discharge locations of withdrawn water were not known, as it would be in a conveyance database. Therefore, the disposal locations were assumed to be the same as the withdrawal locations.

Withdrawal locations in the study are as of 2005. New withdrawal points will be added in the future and some of the 2005 withdrawal points are likely to be eliminated. The 2005 point database, supplied by the basin states (Maryland, Virginia, West Virginia, Pennsylvania, and the District of Columbia), informed the monthly distribution of withdrawals. Just as the points do not change over time, neither does the monthly distribution.

Varying disaggregation methods were used by the states when they prepared the data. For example, some states disaggregated annual data to monthly estimates by dividing by twelve. Other states divided by the number of days in a year, and then multiplied by the days in each month. Still other states had collected data at the monthly time scale and could report actual withdrawals by month.

One of the challenges of working at a geographical scale that spans political boundaries is that different procedures and requirements are in place for data collections. Data are collected using varying criteria. This can make comparing data across regions challenging. With the state-supplied data for point withdrawals, data were collated so that they were comparable. Using the state-supplied data to refine the projections that were made at the county scale allowed greater refinement in monthly withdrawal and specific withdrawal locations. However, the county data used some of the same sources as the state-supplied data. The methodology used in this study would not result in collinearity errors, but collinearity is worth considering in future analyses using these data.

Although assumptions were made based on the best data and information available at the time, these assumptions may be incorrect, and even if correct today, they may change over time.

The following report contains a snapshot of the current conditions in the Potomac watershed (Section 2.2), a review of methods used to estimate current withdrawals and consumptive use (Section 3), the process used for translating county projections to the watershed scale (Section 4), an

explanation of each scenario's assumptions and results (Section 5), and conclusions about future water use in the basin (Section 0). Also included is a discussion of how these conclusions and results compare to other studies that have attempted to answer similar questions (Section 0).

## 2 Water Consumption in the Potomac River Basin

### 2.1 Study Area

The Potomac River basin spans the District of Columbia and parts of four states: West Virginia, Pennsylvania, Virginia, and Maryland. From its headwaters in West Virginia, the Potomac River flows through four distinct physiographic regions including the Ridge and Valley, Blue Ridge, Piedmont, and Coastal Plain, before draining to the Chesapeake Bay.

### 2.2 Current and Projected Population and Land Use

Water consumption is driven by human populations, domesticated animal populations, land uses, and how a society chooses to use the available water. Human population in the Potomac River basin increased 37 percent between 1980 and 2000<sup>1</sup> and is projected to increase another 43 percent from 2000 to 2030. (Figure 1; **Error! Reference source not found.**).

This influx of population has resulted in a rapid change in land use in the watershed. Forested and agricultural land has been developed and future projections show a continued loss of forest and agricultural land (Chesapeake Bay Program, 2009). Agricultural land use was projected to cover 22 percent of the Potomac River basin in 2010, but is projected to cover only 20 percent by 2030 (Figure 2). Forested land was projected to comprise 64 percent of the basin in 2010 and is projected to drop to 62 percent by 2030 (Figure 3).

Infill redevelopment has increased the density of urban lands (Figure 4). Urban land uses are expected to increase from 14 percent in 2010 to 17 percent by 2030 (Figure 5). The urban areas are expanding in concentric rings out from the Washington, D.C. metropolitan area.

Cumulative land use change of a few percentage points may have relatively low ecological impacts on a basin scale, but the location of specific land use changes is of concern. The ecosystem services provided by a large forest in the western portion of the basin, upstream of the Washington area, are great, but a forested stream buffer in Montgomery County, Maryland, just outside of the city, may provide more concentrated ecosystem services because there are more pollutants delivered to that forested stream buffer. The land area alone does not give an indication as to the measure of ecosystems services.

Domesticated animals of all types require a certain amount of water. Livestock and cropland needed to feed livestock can require a substantial amount of water. Accounting for the animal population in the watershed is essential to understanding water use and the subsequent consumptive use.

The 2010 animal population as projected by CBP is shown in Figure 6.

---

<sup>1</sup> 1980 and 2000 population estimates based on U.S. Census data adjusted by assigning census tracks entirely in or out of basin based on census track centroid location. See Supplemental Table 1 for explanation of 2010 and 2030 population estimates.

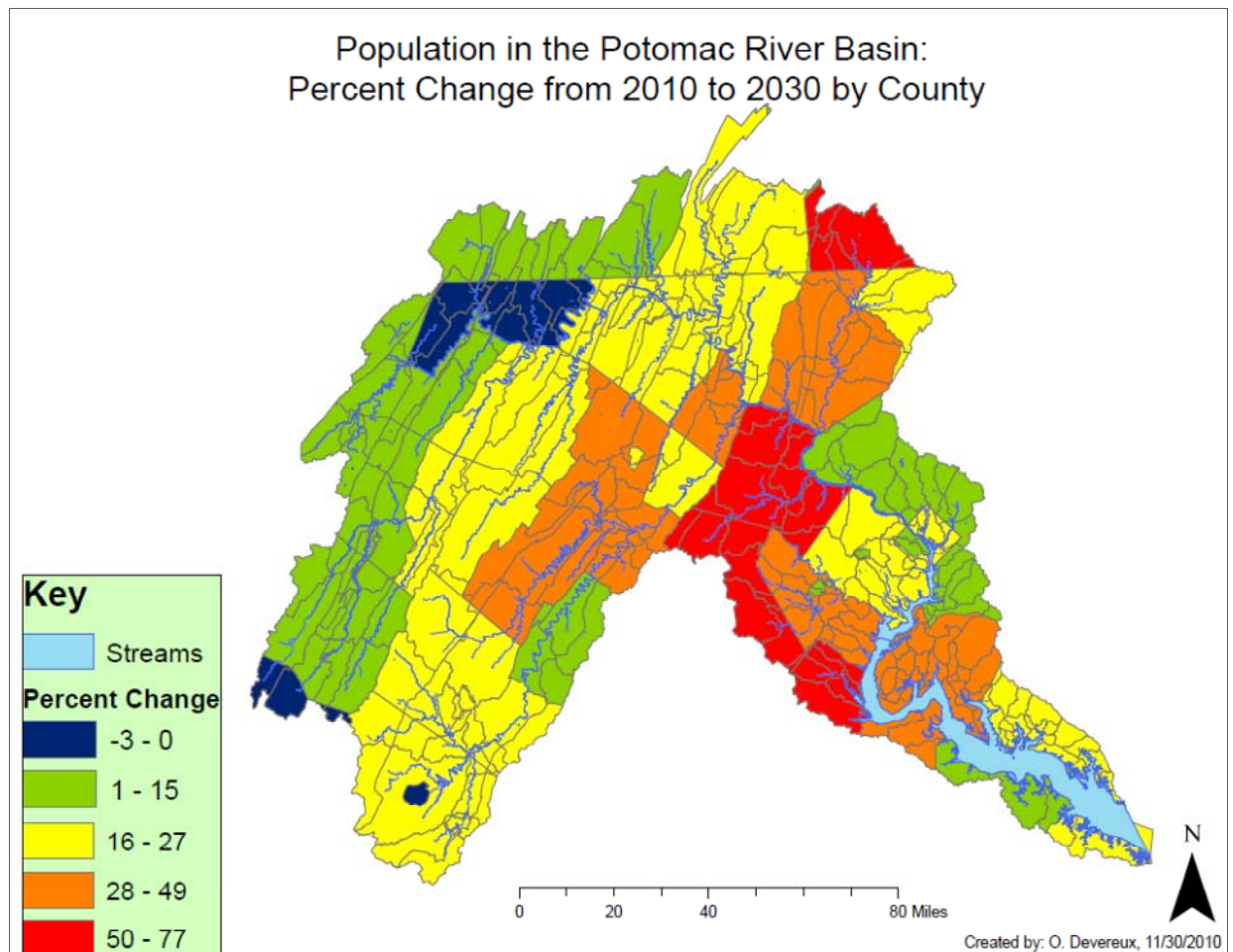


Figure 1. Projected percent change in Potomac River basin population from 2010 to 2030 by county. See Supplemental Table 1 for data sources.

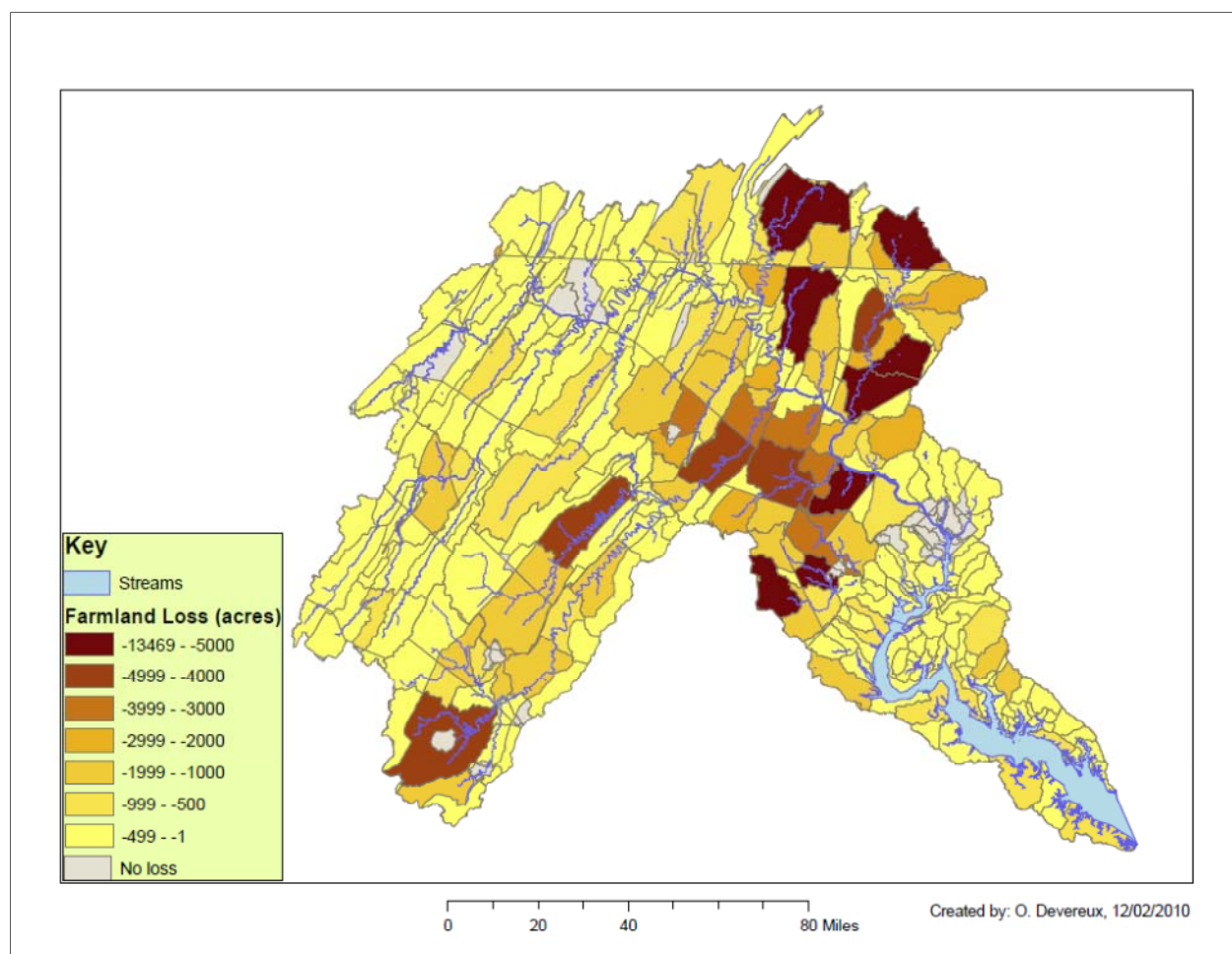


Figure 2. Projected agricultural land use change by river segment between 2002 and 2030.

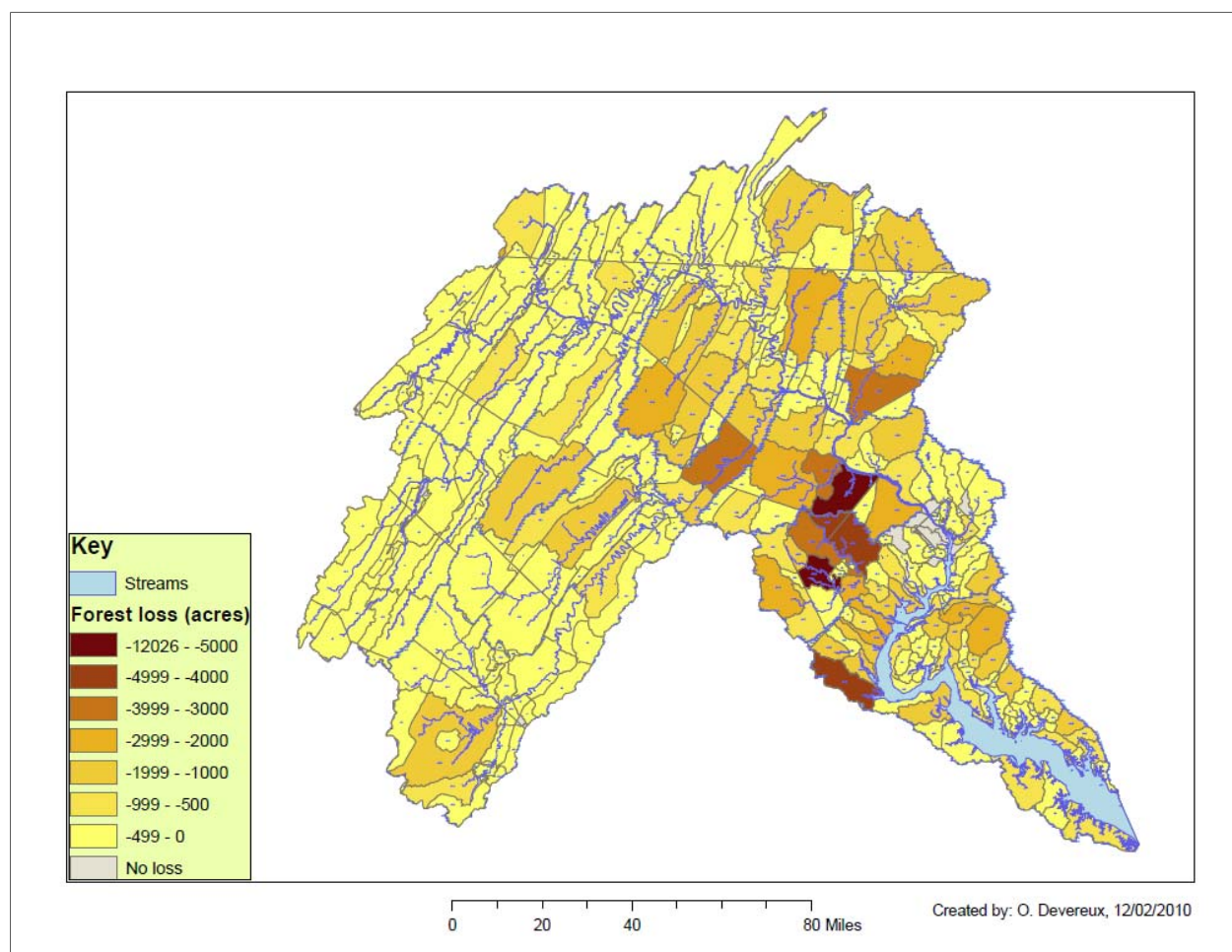


Figure 3. Projected forest loss by river segment between 2002 and 2030.

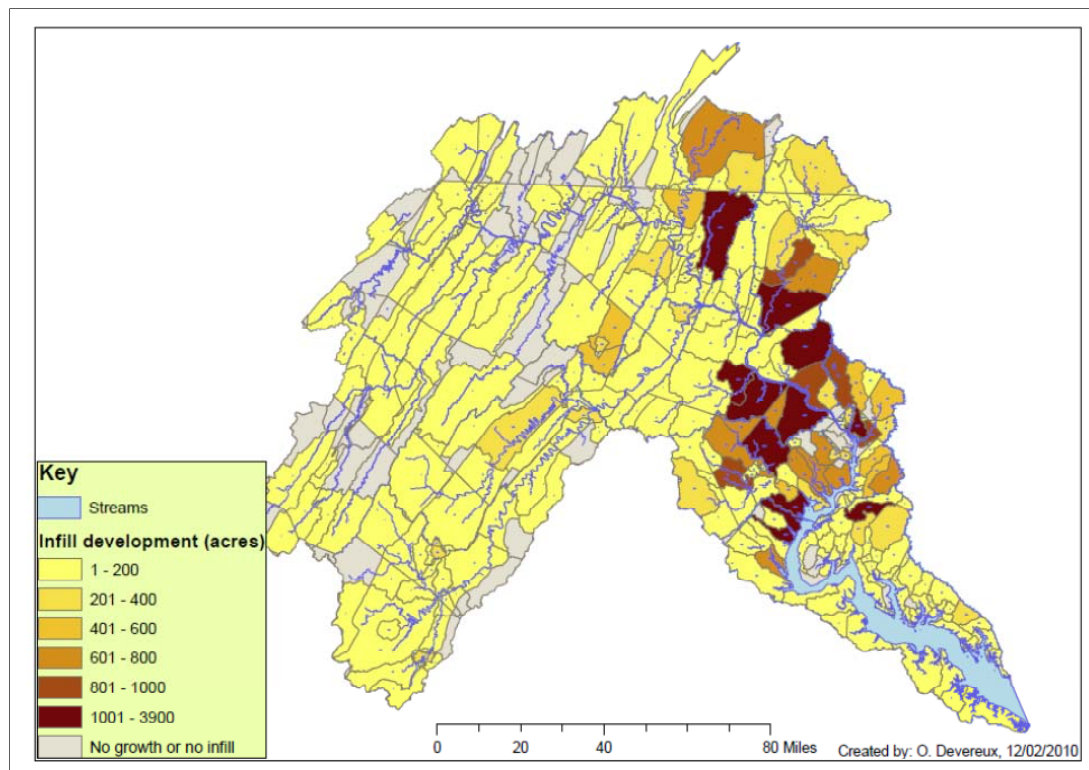


Figure 4. Projected infill redevelopment between 2002 and 2030.

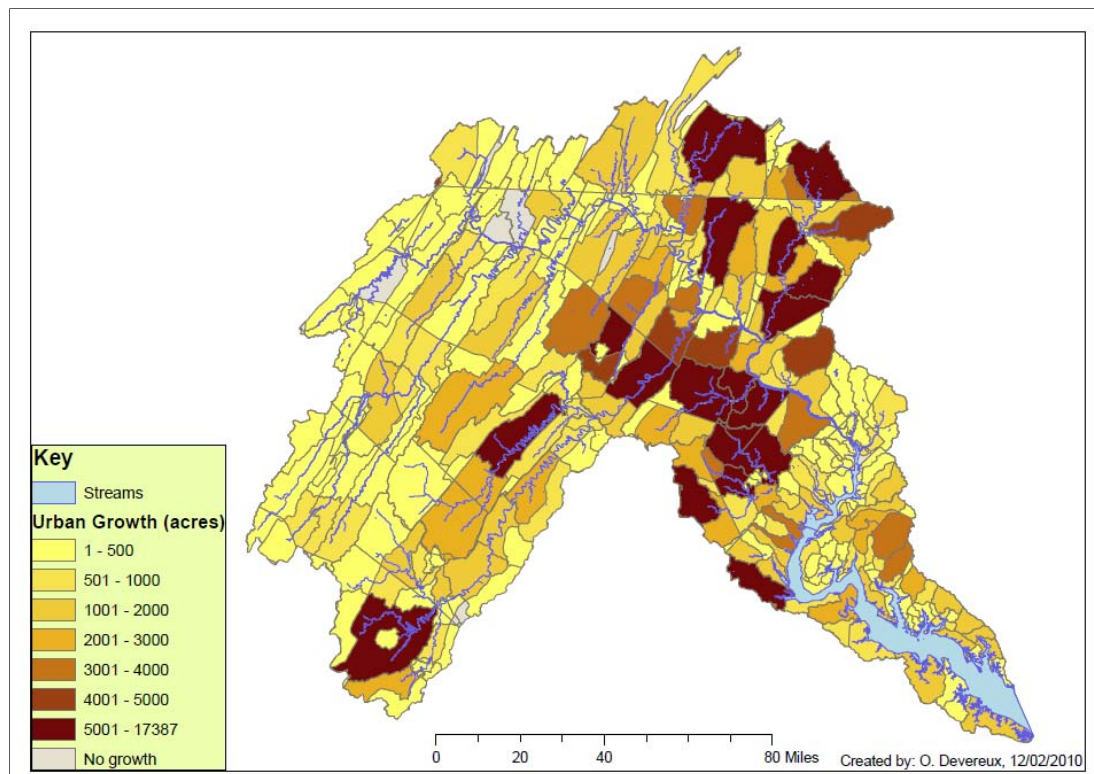


Figure 5. Projected urban land use change by river segment between 2002 and 2030.

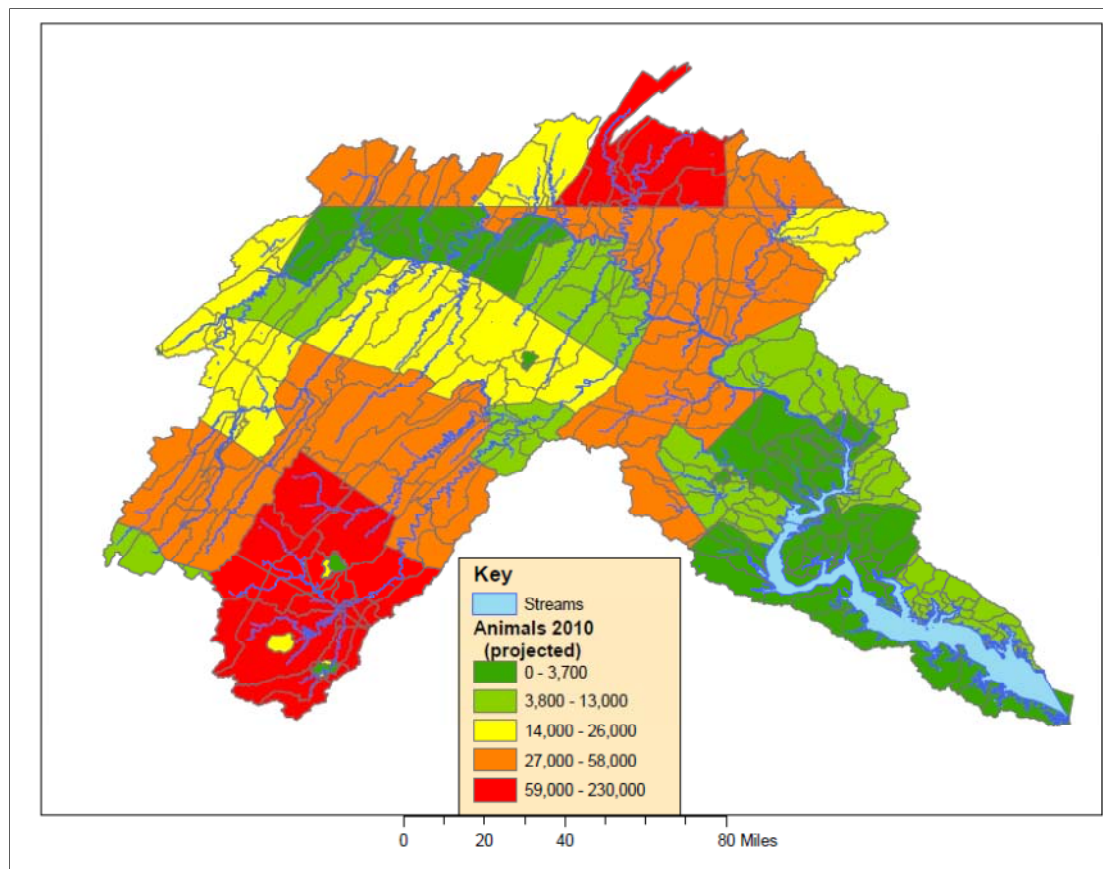


Figure 6. Projected number of animals in the Potomac River basin in 2010.

### 3 Withdrawal and Consumptive Use Projections by Water Use Sector

Water withdrawal estimates in this study are based on USGS county-level withdrawal data that have been attributed to specific withdrawal points in the same county. The specific withdrawal locations were provided by the basin states for 2005 (Figure 7).

Withdrawal and consumptive use data are presented in this study by county and by sub-watershed. Each of these sub-watersheds has an associated USGS flow gage on the mainstem Potomac River. These are noted by distinct colors in Figure 7.

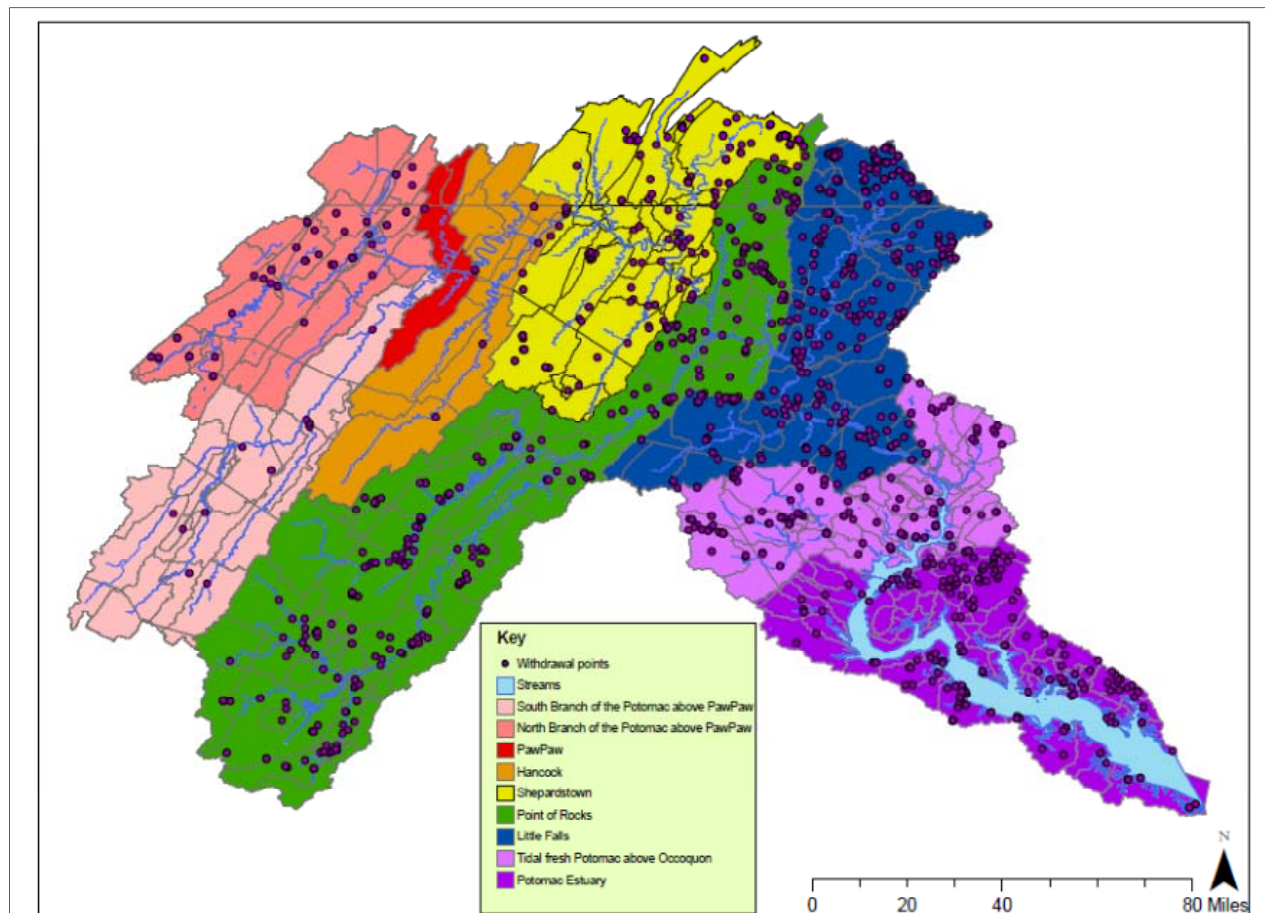


Figure 7. Drainage to gage sites on the Potomac River and location of withdrawal points.

The last flow gage site in the freshwater portion of the Potomac River is at Little Falls. The gage is located one mile upstream of the Washington, D.C. boundary line. In 2009, the annual mean flow was 8,891 cubic feet per second (cfs). According to the USGS, the watershed area draining to the Little Falls gage is 11,560 square miles.

Ultimately, water withdrawals in the basin were divided into six sectors based on the use of the water withdrawn (Table 1). The categories used were:

- domestic and public supply (DP),
- mining (MI),
- thermo-electric power (PO),
- industry (IN),
- livestock (LV), and
- irrigation (IR).

Each sector was considered separately, which allowed for the use of a variety of explanatory variables, thus improving the accuracy of results (Boland, 1997). Interactions among the sectors that could impact available water supply were not considered. Since the scenarios solely considered water demand, not availability, the interactions among the sectors were considered inconsequential for this analysis.

### **3.1 USGS Water Withdrawal Estimates**

Water withdrawal data are estimated for the United States by the United States Geological Survey (USGS) every five years. These data are categorized by sector for each county. The most recent year for which data are available is 2005, which was published in 2009.

Over time, USGS has made many changes to the water use categories it reports. A significant number of changes were made in the 2000 report. Some of these differences are discussed below.

#### *Scale*

The reports previously estimated withdrawals at both the county and watershed scale. In its most recent report, USGS only reported data at the county scale. It is unknown whether it will maintain this format going forward.

#### *Consumptive Use*

Previous USGS reports estimated consumptive use rates based on withdrawal data, but they no longer do so.

#### *Deliveries*

Water withdrawals are sometimes made by public water suppliers, but delivered to another sector. In USGS reports before 2000, delivered water was reported under the sector from which it was withdrawn as well as the sector to which it was delivered. In the 2000 and later reports, delivered water was only reported under the sector that withdrew it, except for deliveries to the domestic water use sector. Deliveries to the domestic use sector were tracked as domestic use.

#### *Domestic versus Public Supply*

The USGS reports inconsistently define domestic and public supply when estimating consumptive use factors. This inconsistency makes it difficult to determine the appropriate consumptive use coefficient for either sector.

For all of these reasons, the withdrawal and consumptive use estimates for the domestic and public supply sectors were combined and reported in this study as a single water use category.

Since 1985, the domestic sector portion of combined domestic and public supply withdrawals ranged from a minimum of 7.41 percent to a maximum of 11.78 percent. In 2005, this figure was 8.41 percent.

In addition to changes in the definitions of some categories, some sectors have been eliminated all together. This is true for the commercial sector, which was eliminated in 2000. These withdrawals appear to be reflected as part of the public supply sector in the 2000 and 2005 USGS reports. This means, for instance, that ski resorts were previously reported as a commercial use but are now reported as domestic or public supply. Water for residential lawns are a part of domestic and public supply water use as well.

The elimination of this category is not considered significant in the Potomac basin because the percent of commercial water use to the total withdrawal amount between 1985 and 1995 was only 1.19 percent.

#### *Thermo-electric Power Industry*

As the awareness of the importance of water use has grown in the thermo-electric power industry, the classifications of water use within that sector have changed. Previous classifications were by fuel type (electric, nuclear, etc.). Currently, water use is categorized by type of cooling (once-through or closed-loop). Because the sector sub-classifications have varied over time, this study only uses the sector totals.

#### *Livestock, Animal Specialties, and Aquaculture*

USGS data for water use in the livestock, animal specialties, and aquaculture sectors were summed to provide consistent, comparable data over time.

Prior to 2005, water use by fish hatcheries was included in the commercial sector; it is now reported in the livestock sector. It is not known if there are or have been significant numbers of fish hatcheries in the Potomac watershed. If there were, then the livestock sector water use may have shown an increase in the 2000 and subsequent reports.

The consumptive portion of fish hatchery water use is quite low because most operations use a flow-through technique, which returns the water to its source. Nevertheless, the effect this might have on the data cannot be evaluated.

#### *Irrigation*

Irrigation includes turf farms and golf courses in addition to the traditional agricultural irrigation of row crops.

### **3.2 Water Use Sectors**

To forecast withdrawal amounts sector definitions must be consistent over time as forecasts are often based on historical data. To facilitate this, the USGS data are classified to make the categories comparable even with the changes discussed above.

Specific sector definitions were used in this study to allow for the use of USGS data through time (Table 1).

Table 1. Water Use Sectors and abbreviations (Templin et al. 2010.).

Sector	Abbreviation	Definition
Domestic and Public Supply	DP	Water withdrawn by public and private water suppliers and delivered to users. Water is typically used for household purposes such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, car washing, and watering lawns and gardens. This category also includes ski resorts.
Mining	MI	Water used for the extraction and on-site processing of naturally occurring minerals including coal, ores, petroleum, and natural gas.
Thermo-electric Power	PO	Water used in the generation of electric power when fossil, nuclear, biomass, solid waste, or geothermal energy are used as fuel.
Industry	IN	Water used to manufacture products such as steel, chemicals, and paper, as well as water used in petroleum and metals refining. Includes water used as process and production water, boiler feed, air conditioning, cooling, sanitation, washing, transport of materials, and steam generation for internal use.
Livestock*	LV	Water used to raise cattle, sheep, goats, hogs, and poultry. Also includes animal specialty water use, which includes horses and aquaculture.
Irrigation*	IR	All water artificially applied to farm, orchard, pasture, and horticultural crops. Turf farms and golf courses are included in this category.

\* The Livestock and Irrigation sectors were later aggregated to form one sector, referred to as “Agriculture.” This is discussed in Section 4.1.

### 3.3 Developing Water Withdrawal Forecasts

Using the 2005 withdrawal data from the USGS as the basis for forecasting future withdrawals, six scenarios were developed to address a variety of potential conditions:

- high domestic and public supply – base conditions/business as usual (high DP),
- medium domestic and public supply (medium DP),
- low domestic and public supply (low DP),
- advanced technologies in the power sector and a new power generation facility (power),
- conditions expected with climate change (climate change), and
- drought conditions (drought).

The scenarios made projections through 2030 at the monthly time-step.

#### 3.3.1 Base Scenario

The base scenario followed “business-as-usual” assumptions when making projections. These projections were then used as a building block on which the alternative scenarios were built. The base scenario had the highest withdrawals rates of all the scenarios (it is also referred to here as the High DP scenario). The other scenarios were developed using the same methodology as the base scenario, but with changes to specific sectors. These alternatives are described in detail in Section 5.

Projections for all sectors were based on the withdrawal locations and did not consider water conveyance from one location to another. The assumption was that water was used at the same location where it was withdrawn.

One exception to this rule was made for the domestic and public supply sector. The intake that provides water supply to Washington, D.C., is located in Montgomery County, Maryland. In order to account for the increased use based on population growth in the city, population projections were added to those of Montgomery County. This is further discussed below.

The projection method used for each sector varied. The method selected depended on the data available to inform the projection.

A summary of the sources of data used in each projection is in Table 3. A discussion of the methods and data sources used for each sector follows below.

#### **3.3.1.1 Domestic and Public Supply**

Domestic and public supply withdrawals are determined by the size of the population and a variety of factors that influence the per capita use rates. These factors can include such variables as climate and lot size.

Additionally, the amount of water used by each person can change over time. One of the most significant historic impacts on domestic water use rates was the passage of the Energy Policy Act of 1992. This Act required low-flow faucets and toilets be installed in new and renovated homes.

##### *3.3.1.1.1 Per Capita Water Use*

The first step in projecting future water use in the DP sector was to calculate the average annual change in per person withdrawals between 2000 and 2005 in each county in the Potomac basin (Figure 8). Data from the 2000 and 2005 USGS reports were used for this calculation. The USGS supplies data for both the total amount withdrawn by county and estimates of the number of people receiving this water.

The change in per person withdrawals at the county scale was calculated as:

$$\frac{WD_{2005}}{WD_{2000}} = rate^5$$

where: WD = average annual withdrawal per person.

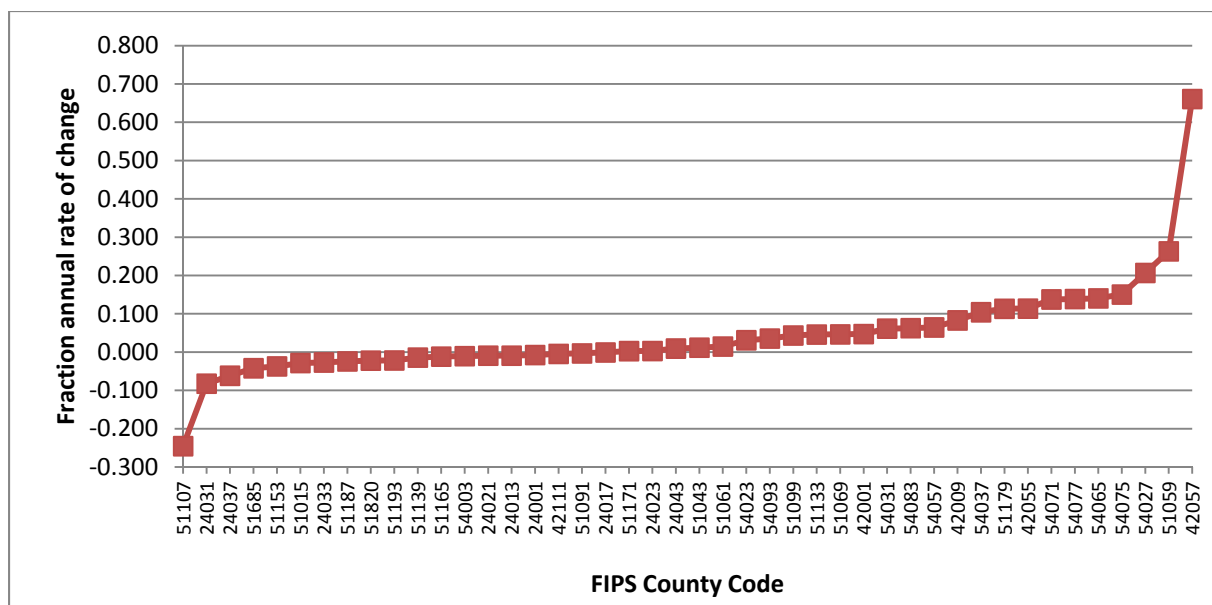


Figure 8. Annual change in water withdrawal per person between 2000 and 2005. The average annual rate of change is 4.38 percent. Data are sorted by the Federal Information Processing Standard code (FIPS), which is unique to each county.

To estimate an annual rate of change in per person water use across the basin, an average of the per person rates for the counties was taken.

Using this method the average annual change in water use did not decrease as anticipated, but rather increased by 4.38 percent per year between 2000 and 2005. On average across counties, the 2005 withdrawal per person was 0.0001 MGD (or 108.22 gallons per day).

The increase used in this scenario can be compared to a previous estimate of a 1.10 percent reduction in water use in the Washington metropolitan area (Hagen et al. 2000).

At the county scale the greatest decreases were seen in Loudon County, Virginia (-20 percent); Montgomery County, Maryland (-8 percent); and St. Mary's County, Maryland (-6 percent). The greatest increases were in: Fulton County, Pennsylvania (66 percent); Fairfax County, Virginia (26 percent); and Hampshire County, West Virginia (21 percent).

Data anomalies are evident, such as with Fulton County. An alternative scenario made corrections for these.

Where large homes are built with expansive lawns, it is not uncommon to see household water use exceed historical levels, even with the implementation of the Energy Policy Act. An increase in areas where large homes are built with lawns is not unreasonable.

Roy et al. (2005) found that an increase in water withdrawal was expected in the Washington, D.C. region when projecting out to 2050. Roy et al. postulate that improvements in efficiency have not

reached a maximum and while some areas of the United States exhibit trends of increasing efficiency, not all areas do.

When reviewing the county-level water use changes it is important to remember that this study assumes that water is consumed in the same county as it is withdrawn. As mentioned above, the exception to this is for Washington, D.C. Since the population in D.C. was projected to grow over time, its population was added to that of Montgomery County for the purpose of calculating the withdrawal per person.

Known large public water suppliers that serve populations in counties other than or in addition to the county where the intake is located include:

- Fairfax Water – intake in Loudoun County, Virginia; serves portions of Fairfax County, Loudoun County, City of Alexandria, Prince William County, and City of Fairfax, all in Virginia
- Washington Aqueduct – intake in Montgomery County, Maryland; serves portions of Washington, D.C., and Arlington County and Falls Church, Virginia
- Washington Suburban Sanitary Commission – Intake in Montgomery County; serves portions of Montgomery and Prince George’s counties in Maryland, and provides limited amounts to Howard and Charles counties, also in Maryland.

#### *3.3.1.1.2 Water Use Projections*

To project water withdrawals for domestic and public supply beyond the USGS’ 2005 estimate, each county’s 2005 per person withdrawal rate was increased by 4.38 percent each year through 2030. These new per person rates for each county were then multiplied by the county’s population for each projection period through 2030.

#### **3.3.1.2 Thermo-electric Power**

To project future water withdrawal rates in the PO sector through 2030, the national average change in electric power generation was applied to each county’s 2005 USGS withdrawal estimate. This rate was determined using the U.S. Energy Information Administration (US-EIA) projections. The US-EIA’s 2010 projection for the national average annual change for the period from 2008 to 2035 was 0.88 percent (US-EIA 2009).

Using these data, the future water withdrawals of the thermo-electric power industry were calculated for each county as:

$$WD_{T_2} = WD_{T_1} \times (1 + 0.0088)^{(T_2 - T_1)}$$

where WD = withdrawal and T = withdrawal year.

#### **3.3.1.3 Industry**

The average annual change in industrial water use was determined using the US-EIA national projection for non-manufacturing shipments. The non-manufacturing projection was used because the manufacturing category includes mining, which is treated as a separate sector in this study.

The average annual increase in non-manufacturing shipments was estimated at 1.37 percent (US-EIA 2009). This rate was applied to the 2005 USGS water withdrawals and projected through 2030. Thus, future withdrawals were calculated as:

$$WD_{T_2} = WD_{T_1} \times (1 + 0.0137)^{(T_2 - T_1)}$$

where WD = withdrawal and T = withdrawal year.

#### 3.3.1.4 Mining

The average annual change in coal and gas production was calculated using the US-EIA projections for the northern and central Appalachian regions. Oil production was not included in the calculation because there is little oil drilling in the Potomac basin.

The proposed drilling of gas in the Marcellus shale, commonly referred to as “fracking,” may have been considered by US-EIA when their projections were made. Marcellus shale is not primarily located in the Potomac River basin, and if considered by US-EIA, the rate of change used in this study may be high.

There is sand and gravel mining in the Potomac basin. However, the methods of mining vary greatly, as does the resultant water use. For mining and quarrying of non-metallic minerals, except fuels, the minimum water use is 30 gallons per short ton and the maximum is 997 (Lovelace 2009).

Projections specifically for the sand and gravel mining industry were not readily available. The USGS 2006 Minerals Handbook does not explicitly offer growth projections for this industry, but does state that the sand, gravel, and quartz-glass mining is likely to see a decrease in production as population grows.

Therefore, the projection for the mining sector was based solely on coal and gas production projections. The annual rate of change for coal and gas was 0.30 percent (US-EIA 2009). This rate of change was applied to 2005 USGS withdrawals in the mining category and projected through 2030.

#### 3.3.1.5 Irrigation

To project the amount of water withdrawn for irrigation, the area of crops and the fraction of these that are irrigated must also be projected. Additionally, the method of irrigation influences the amount of water used. Irrigation methods have changed radically over the past 25 years from sprinkler and flood techniques to drip irrigation. Innovations will likely continue in the future.

Many factors inform decisions to adopt irrigation. Some of these include: federal cost-share programs, precipitation, and policies that inform behavior changes when making irrigation-related decisions. Several years ago, Natural Resource Conservation Service (NRCS) received additional money for irrigation improvements (Jarrett 2010). A noticeable increase in irrigated land resulted.

In addition, the number of applications to state cost-share programs increases in the year following a drought (Eberly 2010). For example, applications rose in 2003 and 2008 – years in which there were agricultural droughts in Maryland.

Rather than predict human behavior or public policy, the average ratio of irrigated to total agricultural acres in each basin state was used. Data are available from a survey conducted by the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). NASS' Farm and Ranch Irrigation Survey (FRIS) is conducted in years ending in three and eight and estimates the number of irrigated acres. NASS also conducts the Agricultural Census in years ending in two and seven. The Agricultural Census provides data on the number of acres in agriculture.

FRIS irrigation data did not include turf grass production. Turf grass is grass grown for resale for landscaping. The FRIS data also did not include golf courses, which also were included in the irrigated land use. Therefore, the projections were based on an increase in irrigated row crops, not turf grass farms or golf courses.

The FRIS data are only available at the state scale. If there was significantly more irrigation in one part of a state, the data may be skewed. This was likely true for Maryland where the Eastern Shore has sandy soils requiring more irrigation than areas in western Maryland. Therefore, the average of Pennsylvania, Virginia, and West Virginia irrigation rates was used for Maryland (Table 2, Figure 9). In Figure 9, the average used for Maryland is reflected in the line labeled "Maryland Rev."

The fraction of irrigated land to total agricultural land was calculated from USDA NASS Agriculture Census data. This fraction was multiplied by the amount of agricultural land reported in the Chesapeake Bay Program's land use estimates (Phase 5.1) for historical years at the county scale. The agricultural land uses tracked by the CBP include: high till with manure, low-till with manure, high till without manure, nutrient management high till with manure, nutrient management high till without manure and nutrient management low till.

For years after 2008, the average of the ratio of irrigated to agricultural land in the years 1998, 2003, and 2008 was used (Table 2). Two of these years experienced above normal annual mean stream flow and one experienced normal flows (USGS 2010).

Table 2. The average of irrigated to agricultural land for each Potomac basin state, calculated from USDA-NASS data.

State	Average Irrigated /Agricultural Land
Maryland	0.097 (The state average of 0.302 was not used.)
Pennsylvania	0.105
Virginia	0.121
West Virginia	0.066
Basin Average	0.093

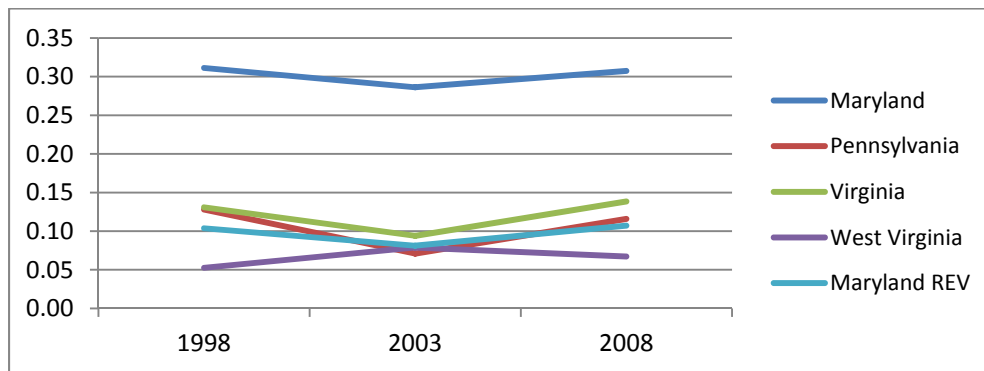


Figure 9. Ratio of irrigated to total row-crop land, using USDA-FRIS data. “Maryland REV” is the average of neighboring state ratios. This was done to avoid over-representation by Maryland’s Eastern Shore, which has different hydrological characteristics influencing irrigation.

The amount of irrigated land in the basin increased by approximately five percent each year. This can be compared to the national average in the five-year period from 2003 and 2008. Nationally, the amount of irrigated land increased by 4.6 percent each year. In contrast, the rate of change between 1998 and 2002 was 4.9 percent per year. The rate of change between 1993 and 1998 was 7.8 percent.

In many counties, the amount of irrigated and total agricultural land dropped precipitously after 2007. This trend is an artifact of the CBP land use data. The reason for this change is not known. The same data set is being used throughout the Middle Potomac study, so it was used here for consistency.

This same trend may also be observed in the withdrawal data. For example, in Frederick County, Maryland, the projected irrigation withdrawal follows the same trend as the projected irrigated land area (Figure 10). Because this report focuses on future projections of 2010 and later and does not use the trend between 2005 and 2010 in a predictive capacity, the study’s results are not impacted by this known error.

The amount of water used for irrigation in the Mid-Atlantic region is approximately 0.64 acre-feet of water for an average rainfall year (Jarrett 2007) or 207,148 gallons per acre. This amount was multiplied by the projected number of acres of irrigated land in each year to estimate water withdrawals through 2030.

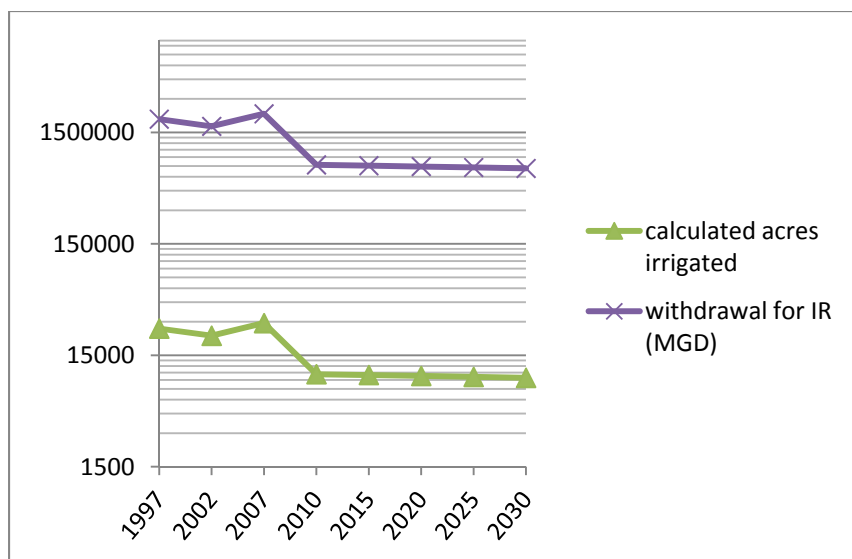


Figure 10. Projected withdrawal and irrigated acres of crop land in Frederick County, Maryland.

### 3.3.1.6 Livestock

Projecting livestock withdrawals depends on the amount of water used per animal type and the anticipated number of these animals. Estimating both the number of animals and the associated water use presents significant challenges given the number of variables and unknown factors.

Multiple methods for estimating both figures were tested for this study. Ultimately, animal units - 1,000 pounds of live animal - and an average water use across all animal types were used. These methods as well as some of the ones rejected are explained in the following section.

#### 3.3.1.6.1 Number of Livestock

To determine the number of livestock in the basin an aggregate number of animal units was calculated regardless of animal type. An animal unit is defined by NRCS as 1,000 pounds of live animal.

Animal weights were taken from Devereux (2009) and are the same as those used by CPB. CPB categorizes animal types into 13 groups, including two types of goats, three types of cows, two types of hogs and pigs, four types of poultry, and horses, sheep and lambs.

To project the number of animals units through 2030, the ratio of animal units to acres of agricultural land in 2010 for each state was calculated (Figure 11). Then, this ratio was multiplied by the projected agricultural acres to estimate the future number of animal units. State-level ratios were used to avoid spatial auto-correlation and ensure that no one county was unduly influenced by short-term patterns.

The agricultural land use and animal projections are from CBP and were used in Phase 5.1 of the Bay Program's Watershed Model. CBP's animal numbers were the NASS data with estimations to fill data gaps. These estimations appear in Devereux 2009.

#### *3.3.1.6.2 Other Possible Livestock Projection Methods*

One possible way for predicting future locations of animal populations is by anticipating locations of vertical integration facilities and animal processing plants in the future. This would be useful, for example, if a hog processing plant was to move into a county. This could cause the county's hog population to move from zero to thousands in a short period of time.

Some factors in locating processing plants include proximity to animal growing operations, proximity to inexpensive labor, and ability to dispose of by-products inexpensively. Each of these factors is difficult to predict independently and together the challenge of prediction is even greater. Thus, projections were not based on individual animal types, but rather an aggregate number of animal units regardless of type.

Whether or not agricultural land area could be used as a predictor of animal population was also explored initially. It was hypothesized that as the number of acres of agricultural land decrease, the number of animal units would remain the same, thus increasing the concentration of animals.

The ratio of animal units to agricultural land was graphed over time for each FIPS code (Figure 11). No pattern of increasing concentration was discerned in the Potomac basin states. Rather, certain FIPS became more concentrated in the near term and less concentrated in the long term as agricultural land was converted to other land uses. Thus, a county-based ratio of animals to agricultural land use was not used.

One source of error in these estimations could be the known problem with the Version 5.1 land use data. (Phase 5.1 was the most recent land use with projections that was available when this analysis was initiated.) As previously mentioned, there is an increase in agricultural land in CPB's 2007 estimate from the previous years.

Even with more reliable land use data, a model that could capture the changing concentrations of animals on agricultural land would need to include multiple variables that are beyond the scope of this livestock water withdrawal projection.

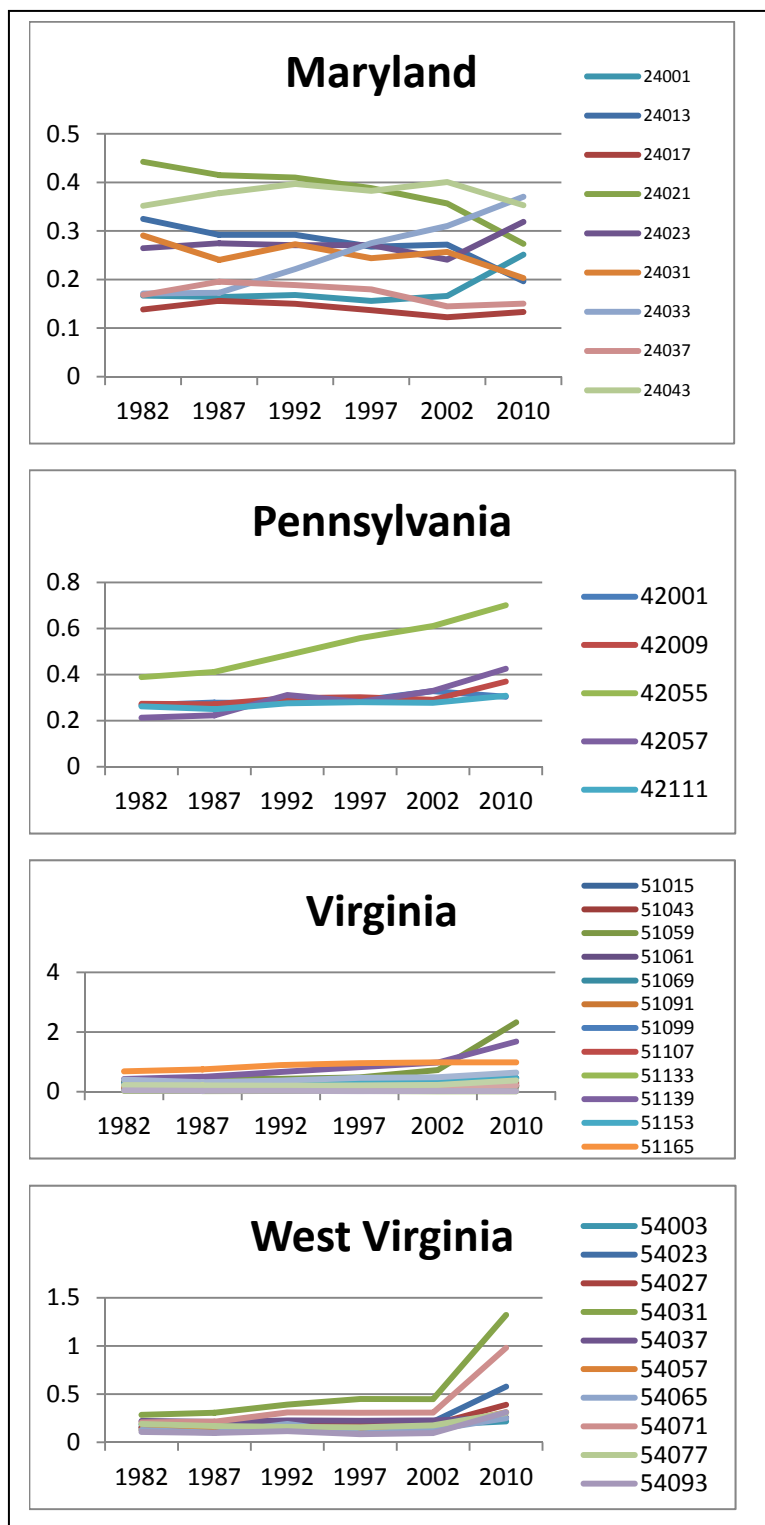


Figure 11. Animal units per agricultural land area by FIPS code from 1982 through 2010.

#### 3.3.1.6.3 Water Use Methods

Water use varies by animal type. For instance, bovines use far more water than goats.

The method for projecting livestock water use is the same procedure that USGS used in its *Estimated Use of Water in the United States in 2005*. Here, the animal units by type, as reported by NASS, are multiplied by a water-use coefficient for each animal type. This results in a total livestock withdrawal by FIPS code.

For the purposes of this study, the withdrawal per animal type was averaged across all types. This was done because the number of animals in the basin was estimated by animal unit as described above. The resulting withdrawal per animal unit was  $3.282 \times 10^{-5}$  MGD. This figure was multiplied by the projected number of animal units through 2030. Using this method, an estimate of 2005 livestock water use in the basin was compared to the 2005 USGS withdrawal data used in this study. A poor relationship between the two results was found. Many factors contributed to this:

- Many withdrawals by the agricultural sector are not required to be reported, nor are they always required to have permits. Each state has a volume threshold before a permit is required. Some agricultural operations fall below these thresholds, which can be as high as 100,000 gallons per day.
- This study's method of aggregating by animal unit. If there was a substantial change in the distribution of animal types in the basin over time, then the future predictions of livestock water use could be off significantly.
- The difference in the figures reported directly by NASS and the Chesapeake Bay Program's version of this data. NASS is required to keep certain portions of its data confidential. Therefore CBP has to use estimation methods to fill in data gaps, explained in Devereux 2009, which could introduce error. Moreover, NASS data are notoriously erroneous due to low survey response rates.
- In spite of the fact that 13 unique animal types are considered by the CBP data, none are aquaculture. This is an issue because the USGS water use estimate for the livestock sector includes aquaculture. Including aquaculture could decrease the water use per animal unit.

The other method tested calculated the withdrawal per animal unit in 2005 and multiplied this figure by the projected number of animal units. Using this method, a third of the FIPS had withdrawal rates well above any estimation of animal water use found in the literature. This method was not used.

Clearly, the available methods for projecting withdrawals in the livestock sector presented many challenges. But given the issues discussed above, in combination with the fact that livestock make up less than one percent of all water withdrawals in the basin, the method of multiplying the number of animals by the water use coefficient was deemed acceptable.

### 3.3.2 Base Scenario Summary

The projections for the base scenario were based on a combination of forecasts by experts in the different sectors, historical data, and on land use projections. The resolution of the forecasted data was not ideal, but it was the best information available at the time. A summary of information used in each sector's projection along with the spatial and temporal resolution of those data are in Table 3.

Table 3. Data sources and rate used to project future withdrawal amounts.

Sector	Data Source	Spatial Scale	Temporal Scale	Water Withdrawal Annual Rate of Change
Power	US-EIA	National	Annual from 2008-2035	0.88%
Industrial	US-EIA	National	Annual from 2008-2035	1.27%
Mining	US-EIA	Northern and central Appalachian regions.	Annual from 2008-2035	0.30%
Domestic and public supply	CBP population projection	County	Decadal based on 2000 and 1990, interpolated to 5-year intervals	4.38% per person
Irrigation <sup>1</sup>	USDA-FRIS	Available at county scale. The national rate was calculated to get a change in the amount of irrigated land.	Rate of change is from 1998-2008.	Results ranged from 6 to 12% change in the ratio of irrigated land to total agricultural land.
	USDA-NASS	Available at county-scale. Calculated at state-scale because of data variability.	Years ending in 2 and 7.	No change in amount of water used - 0.64 acre-feet in an average rainfall year.
	CBP land use (HWM, LWM, HOM, NHI, NHO, NLO)	Available at the "land river segment," calculated at county level.	Annual until 2010, projected at decadal scale through 2030.	Projected amount of future agricultural land in the basin. USDA-FRIS ratio was applied to determine number of acres irrigated.
Livestock	USDA-NASS animal numbers (processed by CBP)	County level, calculated at state scale because of data variability.	2010 and projected forward by decade. Based on historical data in five-year increments from 1982.	$3.282 \times 10^{-5}$

	CBP land use	Available at “land river segment,” calculated at county level.	Annual until 2010, projected to decadal through 2030.	Rate of change based on change in acres of agricultural land.
--	--------------	--	---	---

<sup>1</sup>Water use rate remained the same; number of acres in irrigation was projected.

### 3.4 Estimating Consumptive Use Fraction of Water Withdrawal

The second component to the base scenario is determining the portion of the withdrawal that is consumptively used. Consumptive use is defined as “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” (Kenney et al. 2009).

Estimating the amount of water consumptively used in the basin is important for determining how much water is being permanently extracted from the system and is no longer available for use, whether for humans or for ecological needs.

Until 1995, the USGS national water use reports estimated consumptive use by sector. Now that this is no longer done, a method had to be devised for estimating the consumptive use in 2005 to accompany the 2005 withdrawal data and future projections.

In order to project consumptive use beyond 1995, a coefficient was calculated by averaging the fraction of water withdrawals that was consumptive for each sector in the 1985, 1990, and 1995 reports. These figures are shown in Table 4.

Table 4. Consumptive use fraction of total water withdrawal (Shaffer and Runkle 2007).

Sector	Year	Percent of water withdrawal that is consumptive
Domestic and public supply	1985	13
	1990	11
	1995	9
	<i>Average</i>	<i>11</i>
Industrial	1985	9
	1990	9
	1995	10
	<i>Average</i>	<i>9</i>
Irrigation	1985	92
	1990	85
	1995	68
	<i>Average</i>	<i>82</i>
Livestock	1985	60

	1990	87
	1995	86
	<i>Average</i>	78
Mining	1985	12
	1990	19
	1995	11
	<i>Average</i>	15
Power	1985	6
	1990	1
	1995	1
	<i>Average</i>	3

Several counties withdraw from freshwater sources, but discharge downstream into saline waters. These downstream discharge locations are often in a different county. This is primarily true for the domestic and public supply and industry sectors. For example multiple jurisdictions rely on the Potomac River as a source of drinking water, but send their wastewater to the District of Columbia's Blue Plains Wastewater Treatment Plant which discharges into the saline waters of the Potomac Estuary.

In these instances, the consumptive use portion of a withdrawal was set to 100 percent. This was the case for the Maryland counties of Prince George's, Montgomery, St. Mary's, and Charles; Fairfax County, Virginia; and the District of Columbia.

## 4 Apportioning Water Withdrawals to the River-Segment Spatial Scale and Monthly Time Scale

One way of assessing the impact of water withdrawals on the environment is to use the Chesapeake Bay Program's Watershed Model-HSPF (WSM). This model can compare flows in each of the 487-modeled segments of the Potomac River and its tributaries. It can also compare various withdrawals, rainfalls, land use, and other parameters among scenarios.

For the model to be used in this way, water withdrawals and consumptive use must be represented spatially by river segment. Therefore, data were transformed from a broad scale to a fine scale, both spatially and temporally. Data were converted from county scale to specific withdrawal points using data supplied by each state in the Potomac basin. Once at the point scale, the withdrawals were aggregated by river segment.

### 4.1 Developing Water Use Projections at the River-Segment Scale

Both the point data supplied by the states and the USGS county-scale data have limitations (Table 5). The USGS data were most appropriate for projecting future water withdrawals. The state data were useful for identifying point locations and withdrawal data on a monthly time scale. It should be noted that the USGS national data were generally comprised of the state-reported data that were in the point data set. However, USGS transformed the state-reported data for purposes of their analysis, which made them no longer directly comparable.

Inherent in this apportionment was the assumption that 2005 was a representative year both in terms of withdrawal rates and in terms of the distribution of those withdrawals over the months. USGS stream flow records indicate that 2005 was a normal year (MD-DE-DC Water Science Center 2012).

Table 5. Water withdrawal data resolution.

Data source	Spatial Resolution	Temporal Resolution
USGS	County FIPS code	Years ending in zero and five
Maryland, Pennsylvania, Virginia, West Virginia	Point, many of which were from the address of the reporting site or the county centroid.	Monthly in 2005. Some monthly data were determined by dividing the annual withdrawal by 12.

The sectors in the state-provided data were not a direct match with those in the USGS data set. Particularly, the state data had a sector called "Other." In order to compare these to the USGS sectors they were individually examined and classified in the appropriate sector (Table 6). Additionally, the state data were reclassified so that commercial and water supply withdrawals were accounted for in this study's domestic and public supply sector. To make the USGS data

comparable to the state data, the livestock and irrigation projections were combined into a single “agriculture” sector.

Table 6. Sector reclassification of state and USGS data.

State-reported data sectors	USGS data sectors	State-reported data were reclassified into USGS sectors
Agriculture	Livestock Irrigation	USGS Livestock and Irrigation sectors were summed to match state Agriculture sector.
Industrial	Industrial	Direct relationship
Mining	Mining	Direct relationship
Water supply	Domestic and Public Supply	State water Supply and Commercial sectors were summed to match USGS Domestic and Public Supply sector.
Commercial		
Power	Power	Direct relationship
Other	—	The nine items in this category were researched and reclassified based on business or use type.

The state-reported data included latitude and longitude information for each withdrawal point. This allowed for the creation of a crosswalk table between the county data and the state point data. Thus, the crosswalk between the county-level data and the point data was used to downscale the USGS withdrawal data.

Uncertainty is introduced with any method for scaling data from the county level to individual withdrawal points. In this study, a statistical method was employed for this down-scaling. The dynamical approach of nesting a point data set into the county data and assuming stationarity was used.

To apportion the projected county water withdrawals to specific withdrawal points, the rate of change of withdrawals in each county by sector was calculated as:

$$\frac{WD_{T_2}}{WD_{T_1}} = rate^{(T_2-T_1)}$$

where: WD = withdrawal and T= withdrawal year.

This rate of change was then applied to each withdrawal point in the state-provided data set at the monthly time step. The following equation was used:

$$WD_{T_2} = WD_{T_1} \times (1 + rate)^{(T_2-T_1)}$$

where WD = withdrawal and T = withdrawal year.

Thus, the future projections using the state-provided point data follow the same slope as the projections using the USGS county-scale data.

For instances where there was no reported withdrawal for a particular sector in the USGS data, the calculated rate of change was zero. There were some points that had a withdrawal rate greater than zero in the state-reported data set, but the sector had no reported withdrawals in the USGS data for that county. In these cases, the rate of change was set to the average of the nearest neighbors in the same sector.

Additionally, if in the state data a withdrawal rate in a particular month of 2005 was zero, then that month would always have a zero withdrawal rate going forward.

#### **4.2 Developing Consumptive Use Projections at the Point Scale**

Using the consumptive use projections generated at the county level for each sector, a consumptive use factor was calculated as:

$$\frac{CU_{T_1}}{WD_{T_1}} = \% \text{ consumptive}$$

where: CU = consumptive use, WD = withdrawal, and T = withdrawal year.

This consumptive use factor was multiplied by the sector projections that were transformed to the point scale. This was done independently for each 5-year projection period.

Each point's withdrawal was projected through 2030. No new points were added over time. Accordingly, where there was no withdrawal point in 2005, it was assumed that there would never be a withdrawal in the base scenario.

For example, if there was no power withdrawal in a given county, then it was assumed that there would never be a power sector withdrawal in that county. If, however, there was a withdrawal for power in 2005, then it would have been assumed that the withdrawal would change by the calculated rate over time through 2030.

In actuality, it is likely that some points will be eliminated over time and others will be added.

#### **4.3 Quantifying Withdrawals by Source Type — Groundwater and Surface Water**

The state-provided data set separated withdrawals by their source, as either surface water or groundwater. This information was not used explicitly in this study, but was maintained when the withdrawal and consumptive use projections were calculated for information purposes.

In the point-scale projections, the proportion that was from groundwater in 2005 was held constant over time. The amount calculated as consumptive did not depend on whether the withdrawal was from ground or surface water.

This level of information was not available in the USGS data. The assumptions used in the projections performed at the county scale were based on water demand by sector and did not consider where the water was withdrawn.

#### **4.4 Inter-basin Transfers and Water Conveyance**

Inter-basin transfers and transfers among counties occur in the Potomac River basin. However, information on these transfers was not included in the data sets used for this study. Detailed information on water use and transfers in the Washington, D.C., metropolitan area is available in ICPRB's 2010 report on metro area water demands (Ahmed et al. 2010).

To calculate where water was withdrawn, conveyed, and ultimately discharged, additional data would have been required that was not readily available. Data to calculate conveyance is likely available in National Pollutant Discharge Elimination System (NPDES) permits. Reviewing each NPDES permit was beyond the scope of this project.

For future studies, it is recommended that conveyance data be included. Were conveyance data available, then additional factors could have been examined. For example, conveyance data could be used to calculate withdrawals per household. This could be used in conjunction with seasonal demand information and future population projections to develop a more detailed understanding of future withdrawals.

Another conveyance cycle that was not considered exists in a less urban area. Estimates of groundwater withdrawals for farm irrigation, demand based on cropland acres and crop type, and consumptive losses have been calculated. With additional data, infiltration and evapotranspiration, recharge of groundwater, and ultimately the amount available to be withdrawn from groundwater could have been analyzed.

In this study, it is not known 1) if disposal is to surface or groundwater, 2) how much is lost to conveyance (leaky infrastructure), or 3) where discharge is occurring.

## **5 Future Water Withdrawal and Consumptive Use Scenarios**

Water resources planning involves making assumptions about plausible future conditions (for example, temperature, precipitation, land use, population, human adaption, and technological change). The exact assumptions made are most likely determined by the available information. While science is not capable of predicting the exact magnitude of changes under various conditions, methods are available to characterize a range of possible changes.

In order to present a set of possible future withdrawals in the Potomac basin, multiple water scenarios were designed to test various “what-if?” conditions (Table 8). Two scenarios looked at the rate of change in per capita use in the domestic and public supply sector. Three other scenarios were examined based on changes likely to be seen under climate change, during a drought period, and in power sector withdrawals.

All the scenarios produced total withdrawal and consumptive use amounts at five-year intervals from 2005 through 2030, except for the Climate Change and Drought scenarios which only made single-year forecasts for 2030. These projections were developed at the monthly time scale. Results are available at both the county and river-segment scale (Table 17 and Supplemental Table 2 through Supplemental Table 7).

Table 7. Summary of assumptions for future water withdrawal and consumptive use scenarios.

Name	Scenario Basis	Changes
High DP	Base conditions	No changes. Used methods described in previous section.
Medium DP	High DP	Changed DP assumption: 1.82% annual growth in withdrawal per person.
Low DP	High DP	Changed DP assumption: 0% growth in withdrawal per person.
Power	Medium DP	New power plant in Frederick County, Maryland. Decreased withdrawals at Dickerson, Mirant, and R. Paul Smith plants from retrofits. Increased consumptive use rates at for Dickerson, Mirant, and R. Paul Smith plants.
Climate Change	Medium DP	Applied IPCC projections: Global temperature change – +0.4°C by 2030 Variable precipitation patterns, resulting in changes in human decision making. Amount of irrigated land increased by 50%. 0.8% increase in power demand during summer months. 5% increase in domestic and public supply sector demand in summer months.
Drought	Medium DP	Domestic and public supply sector withdrawals increased by 15.21% in April through August. Power sector withdrawals increased by 6.15 % in May through September. Irrigation sector withdrawals increased by 283.9% in May through September.

Each of these scenarios is described in detail, along with its results, in the following sections.

### 5.1 High Domestic and Public Supply Scenario (High DP)

The high DP scenario used the data and projection methodologies outlined in Section 3.

#### *Results*

Analysis of this scenario showed that the power sector, followed by the domestic and public supply sector, had the largest total withdrawal amount over the forecast period (Figure 12). The domestic and public supply sector had the largest fraction of its withdrawal used consumptively. The power sector followed. Agriculture (sum of livestock and irrigation sectors), industrial, and mining each comprised less than five percent of both withdrawals and consumptive use.

A complete table of results is in **Error! Reference source not found..**

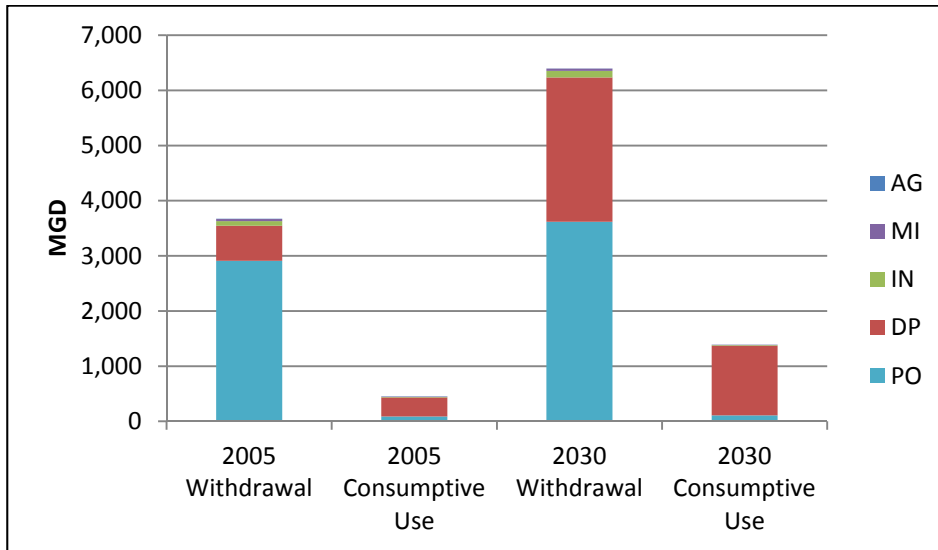


Figure 12. Water withdrawal and consumptive use by sector in 2005 and 2030. Units are in million gallons per day.

All of the sectors except mining depended more heavily on surface water than groundwater (Figure 13).

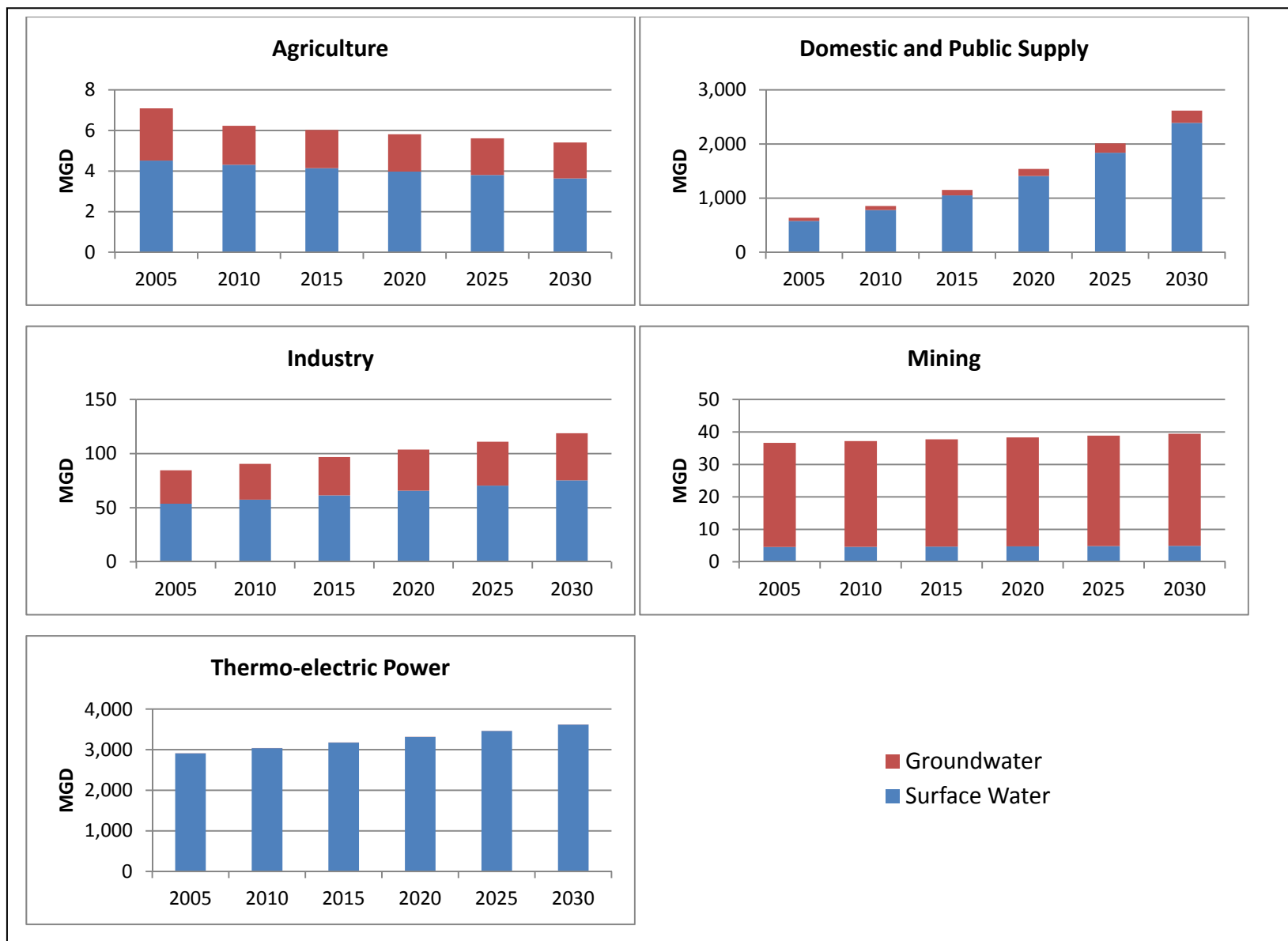


Figure 13. Water withdrawal by sector for surface and groundwater.

The rate of change in withdrawal amounts was calculated by averaging the rates across all FIPS codes by sector between each five-year forecast interval (Table 8). The agricultural sector is the only sector where a decrease in water use is expected over time. This was primarily due to the future conversion of agricultural land to urban land uses.

The average rate of change for the industrial, mining, and power sectors remained flat over time, since these sectors were not influenced by population or land use change. While growth for the domestic and public supply sector increased overall, the average rate of change decreased slightly.

Table 8. Averaged county rates of change in water withdrawal amounts by sector.

Sector	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030
AG	-0.06	-0.04	-0.06	-0.03	-0.03
DP	0.33	0.31	0.31	0.29	0.29
IN	0.07	0.07	0.07	0.07	0.07
MI	0.01	0.01	0.01	0.01	0.01
PO	0.04	0.04	0.04	0.04	0.04

## 5.2 Medium Domestic and Public Supply Scenario

The medium DP scenario (DP2 scenario) was created to correct data inconsistencies in several of the withdrawal values reported by USGS for certain jurisdictions. The resulting changes led to a reduction in the annual change in the per person withdrawal rate. The method for determining this new rate is explained below.

Based on the fact that some counties' 2005 withdrawals were substantially (at least a power of magnitude) outside the range of any other year in the data or inconsistent with the trend, withdrawal data for the following counties were determined likely to be erroneous:

- Fulton County, PA 42057
- Loudoun County, VA 51107
- Fairfax County, VA 51059
- Hampshire County, WV 54027

Other counties were removed from the data set because of data gaps. In some cases, this was because the jurisdiction receives its water from a supplier outside the county. Those removed for this reason included:

- Arlington County, VA 51013
- Alexandria City, VA 51510
- Harrisonburg City, VA 51660
- Manassas City, VA 51683

When the withdrawal in these cities and counties were removed, the annual increase in the withdrawal per person between 2000 and 2005 dropped from 4.38 percent to 1.82 percent.

All other assumptions for withdrawals and consumptive use remained the same as in the high DP scenario.

#### *Results*

In the high DP scenario, the domestic and public supply sector withdrawal was 2,618 MGD in 2030. Using the revised per person annual withdrawal increase, the total withdrawal dropped to 1,409 MGD (Figure 14, Table 9). Thus, this scenario was dominated more by population growth than by an increase in per capita withdrawal rates.

A complete table of results is in **Error! Reference source not found..**

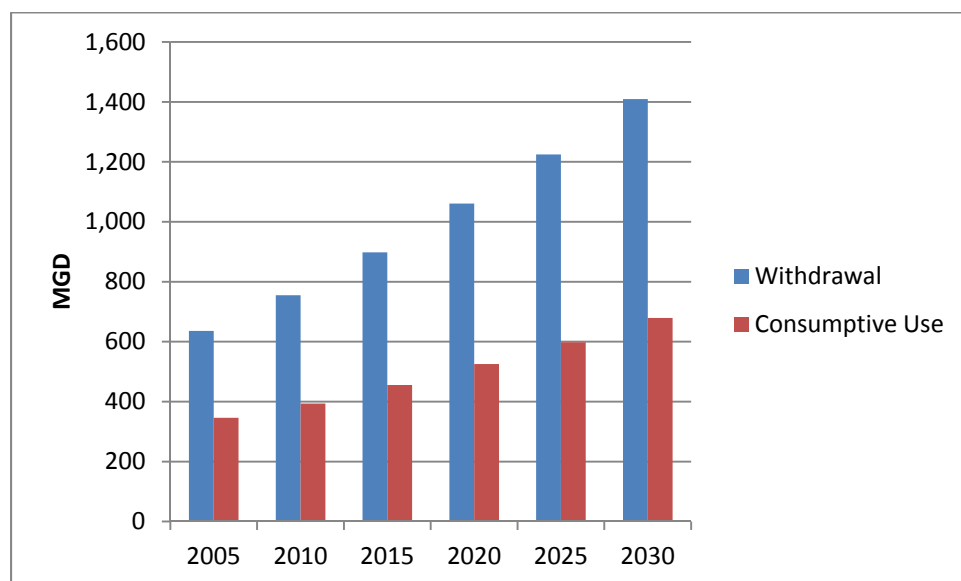


Figure 14. Domestic and public supply withdrawal and consumptive use in the medium DP scenario.

### **5.3 Low Domestic and Public Supply Scenario**

The low DP scenario (DP1 scenario) isolates the growth in the domestic and public supply sector withdrawal that was due solely to projected population growth. This scenario assumed that there was no change in withdrawal per person over time, holding the withdrawal per person constant at the 2005 rate.

#### *Results*

In this scenario, the domestic and public supply withdrawal was 899 MGD in 2030 (Figure 15, Table 9).

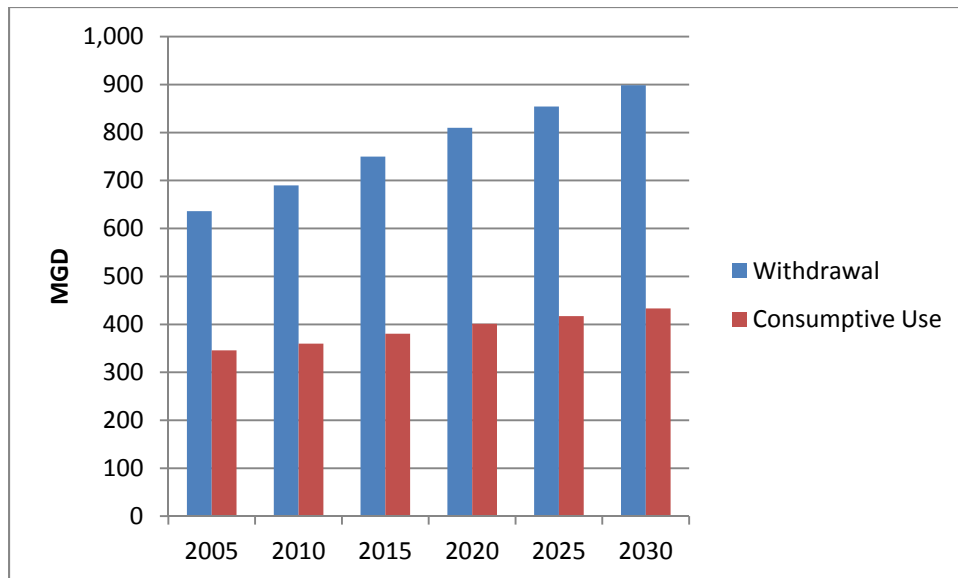


Figure 15. Domestic and public supply withdrawal and consumptive use in the low DP scenario.

A complete table of results is in **Error! Reference source not found..**

Table 9. Comparison of domestic and public supply scenario results for 2030.

Scenario	Annual rate of growth for per capita withdrawals	2030 Withdrawal (MGD)
High DP	0.0438	2,618
Medium DP	0.0182	1,409
Low DP	0.0	899

#### 5.4 Power Sector Scenario

The power sector scenario assesses the withdrawal and consumptive use impacts that could be expected if a new plant becomes operational in the basin. It also assesses the potential impacts of plant retrofits, such as closed-loop cooling and CO<sub>2</sub> capture technology, becoming more widespread.

In this scenario, a new plant would be required to support demands from a growing population and accommodate the increased draw on power required by CO<sub>2</sub> capture technology. The scenario sites the new plant in Frederick County, Maryland. Retrofitted plants for the scenario were Dickerson in Montgomery County, Maryland; Potomac-Mirant in the City of Alexandria, Virginia; and R. Paul Smith in Washington County, Maryland. The retrofits included closed-loop cooling systems and CO<sub>2</sub> capture.

Closed-loop cooling reduces the total amount of water used but increases the consumptive portion. Carbon capture requires additional power to function, as well as presenting potential water quality

concerns since the scrubbers remove nitrogen and discharge it into streams. The increased power requirement for carbon capture reduces the availability of power for consumers (Figure 16).

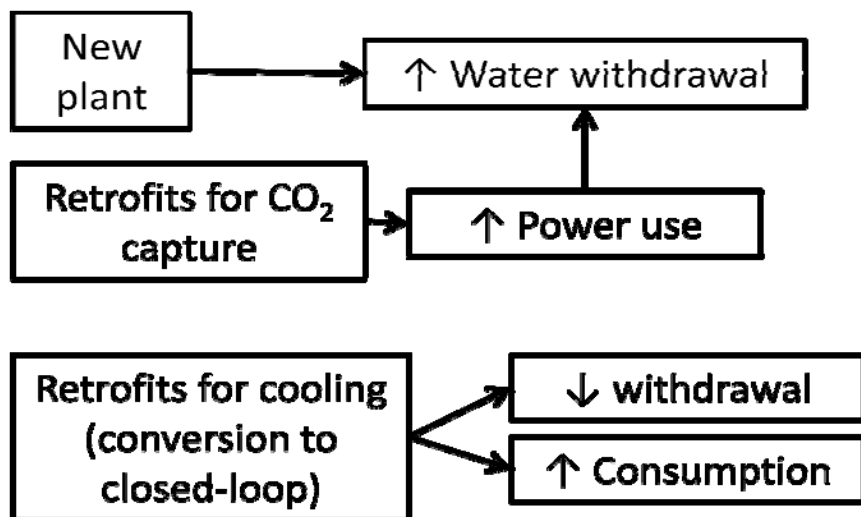


Figure 16. Power sector causal link model.

Implementation of closed-loop systems in the power scenario resulted in projected 2030 withdrawal amounts that are 28 percent of the open-loop system withdrawals in the medium DP scenario. The retrofits resulted in consumptive use values that are 3.25 times greater. This does not include additional withdrawals from the new plant.

Currently, the power sector is the largest withdrawer of water in the Potomac River basin. In the basin, there are 46 cooling systems at 41 plants. The fuel types that are used by the plants include:

- 8 bituminous coal;
- 1 synthetic coal;
- 13 Distillate, light fuel oil, no. 2 fuel oil , diesel oil;
- 1 petroleum heavy fuel;
- 6 natural gas;
- 4 land fill gas;
- 3 municipal solid waste biomass; and
- 5 water (dam).

Most of these plants did not report withdrawal and consumption data to the U.S. Energy Information Administration. Withdrawal data are taken from the USGS water use report (Kenney et al. 2009) and the state-provided data sets. Of the eight plants that did report to US-EIA, only two reported consumptive uses. At Possum Point in Prince William County, Virginia, the consumptive portion was seven percent. At Covanta in Fairfax County, Virginia, the consumptive portion was 84 percent. The other six reported discharges equal to the withdrawal amounts.

There is an air-cooled condenser operational in Grant County, West Virginia; air-cooled condensers are not consumptive. There are also two closed-loop condensers operational in the Borough of Chambersburg, Pennsylvania; closed-loop condensers have high consumptive use rates but very low withdrawal rates.

Several plants were identified in the US-EIA data, but not in the water use data provided by the states. Each state was contacted to determine why some plants may not have been included. The reasons were similar across states. Since withdrawal data were generally not available in the US-EIA data, no alternative was identified to using the state-provided and USGS data.

Reasons why a plant might not appear in the water-use data include:

- Many of the plants withdraw water below the threshold required for a permit (Pennsylvania, Maryland, and Virginia). Data were collected from only those companies that have permits.
- Many of the small power plants use a public water supply and are therefore reported in the DP sector (Pennsylvania, Maryland, and Virginia).
- Plants that do not use water consumptively are not required to report (Virginia).
- Some plants are producing power solely for facility operations. These facilities are industrial and the water withdrawal is included in the industry sector (Maryland).

#### **5.4.1 Power Plant Technology and Water Use**

Carbon capture is likely to be required of power plants as a result of the 2005 Energy Policy Act (Elcock 2010). Carbon capture technology (CO<sub>2</sub> mitigation) indirectly increases water consumption by increasing the amount of power required to operate the plant.

Cooling technology is likely to change from open-loop (once-through) to closed-loop (wet recirculation) technology due to the requirements of the Clean Water Act Section 316(b). The transition to closed-loop cooling systems is likely to occur because of a regulatory forcing function.

The problems with open-loop systems are entrainment and impingement. Entrainment occurs when the screening system is not fine enough to prevent small organisms from entering the cooling system. Impingement is where organisms are caught on the intake screens and mortality results. Because of entrainment and impingement problems, revisions to the Clean Water Act Section 316(b) are under consideration (Goldstein 2010).

Closed-loop systems consume more water than the open-loop systems because of the increased evaporation and water used in “blow-down.” Blow-down refers to the cleaning the salts out of the system by flushing it. Dry cooling (air-cooling circulation) does not require water.

Even with open-loop technology, Electric Power Research Institute (EPRI) reports that evaporation downstream of the plant continues and is likely as high as closed-loop when considering the downstream evaporation (Schuster 2009). Evaporation rates for distances downstream were not considered in this scenario.

Supercritical boiler types, flue gas desulfurization systems (FGD), Integrated Gasification Combined Cycle (IGCC), and Natural Gas Combined Cycle (NGCC?) technologies all require less water than the alternative technologies. Determining how the types of boiler, FGD, and cooling technology relate to the water withdrawal data was difficult. Decisions to retrofit were complex and difficult to generalize, and were outside the scope of this project. (For a detailed explanation of these technologies, see pages 22-23 of Schuster 2009.)

#### 5.4.2 Scenario Options

Several options for the power scenario were considered. They included:

1. Increase consumptive use coefficient over time.
2. Apply upgrades to all plants, rather than predicting which plants were more likely to upgrade.
3. Consider upgrading all freshwater plant withdrawals to carbon capture and closed-loop. In options 2 and 3, the consumptive use coefficient moves to 58 percent (average of open and closed loop cooling for the year 2030 (Schuster 2006). This coefficient is likely lower than the actual consumptive use, but since retrofits are complex and sites are difficult to predict, applying a lower consumptive use rate to all plants could provide a reasonable scenario.
4. Increase consumptive use coefficient only for those plants likely to be upgraded (Dickerson, Potomac-Mirant, and R. Paul Smith). Decrease withdrawal for these plants, assuming they move to closed-loop with CO<sub>2</sub> capture. Add a plant that has a withdrawal point in Frederick County, Maryland. The withdrawal would be an average of the other plants in the watershed.

The last option was selected as it was the most likely and most precise. With precision comes the greater risk of error, but applying an upgrade across all plants was considered unlikely and potentially not useful for evaluating flows because it was too general across space.

Frederick County, Maryland, was selected as the location of the new plant. Frederick County has many of the characteristics that are considered when selecting a site for a new plant including fuel source, energy transmission capacity, and water (PJM 2010 and Strebel 2010).

The three existing plants and the hypothetical new plant were deemed likely for upgrades, and therefore increased water consumption, were selected for multiple reasons. Cooling system upgrades are most likely for power plants that are in freshwater systems where there is greater competition for water. Of the 41 plants in the Potomac River basin, Dickerson, Potomac-Mirant, and R. Paul Smith were the largest withdrawers in the freshwater portion. Possum Point and Morgantown were also fairly large withdrawers, but were located in the estuary.

Because the retrofit plants were among the largest water withdrawers, they were considered a priority for cooling water retrofits. It was assumed that CO<sub>2</sub> capture would be installed in those same plants.

### 5.4.3 Withdrawal and Consumptive Use Projection

Projected future water uses were calculated for the selected power plants by adjusting the medium DP scenario values to represent close-loop systems. Literature values obtained from Dziegielewski and Bik (2006) were utilized to develop the necessary conversion factors.

Dziegielewski and Bik reviewed 397 open-loop systems, 116 closed-loop systems with ponds, and 347 closed-loop systems with cooling towers. For each type of system, the median water withdrawal (gallons/kWh) and median consumptive use (gallons/kWh) were provided. The medium DP scenario withdrawals and consumptive uses were adjusted using the reported differences in median water use between system types. Not knowing whether the upgrades in the Potomac will utilize recirculation with ponds or cooling towers, the average of the two system types were used to determine a general expected water use for closed-loop systems.

Utilizing this approach, medium DP withdrawals were multiplied by 0.279545 and medium DP consumptive use values were multiplied by 3.25 to obtain the power scenario withdrawal amounts for the three existing plants. To simulate the impact of a new plant being constructed, an additional withdrawal point was added along the Monocacy River. The withdrawal forecast from the Dickerson plant was copied to generate a realistic, but conservative scenario for the new plant. There was a substantial decrease in withdrawal for the existing plants (Table 10).

The effects of regulatory practices in the Potomac Basin such as low-flow consumptive use restrictions were not considered in the withdrawal and consumptive use projections.

Table 10. Change in withdrawal between the medium DP scenario with open-loop cooling and the power scenario with closed-loop cooling and CO<sub>2</sub> capture technology.

FIPS	Plant	Medium DP scenario (open loop) Withdrawal in 2030 (MGD)	Power Scenario (assumed closed loop) Withdrawal in 2030 (MGD)
24031	Dickerson	481	134
24043	R. Paul Smith	35	10
51510	Mirant	292	82
24021	New Plant	N/A	134

### 5.4.4 Results

Even with the addition of the new plant in Frederick, the power sector withdrawals decreased compared to the base conditions (also used in the high DP and medium DP scenarios). The 2030 power sector withdrawal in the original scenario was 3,617 MGD, while in this power scenario the withdrawal was 3,093 MGD (Table 11).

Table 11. Comparison of 2030 power sector withdrawals under base conditions (high DP and medium DP scenarios) and in the power scenario, with and without the new plant.

	<b>PO sector withdrawal under base conditions (MGD)</b>	<b>PO withdrawal <u>without</u> the new plant in power scenario (MGD)</b>	<b>PO withdrawal <u>with</u> the new plant in power scenario (MGD)</b>
Withdrawal	3,617	2,959	3,093
Consumptive Use	109	138	185

Energy policy changes can have dramatic effects on water consumption. The site selection of power plants, cooling technologies, and CO<sub>2</sub> capture technology all affect how much water is used, as well as the impact on water quality. This is especially true in the case of CO<sub>2</sub> capture, where air quality is improved but water quality and quantity may be compromised. In addition, there is potential for energy to be generated by methods, such as wind, that do not require a water withdrawal. In Maryland, two-thirds of all power could potentially come from wind, for example (K. Cooke 2010).

A complete table of results is in **Error! Reference source not found..**

## 5.5 Climate Change Scenario

Climate change is anticipated to impact water demand and availability (Bates 2008). The climate change scenario developed for this project assesses the impact of climate changes on water demands.

There is a paucity of data available for near-term climate change forecasts. A widely used climate change model has forecasts beginning in 1990 (IPCC 2007). Forecasts for land-use change, population, and other variables become less accurate the further they are removed from the present; long-term forecasts for these data are considered to be 2030.

For these reasons, applying climate change projections to present-year land use, population, and per person usage estimates is common in the literature (Abler 2002). Yet, it is known that there will be continued change into the future. Rather than ignoring the fact that, at a minimum, land use and population will change, this study chose to use the 2030 water demand projections and apply a near-term adjustment for climate change.

To isolate the effects of climate change, the estimated withdrawals under this climate change scenario are compared to medium DP scenario. This climate change scenario, as described below, alters the assumptions in the medium DP scenario for the irrigation, livestock, thermo-electric power, and domestic and public supply sectors.

### 5.5.1 Climate Change Effects

Alteration of temperature and precipitation patterns is the dominant effect of climate change on water demand. Other anticipated effects of climate change include increasing greenhouse gas concentrations and sea-level rise. Neither of these impact water demand in this scenario.

#### 5.5.1.1 Temperature

Climate models are constructed to model global dynamics. Downscaling these models results in a precision of only one to two degrees latitude and longitude (Najjar 2010). There is necessarily some uncertainty when applying climate change model results to a localized area such as the Potomac River basin. Moreover, there are multiple models available for downscaling, but no clear consensus on which ones provide reasonable projections.

There is much better agreement among climate change scenarios for near-term global average temperature change. Thus, this study uses the global average temperature change to predict warming trends through 2030.

In this scenario, temperature is predicted to rise 3.4 degrees Celsius (°C) between 2090 and 2099. By 2030, the temperature is projected to be 0.4°C higher than 2010 temperatures (a temperature of 0.5°C in 2010 would result in a projected temperature of 0.9°C in 2030). This is consistent with the IPCC (2007) estimate of a warming trend of about 0.2°C per decade for the next two decades in all of their scenarios.

Although all of the scenarios described in the IPCC Special Report on Emission Scenarios (SRES) were in agreement about the near-term temperature effects, the A2 scenario was selected in this study as a benchmark for background information and decision-making (Figure 17). The A2 scenario describes future conditions as "... a very heterogeneous world with high population growth, slow economic development and slow technological change" (IPCC 2007). It predicts a higher temperature increase than other SRES scenarios in the long term.

This scenario was chosen to inform this study's climate change scenario because it has the greatest estimates of climate impacts. Therefore, it is the most conservative and provides the upper bound for potential water demand increases.

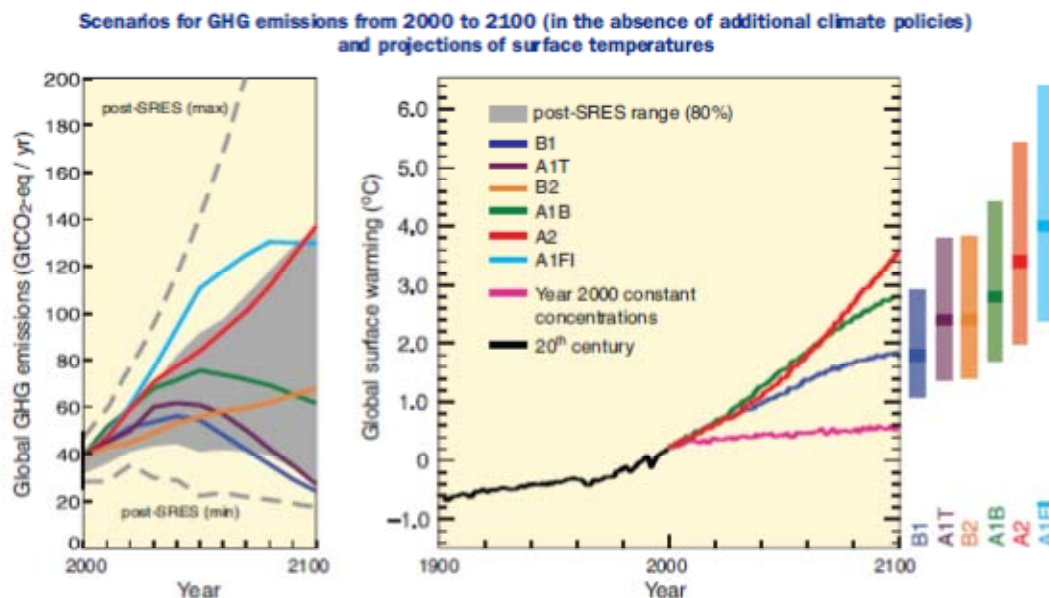


Figure 17. IPCC Scenarios (Pachauri et al. 2007).

### 5.5.1.2 Precipitation

#### 5.5.1.2.1 Amount

There is uncertainty in the climate change precipitation projections. There is no clear consensus regarding annual precipitation change (IPCC 2007 and Najjar 2010). Given the lack of clear consensus, the annual amount of precipitation was not considered as a variable in this climate change scenario.

#### 5.5.1.2.2 Timing

Timing of precipitation is critically important for plant growth and proper seed and fruit formation. The general consensus is that there will be more variation in precipitation in the summer and fall, with wetter winters and springs (IPCC 2007; Austin and Hawkins 2010).

The exception to this general consensus was J.P. Schmidt's (2010) research which showed drier summers and wetter falls when comparing the periods of 1895 through 1945 to 1950 through 2005.

Rain intensity is projected to increase, even though there are expected to be fewer events (North American Regional Climate Change Assessment Program, RCM3 and GCM3 2010). Therefore, adjustments in the climate change scenario are solely based on precipitation variability. The implications of this are discussed separately in each water demand sector.

### 5.5.2 Climate Change Effects on Water Demand

In the climate change scenario each sector is considered separately. The potential effect of climate change on the mining, thermo-electric power, industry, agricultural (livestock and irrigation), and domestic and public supply sector is discussed below.

Looking at each sector individually allows for a variety of explanatory variables and, therefore, increases accuracy (Boland 1997). The drawback is that the interactions among the sectors for available water supply are not considered. The scenario only considers water demand, not availability. Therefore the interactions among the sectors are considered inconsequential for this analysis.

#### 5.5.2.1 Monthly Variation in Demand

Prior to examining the impact on each sector, an understanding of how temperature influences withdrawals in the Potomac basin was needed.

As temperatures rise each spring, the growing season for crops and lawns commences, air conditioners are powered up, and the rate of evaporation increases. These factors translate to an increase in demand across the basin.

To determine which months reflected higher water use due to warmer temperatures, the winter base rate was calculated by subtracting the winter months' water use from the warmer-weather months for each basin state (LaTour 1991 and Mullaney 2004).

The state withdrawal data sets for 2005 were used for this calculation. Winter water use was 46% of the annual water use on average across states. For most basin states, this analysis showed a substantial increase in water demand during the period from May through October above the winter rate. Therefore, these months were selected as those when demand is influenced by temperature.

The proportion of water withdrawn each month as compared to the annual withdrawal followed a similar pattern across the states in the basin (Figure 18). Maryland, which included D.C. withdrawals, showed the highest water withdrawals in the warmer months, but also the lowest in the winter and late spring. Virginia and West Virginia predominantly followed the same pattern as Maryland, but the Pennsylvania peak withdrawal was one month later. This pattern followed the USDA plant hardiness zones (USDA 2003), which was developed with numerous temperature data points. Less temporal variation was present in Pennsylvania water withdrawals. West Virginia's withdrawals tended to be steady across most months, with a dip in withdrawals from January through April.

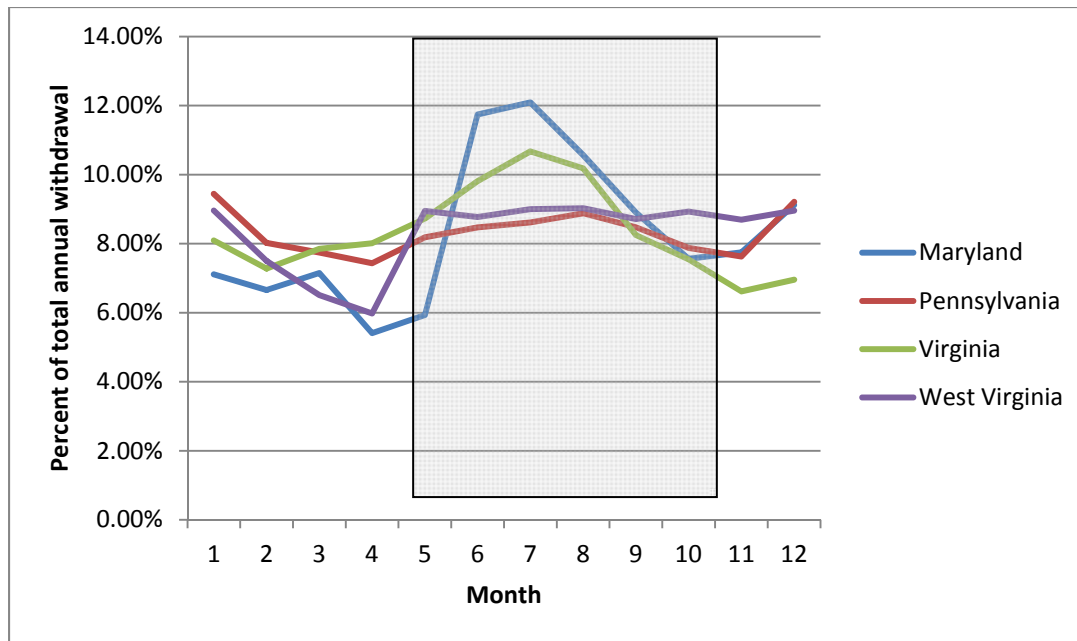


Figure 18. Monthly withdrawal as a percent of annual withdrawal for each state. The box shows those months where withdrawals increase due to increased temperature. Data are derived from each state's withdrawal database for 2005.

The withdrawal by sector for each state showed that the agricultural sector increased withdrawals in June and again in September when fall crops were planted in Maryland and West Virginia (Figure 19). Agriculture had a single peak in July and August in Virginia and Pennsylvania.

The power sector peaked earlier in the summer – June and July in Maryland and Virginia. An even higher increase was seen in August in Pennsylvania. There was an increase in warmer month power withdrawals in West Virginia, but no clear monthly pattern.

The industrial sector showed a peak in June in Maryland and in March in West Virginia. Since there were multiple industry types in the basin, it was difficult to isolate the driver behind these increases.

Mining was less influenced by temperature and remained fairly constant throughout the year in Maryland and Pennsylvania. There was a peak in mining water withdrawals in West Virginia in July, and in Virginia in October.

Domestic and public supply withdrawals included outside water use for activities such as lawn and garden watering. The slope for domestic and public supply was smaller, but rose across the warmer weather months.

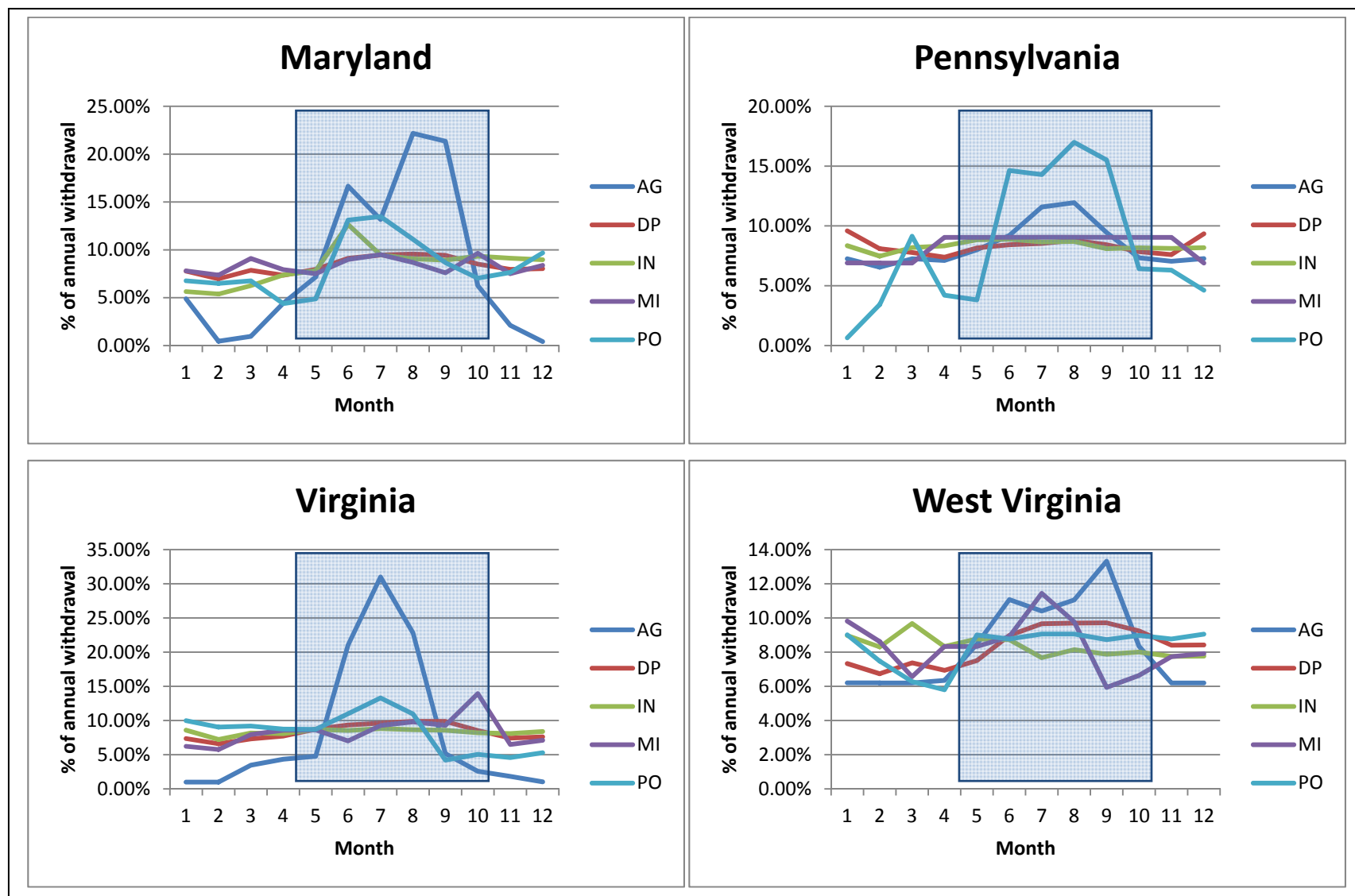


Figure 19. Percent of total water withdrawal by sector on a monthly time scale for each basin state. The box shows those months where withdrawals increase.

### 5.5.2.2 Climate Change Impacts by Sector

#### 5.5.2.2.1 Mining and Industry

Climate change will not result in any changes to the mining and industry sectors. These two sectors are neither dependent on temperature nor on the amount nor timing of precipitation for their operations.

#### 5.5.2.2.2 Agriculture

The agricultural water use sector is a combination of the livestock and irrigation sector projections. Each is discussed separately below.

##### *Livestock*

This study assumes that climate change will not impact livestock sector water withdrawals. It is understood that livestock do drink more water with warmer temperatures. However, the vast majority of the water used in livestock operations is wash water and not for drinking water purposes. (Jarrett 2007 and Erdman 2010).

The livestock sector withdrawals for this scenario remain the same as under the base conditions.

##### *Irrigation*

Transpiration: There is little consensus regarding plant transpiration changes as a result of climate change. With higher temperatures, transpiration is known to increase. Yet, the higher CO<sub>2</sub> levels in the atmosphere may result in closed stomata (stomata are the openings on a plant leaf used for gas exchange). The closed stomata may reduce transpiration.

Bates (2008) cites an estimate reported by Döll (2002) that increases in transpiration will result in increased irrigation of five to eight percent globally by 2070. R. Najjar in his work on downscaling climate change models concurs that transpiration increases with climate change (Najjar 2010).

In contrast, Downing (2003) writes that transpiration may be critically important when evaluating single crop types, but when aggregating crop types transpiration is difficult to generalize.

In this study crop types have been aggregated, unlike in Najjar's work. Therefore, transpiration is not evaluated as part of this climate change scenario.

Economic: In agriculture, the indirect impacts of climate-economy interactions must be considered as well as climate-environment interactions (Abler 2002). The economic effects of climate change depend on what happens to agricultural production elsewhere in the world. Global production changes cause world commodity prices to change (Reilly 2003).

Using a computable general equilibrium model, D. Abler (2010) was able to show that there would be a rise in fruit and vegetable production in the Chesapeake Bay region.

Fruit and vegetable production is a labor intensive operation. Therefore it would be unwise for a farmer to move into such production without investing in irrigation equipment (Steinhilber and

others 2010). It is assumed that farmers are rational actors and therefore will switch to fruit and vegetable production based on world-wide economic demand and prices.

Traditional crop types such as corn, soybean, and wheat, will continue to be grown. With the increase in temperature, the plants will have more rapid growth from an increase in growing days (Kratovil 2010). Some farmers will continue to grow these traditional crops and will irrigate to meet the higher water demand from more rapid growth.

These factors are modeled such that the rate of farmland conversion to irrigated land will increase by 50 percent. This scenario maintains zero agricultural land in the District of Columbia, as there is none currently.

Table 12. Fraction of irrigated land to all crop land under climate change assumptions.

State	Fraction of all crop land that is irrigated land	
	2030 - high DP scenario	2030 - climate change scenario
Maryland	0.097	0.146
Pennsylvania	0.105	0.158
Virginia	0.121	0.182
West Virginia	0.066	0.099

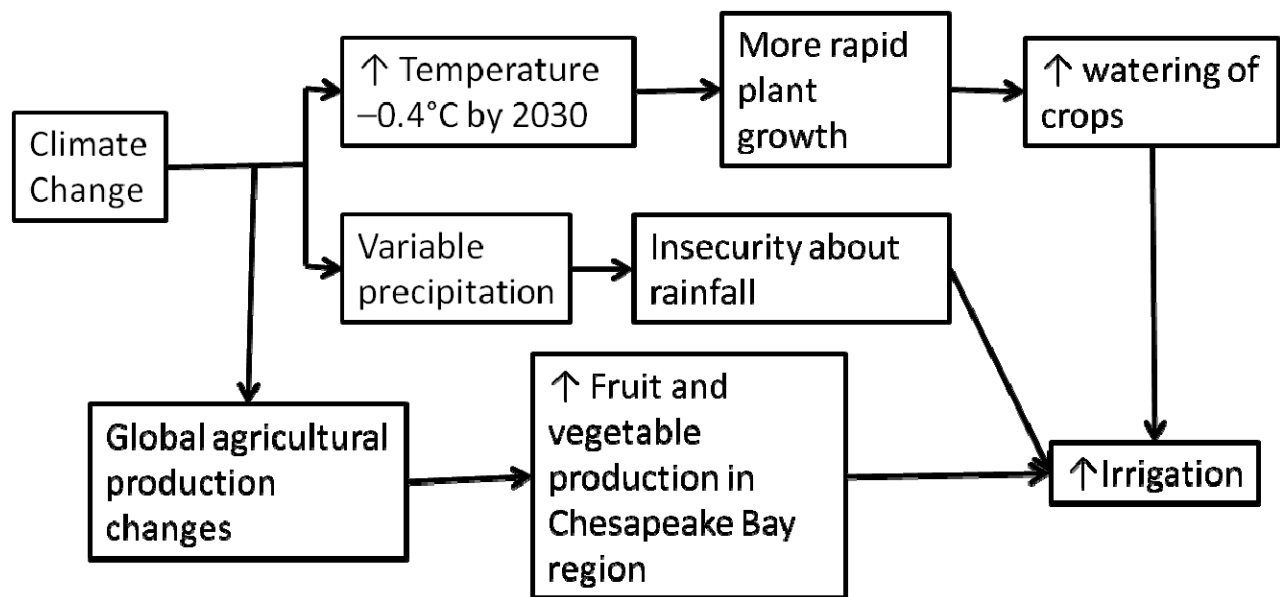


Figure 20. Irrigation and climate change causal links.

#### 5.5.2.2.3 *Thermo-electric Power*

An increase in temperature of 0.4°C by 2030 would be expected to increase demand for air conditioning in the summer. The increased air conditioning will increase power demand. Power demand is estimated to increase by 0.8 percent in the summer months (May through September). In this climate change scenario, the power sector increases its water withdrawal proportional to increased power demand.

While there is not an abundance of studies that quantify the increase in power demand per increase in temperature, some data on the electricity market is available. For example,

- Mideska (2010) conducted a review of electricity demand as it relates to temperature changes.
- DeCian et al. (2007) is cited as showing a one percent increase in summer temperatures resulting in a 1.17 percent increase in electricity demand in warmer countries in a global study.
- Also reported by Mideska was a study by Scott and Huang (2007) that showed a one degree Celsius rise in temperature resulted in a five percent energy consumption change in the United States.
- Bates (2008) reported on a study by Protopapas et al. (2000) that showed an increase in electricity demand of two percent per one degree Celsius rise in temperature per capita. This study was a statistical analysis of water demand in New York City.

There is clearly a link between temperature and power consumption, but the magnitude of the effect varied across the three studies, in part due to regional variations. Using the most local of the three studies and adjusting for the assumed temperature increase of 0.4°C by 2030, the increase in energy consumption is projected to be 0.8 percent.

Use of alternative energy sources such as wind and solar is projected to increase in the future, but will not replace conventional energy sources, which will continue to grow (US-EIA 2009). These alternative power sources do not have a high demand for water. Therefore, alternative energy sources were not considered in this scenario.

A factor not considered is the increased energy required for power plant cooling. The temperature differential between the cooling water and the machinery is required for power plant cooling to be effective. Warmer air temperatures will mean warmer cooling water. At the same time, the efficiency in producing power decreases because of thermal efficiency loss (Mideska 2010). These factors are difficult to generalize and require data and analysis beyond the scope of this study.

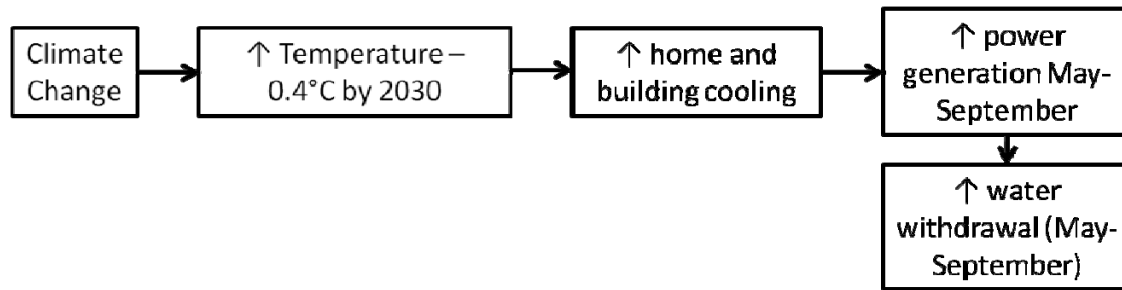


Figure 21. Thermo-electric power and climate change causal links.

#### 5.5.2.2.4 Domestic and Public Supply

The estimated increase in temperature of 0.4°C by 2030 is expected to increase the domestic and public supply sector's water demand. The literature provides little guidance in terms of quantifying the increase of water withdrawals due to an increase in temperature. Yet, using the relationship of increasing temperature to increasing summer water demand is clearly supported. It is assumed that water demand will increase for outdoor water uses, such as lawn and garden watering.

Quantifying that value is challenging because there is a lack of consensus in the literature (Table 13). Bates (2008) states in an IPCC report on studies by Mote et al. (1999) and Downing et al. (2003), that the increase in outdoor water use is likely to be less than five percent by 2050. This conflicts with another statement in the same Bates-IPCC report that there is an anticipated increase of 14 to 83 percent by 2050 per the Millennium Ecosystem Assessment (2005).

Frederick (1997) indicates that a 2.2°C increase could result in a residential water demand increase of 2.8 percent in summer and as much as 8 percent in June.

Downing et al. (2003) conducted a substantial analysis of water demand by sector for England. The authors assessed a variety of methods including: 1) the relationship between degree days and temperature and 2) the relationship between maximum temperature and precipitation. Ultimately, the authors found that the relationship between average temperature and water consumption gave the most robust results.

The authors report that a 2.3°C rise in temperature could result in a 21 percent increase in summer average withdrawals in southwest England. In southeast England, which includes the Thames drainage area, a 2.8°C rise in temperature results in a two percent increase in summer average withdrawals. The southeast England data was computed over a shorter time series so is more sensitive to changes.

Table 13. Literature summary of water demand changes due to climate change.

Study	Outdoor Water Use	Study Location
IPCC (2007) citing Mote et al. (1999) and Downing et al. (2003)	< 5% increase by 2050	Not reported
IPCC (2007) citing Millennium Ecosystem Assessment (2005)	14-83% increase by 2050	Not reported
Frederick (1997)	2.8% increase for 2.2°C temperature rise	Utah
Downing et al. (2003)	21% increase for 2.3°C temperature rise 2% increase for 2.8°C temperature rise	England – Southwest England – Southeast

An analysis of 2005 water withdrawal data in the Potomac region shows that domestic and public supply water use increased from May through October. In August, five percent more water was used than in June in the highest water-withdrawing counties.

The size of an increase in summer water demand given a 0.4°C temperature increase can only be bounded by a likely or reasonable percentage. From the analysis of the Potomac region's 2005 withdrawal data, five percent is the upper bound to which water withdrawals are likely to increase given the 0.4°C temperature increase. The five percent increase is the most conservative choice when considering the ultimate goal of this study, which is to evaluate the ecological health of the Potomac River. This rate of increase was applied in the climate change scenario.

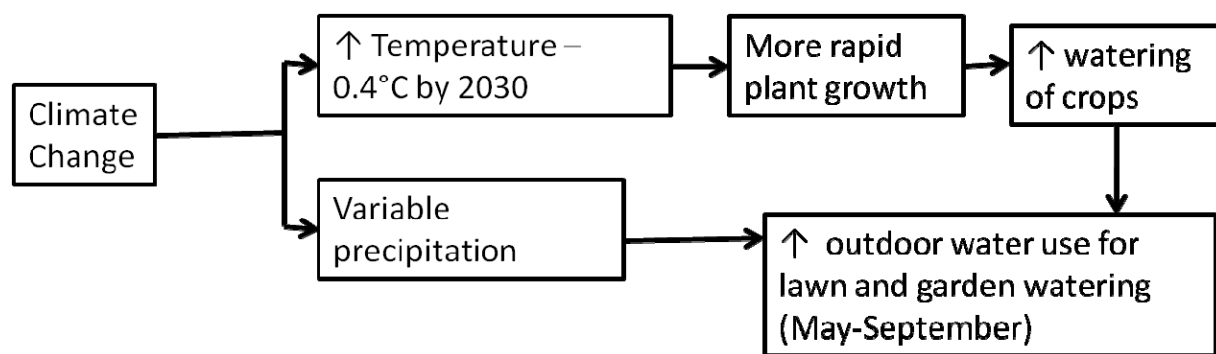


Figure 22. Domestic and public supply and climate change causal links.

### 5.5.2.3 Consumptive Use

The purpose of modeling climate change is to determine the effects of climate change on future water withdrawals. While the adjustments for the climate change scenario affect withdrawal amounts, the fraction of this that is consumptively used is not anticipated to change.

### 5.5.3 Summary of Climate Change Scenario Adjustments

Table 14 summarizes the adjustments made for the climate change scenario by sector. In Figure 23, the link between climate change and water demand is diagramed for all sectors. Not considered in this climate change scenario is human adaption, which is shown in the blue box in the figure.

There are plausible policy interventions such as public education, industrial reuse/recycle, or other advanced water conservation measures that could reduce water use. These public policy interventions and improved efficiencies may reduce water use below what is seen at stationary climate levels, even considering diminishing rates of change over time (Boland 1997).

Table 14. Summary of sector adjustments for the climate change scenario.

Sector	Estimation method for climate change scenario
Mining	No changes
Industry	No changes
Agriculture - Livestock	No changes
Agriculture - Irrigation	50% increase in irrigated land
Thermo-electric Power	0.8% increase in water withdrawals in summer months (May-September)
Domestic and Public Supply	5% increase in water withdrawals in summer months (May-October)

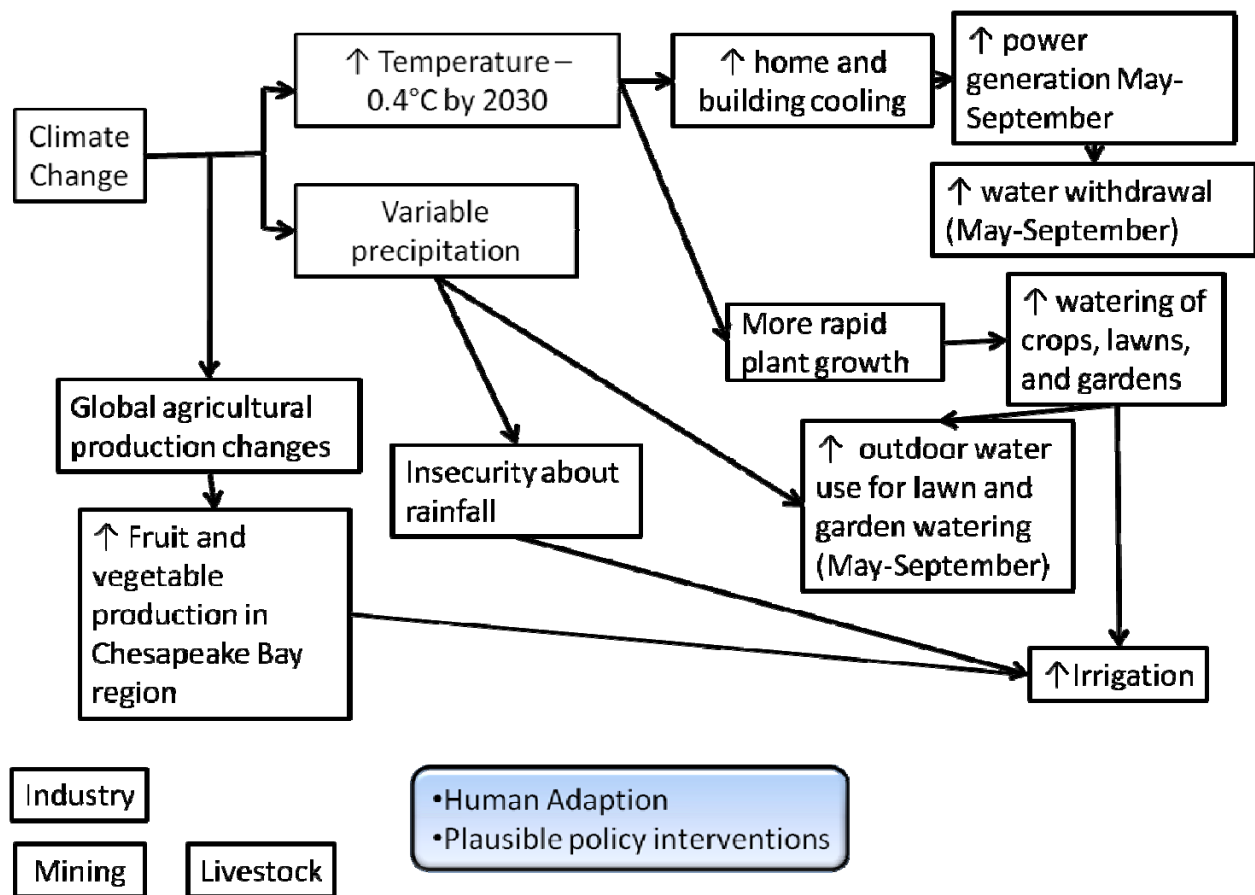


Figure 23. Comprehensive causal links diagram for the climate change scenario.

#### 5.5.4 Climate Change Scenario Results

The results of this scenario indicate that climate change will have a noticeable effect on water withdrawals and consumptive use in 2030. The total withdrawal in the high DP scenario was 6,398 MGD in 2030. This compares to the 2030 withdrawal in this climate change scenario of 6,571 MGD (Figure 24). This is a 2.7 percent increase in withdrawals.

A complete table of results is in Supplemental Table 6.

Although there was an increase in water withdrawal in this climate change scenario, the primary climate change impact on the Potomac River basin will be on water quality, not water quantity. The changes in precipitation with climate change include precipitation timing, storm intensity, and storm duration. As referenced in the previous sections, it was unclear from the various climate change scenarios if the total annual rainfall will vary. However, there was good agreement that storm events will be of greater intensity and shorter duration. Greater intensity storm events are more highly erosive. With increased erosivity, delivery of sediment and associated phosphorus will likely increase. The increase in total suspended sediment and total phosphorus are likely to be the primary effects of climate change, not water demand or consumptive use.

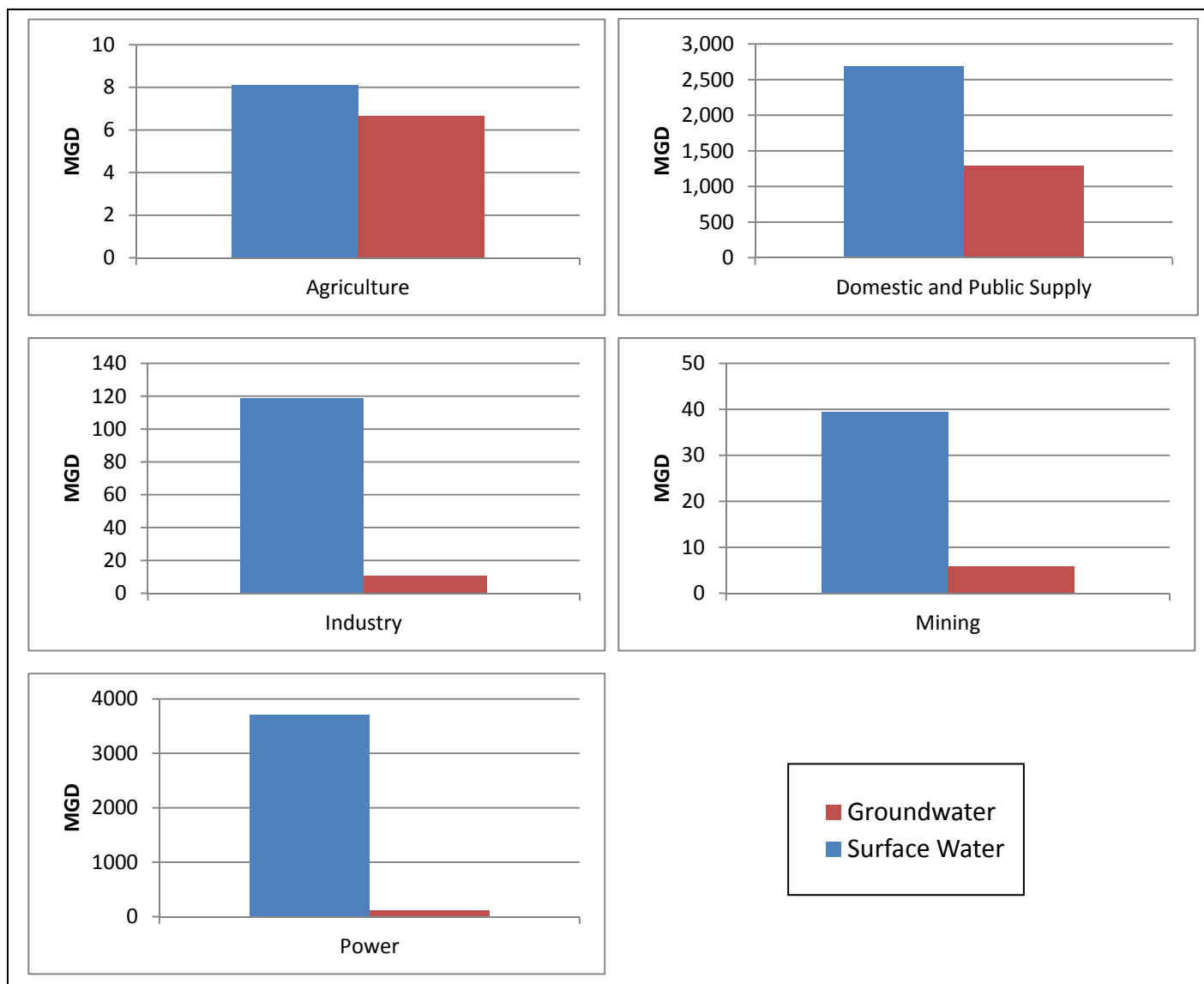


Figure 24. Withdrawal and consumptive use in the climate change scenario for 2030. Units are in million gallons per year.

Table 15. Comparison of 2030 withdrawals and consumptive use in the CC and high DP scenarios. Withdrawals in the mining and industry sector are not expected to be affected by climate change.

Use Type	Scenario	Withdrawal 2030 (MGD)	Consumptive Use 2030 (MGD)
Agriculture	CC	8	7
	High DP	5	4
Domestic and public supply	CC	2,690	1,296
	High DP	2,618	1,262
Power	CC	3,716	111
	High DP	3,617	109
Mining	CC	39	6
	High DP	39	6
Industry	CC	119	11
	High DP	119	11
Total	CC	6,572	1,431
	High DP	6,398	1,392

## 5.6 Drought Scenario

During hot and dry weather an increase in water withdrawals may be observed. Lack of rain increases withdrawals for agricultural irrigation and household watering of lawns and gardens. The heat results in higher demands for air conditioning, and, therefore, more power generation. Increased power generation requires more water use for power plant cooling (Figure 31).

This scenario projected withdrawals and consumptive use in 2030. It did not consider water restrictions or other management decisions that could be enacted during drought periods.

The medium DP scenario was the starting point for this scenario. No changes were made to the mining, industrial, or livestock sectors. While livestock are known to drink more water during hot weather, the primary use of water in the livestock sector is for wash water, which is not affected by temperature increases or precipitation decreases.

The other sectors were assessed individually. Changes to these sectors were:

- Domestic and public supply withdrawals increased by 15.21 percent for the months April – August
- Power withdrawals increased 6.15 percent for the months May – September
- Irrigation withdrawals increased by 283.9 percent for the months May – September

Each of these assumptions is discussed in detail below.

### 5.6.1 Domestic and Public Supply

Temperature and precipitation data were examined in conjunction with water withdrawal data from the Washington, D.C., metropolitan area (WMA). Specifically, data from 2002 and 1999 were

analyzed, as they are the most recent drought years. The temperature and precipitation data were from selected weather stations in the WMA.

The withdrawal data came from the three major public suppliers in the WMA: Fairfax County Water Authority (Fairfax Water), Washington Aqueduct (WAD), and Washington Suburban Sanitation Company (WSSC). The withdrawals were production data from their intakes in the Potomac River. They do not include the withdrawals from the Occoquan reservoir and the Patuxent River. These data did not include drought management restrictions.

#### 5.6.1.1 **Precipitation**

Water withdrawals and precipitation were not correlated ( $r^2 = 0.009$ ) (Figure 25). Precipitation was not a strong predictor of withdrawals for public supply, even when analyzed solely for summer months. One would not expect a correlation since water is not stored by households for use. More importantly, water has many uses beyond those affected by lack of precipitation. In the domestic and public supply sector, uses that would be affected by lack of precipitation, such as outdoor watering of lawns and gardens, only represent a small(?) portion of all water uses.

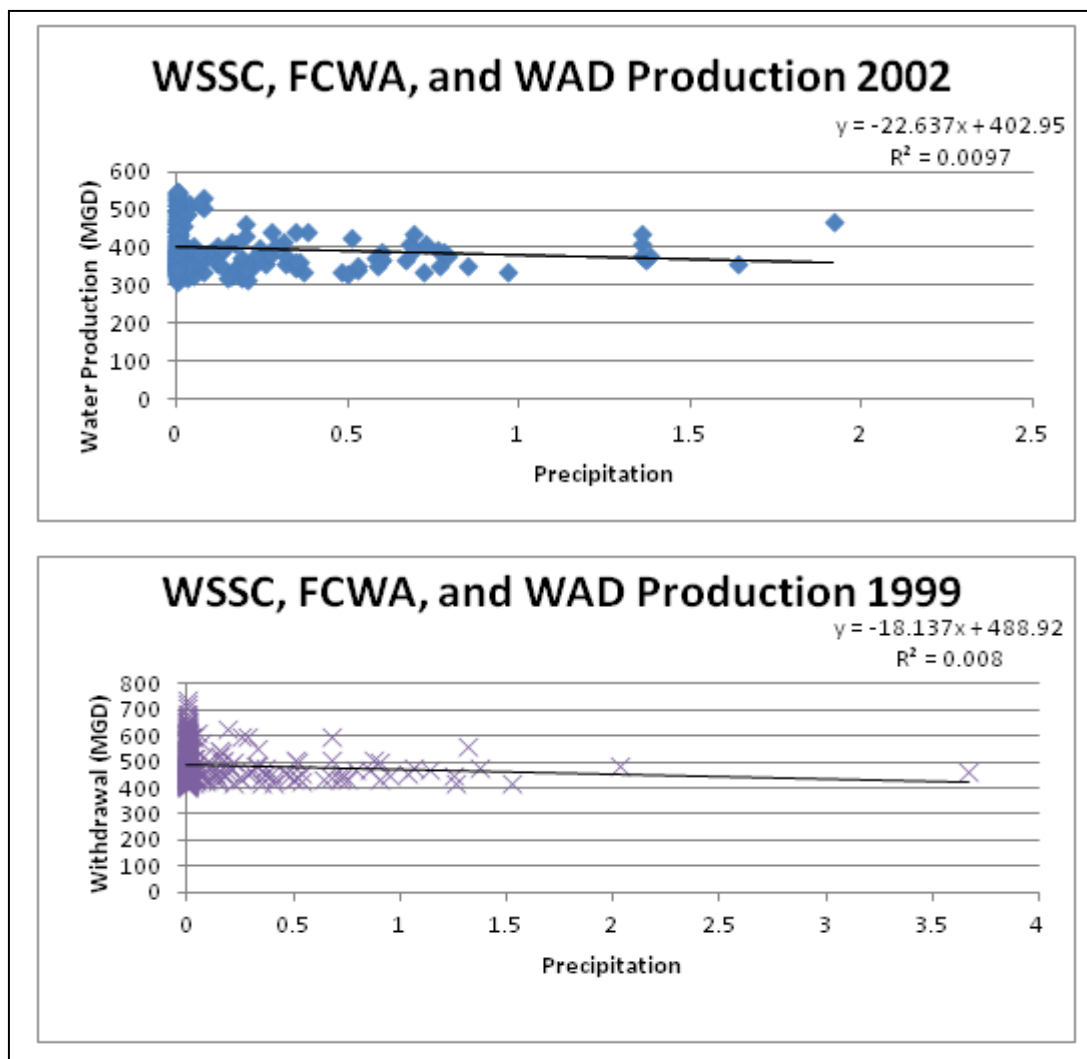


Figure 25. Combined water production at WMA suppliers and precipitation for drought years 1999 and 2002.

#### 5.6.1.2 Temperature

The regression of temperature and withdrawals in 1999 and 2002 showed a significant relationship at  $p < 0.00$ . As the temperature increased, the withdrawals increased. The 2002 data have an  $r^2$  value of 0.78. For the 1999 data the  $r^2$  value was 0.72 (Figure 26). This relationship was used to inform an increase in withdrawals given an increase in temperature in this drought scenario.

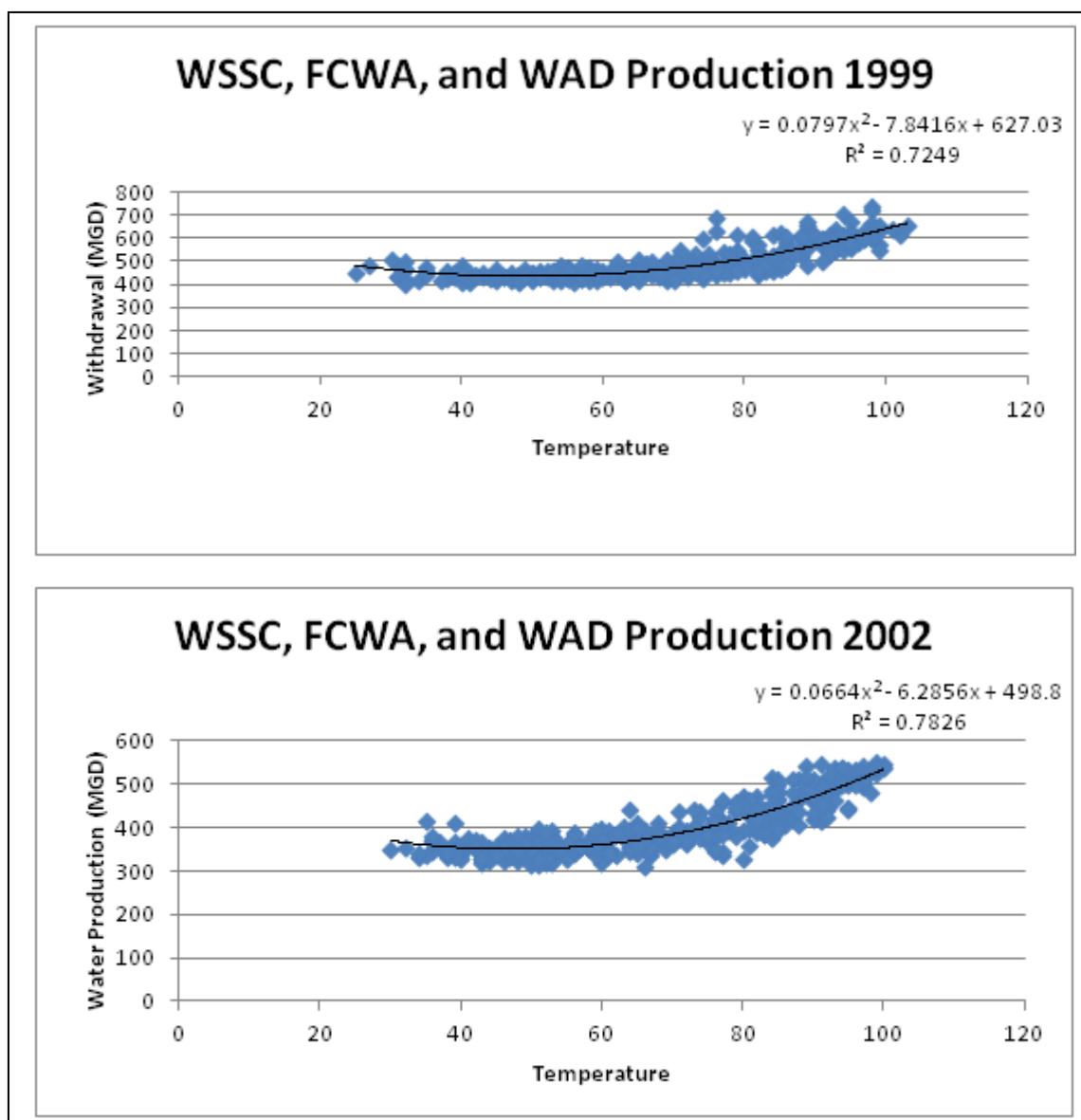


Figure 26. Water production at WMA suppliers and temperature for drought years 1999 and 2002.

While the 1999 and 2002 temperature and withdrawal data showed an exponential curvilinear relationship for a 12-month period, there was a linear relationship for temperatures above 70°F. The months with temperatures over 70°F included April through August.

Using the monthly average withdrawals from the WMA for those months, the increase in summertime withdrawals during 1999 and 2002 were compared to those in 2005. The average monthly increase from April through August in 1999 and 2002 was 9.64 percent. July of both 1999 and 2002 showed the largest percent difference when compared with 2005 (16.08 percent and 14.35 percent, respectively). The average increase in withdrawals in July of both years was 15.21 percent.

Thus, for the drought scenario the 2005 withdrawals were increased by 15.21 percent and then projections were made through 2030.

Increasing the domestic and public supply sector withdrawals required several assumptions to be made. First, it was assumed that the withdrawal and temperature relationship for the years 1999 and 2002 would hold true for future drought years.

To determine the likely temperature increase in a drought year, the temperature data from the longest drought on record in the Potomac basin (1930) was analyzed. The drought of 1930-31 had a recurrence interval of greater than 25 years (James 2010).

The temperature in 1930 was compared to that in 2005 – the year on which all withdrawal projections were based in this study (Figure 26). On average, the temperature was 10.8 percent higher in 1930 than in 2005 (Figure 28).

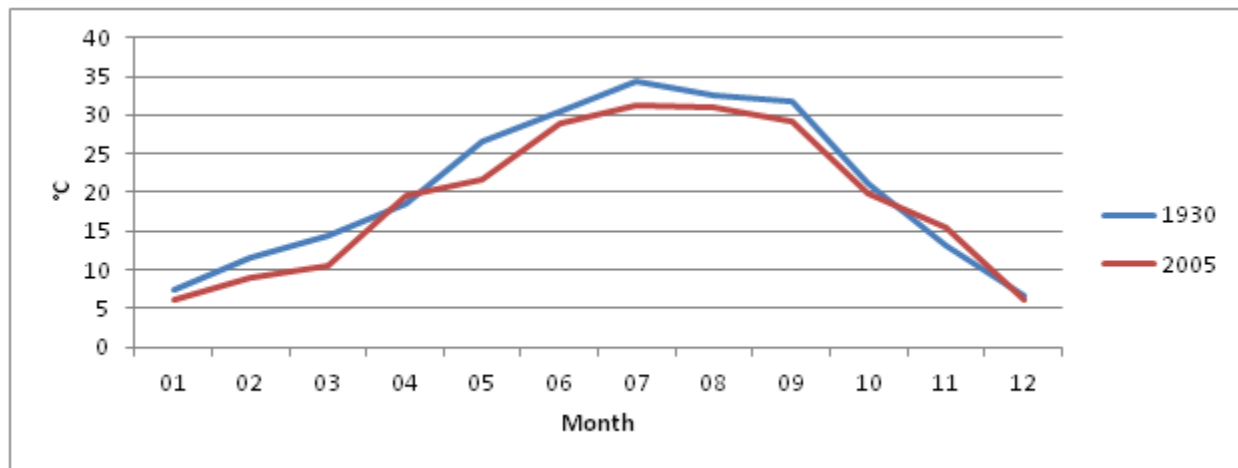


Figure 27. Monthly average temperature in 1930 and 2005.

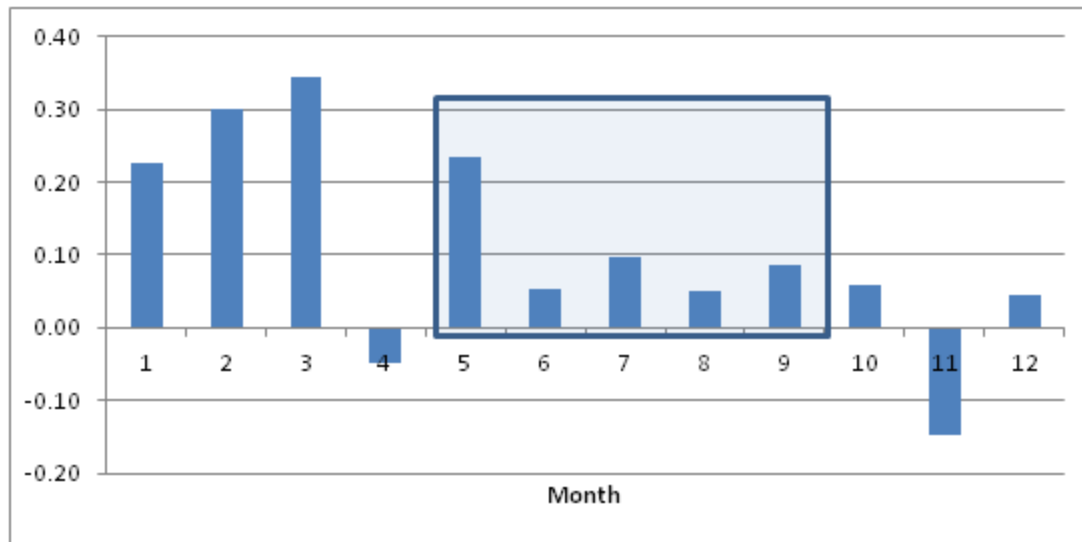


Figure 28. Difference in temperature between 2005 and 1930 (1930-2005/2005). The box shows the months that the temperature is adjusted in the drought scenario.

The second assumption for this increase was that the relationship between temperature and withdrawals seen in the WMA data was valid for DP withdrawals throughout the basin. Figure 29 shows that the 1999 and 2002 droughts covered more than 50 percent of the Potomac River basin.

The final assumption made was that increases in withdrawals would always be seen from April through August in drought years, as there were in 1999 and 2002.

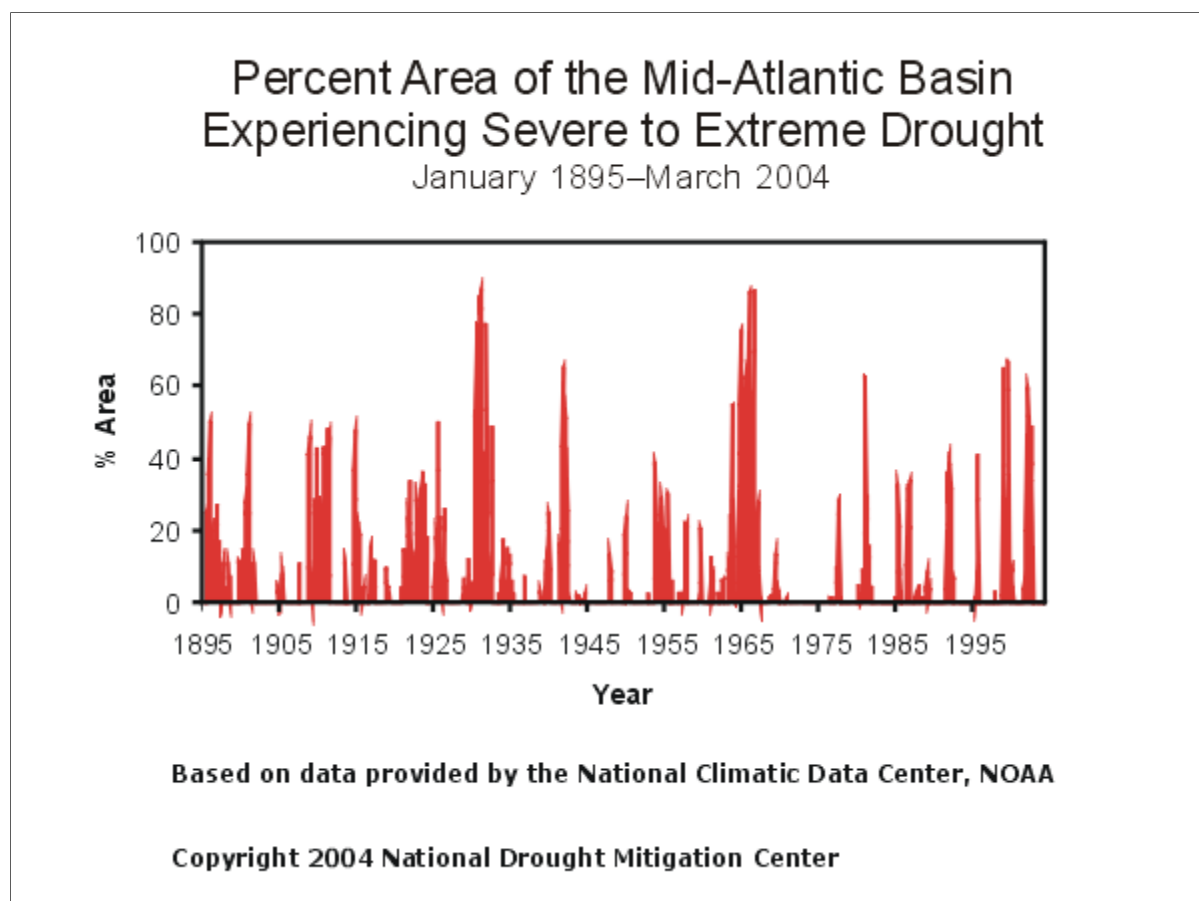


Figure 29. Historical drought coverage (Image from <http://www.drought.unl.edu/whatis/palmer/midatlan.gif>).

### 5.6.2 Power Sector

For this scenario it was assumed the power sector would increase its water withdrawal in a drought year proportional to the increased power demand. It also assumed a linear increase in air conditioning use to temperature.

The analysis described above showed a 10.8 percent increase in temperature between the drought of 1930 and those reported in 2005. Given this, power sector withdrawals were adjusted using the relationship defined by Protopapas et al. (2000) and reported in Bates (2008). Protopapas found that for every 1°C increase in temperature, electricity demand increased two percent (Bates 2008). The Protopapas study was a statistical analysis of water demand in New York City.

Applying the 10.8 percent temperature increase to 2005 temperatures resulted in an increase of 3.07°C, or 4.16°F, on average across the WMA in May through September. Subsequently, based on the Protopapas study, PO water withdrawals were increased by 6.15 percent in May through September for this scenario's projections.

The period of May through September was selected because there was a substantial increase in the water withdrawal above the winter rate between May and October in most states.

### 5.6.3 Agriculture Sector

Farmers who do not have irrigation equipment in place cannot irrigate. Therefore, it was assumed for the drought scenario that irrigation withdrawals could only increase for those acres of land currently using irrigation. Furthermore, the scenario assumed that no new irrigation systems were installed as a result of a drought between 2010 and 2030. Irrigated lands were modeled at the same fraction of agricultural land as the average of that in 1998, 2003, and 2008.

In other scenarios, the estimate of water use per acre of cropland was 0.64 acre-feet of water per acre irrigated in an average rainfall year (Jarrett and Roudsari 2007).

A graph of drought recurrence interval and water use per acre was created using Jarrett (2007) data for Pennsylvania (Figure 30). In this drought scenario, the recurrence interval of 25 years was used. This approximates the 1930 drought (James 2010). This relationship shows that the amount of water used on irrigated land given a 25-year recurrence interval drought would be 290.49 MGD per acre (Figure 30). Therefore, the withdrawals for irrigated acres were increased to 290.49 MGD per acre. This compares to 75.66 MGD per acre in a non-drought year.

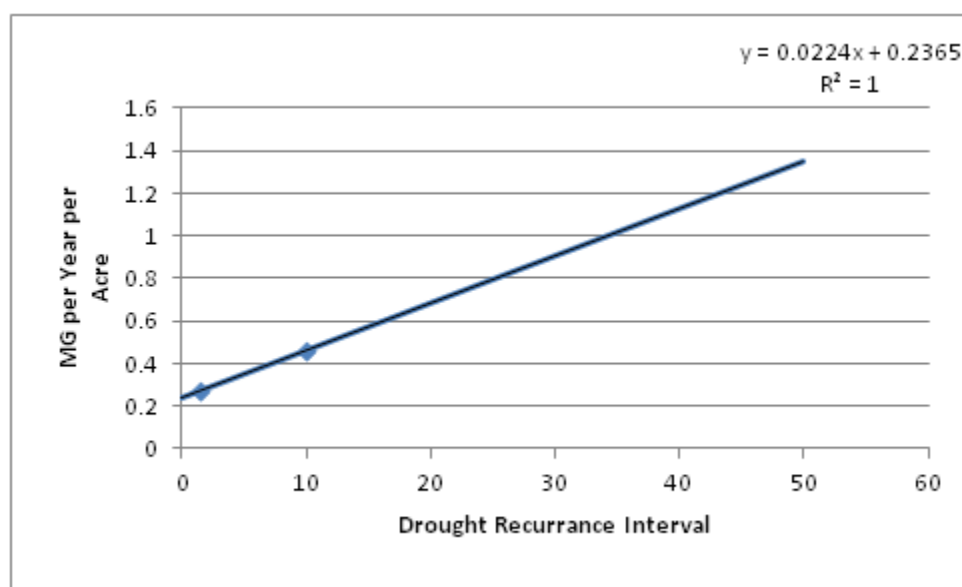


Figure 30. Drought recurrence interval and irrigation withdrawal (Jarrett 2007).

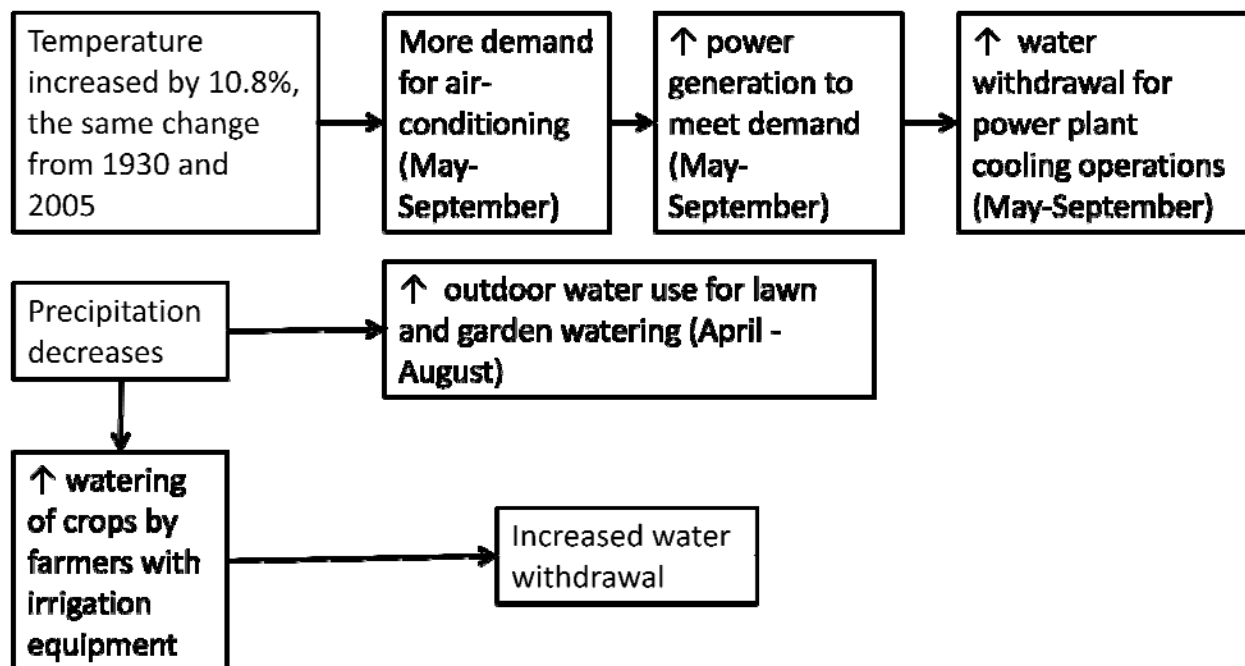


Figure 31. Causal link diagram for the drought scenario.

#### 5.6.4 Consumptive Use

The fraction of consumptive loss was not changed for this scenario. While the increase in temperature would lead to increased evaporation, the amount is considered negligible compared with water withdrawal changes. Therefore, it was not considered.

#### 5.6.5 Results

Overall, 2030 water withdrawals increased from 5,190 MGD in the medium DP scenario to 5,401 MGD in drought scenario described here. The corresponding consumptive use was 809 MGD in the medium DP scenario and 867 MGD in the drought scenario.

The power and domestic and public supply sectors showed slight increases from the projections in the medium DP scenario (Table 16). For the power sector, 2030 withdrawals increased from 3,617 MGD to 3,722 MGD, or by three percent. For the domestic and public supply sector, the 2030 withdrawal increased from 1,409 MGD to 1,504 MGD, or by seven percent.

The sharpest increase in withdrawals was in the agricultural sector. This change was solely a result of increased water use for irrigation. The 2030 withdrawal increased from five MGD to 17 MGD (240 percent) due to hot and dry weather. In spite of this substantial increase, the relative significance of the agricultural sector's withdrawal remained approximately less than one percent of the total water withdrawn and approximately one percent of all water consumptively used.

A complete table of results is in Supplemental Table 7.

Table 16. Comparison of drought and medium DP scenario results.

Sector	Scenario	2030 Withdrawal (MGD)	2030 Consumptive Use (MGD)
Agriculture	Drought	17	14
	Medium DP	5	4
Domestic and public supply	Drought	1,504	725
	Medium DP	1,409	680
Power	Drought	3,722	112
	Medium DP	3,617	109

While this increase in withdrawals and consumptive use may be of concern, there are a multitude of policy options that could counter this increase due to hot and dry conditions.

## 6 Analysis of Water Consumption by Watershed

Data are presented by the cumulative area that drains to a gage on the Potomac for the medium DP scenario (DP2) (Table 17, Figure 32. Drainage area flow diagram). The DP2 scenario assumes a 1.82 percent increase per capita use in domestic and public supply water use sector.

The North and South Branches of the Potomac are presented separately; both drain to the Paw Paw gage. The next downstream gage is Hancock, which includes Paw Paw. Shepherdstown is the next downstream gage and includes Hancock. The Point of Rocks gage is downstream from Shepherdstown and includes the Shepherdstown drainage area. Monocacy is presented as a discreet drainage area. Little Falls is the next downstream gage on the Potomac and includes Monocacy and all other drainage areas above the gage. All of the tidal fresh areas above Occoquan are reported. The entire Potomac is presented for comprehensiveness.

Table 17. Withdrawal and consumptive use by drainage area to Potomac River gage sites as projected by the DP2 scenario (MGD).

Basin (drainage area to gage)	Withdrawal 2005	Withdrawal 2030	Consumptive Use 2005	Consumptive Use 2030
North Branch Potomac to Paw Paw	1,174	1,470	40	51
South Branch Potomac	11	18	1	2
Paw Paw	1,185	1,488	41	53
Potomac River at Hancock	1,186	1,489	41	53
Potomac River above Shepherdstown	1,259	1,605	48	63
Potomac River above Point of Rocks	1,336	1,748	58	81
Monocacy Watershed only	43	88	6	10
Potomac River above Little Falls	2,179	3,210	385	700
Potomac Tidal Fresh above Occoquan <sup>a</sup>	2,252	3,391	114	228
Potomac Tidal	3,673	5,190	172	315

<sup>a</sup>Withdrawals from Washington Aqueduct, WSSC, and the City of Rockville were assumed to be 100% consumptive, sending all water to the Blue Plains Wastewater Treatment Plant. A portion of this water is assumed to be discharged back into the river in the Potomac Tidal Fresh above Occoquan sub-watershed. The study assumed an 11% consumptive use rate for all DP withdrawals not discharging to Blue Plains so 89% of the withdrawal at these drinking water facilities was added to the “Potomac Tidal Fresh above Occoquan” and “Potomac Tidal” sub-basins. For the purposes of this study, withdrawals in Loudoun County, Virginia, were not assumed to be sent to Blue Plains. Therefore, because Fairfax Water's intake is in Loudoun County, its consumptive use rate was 11%.

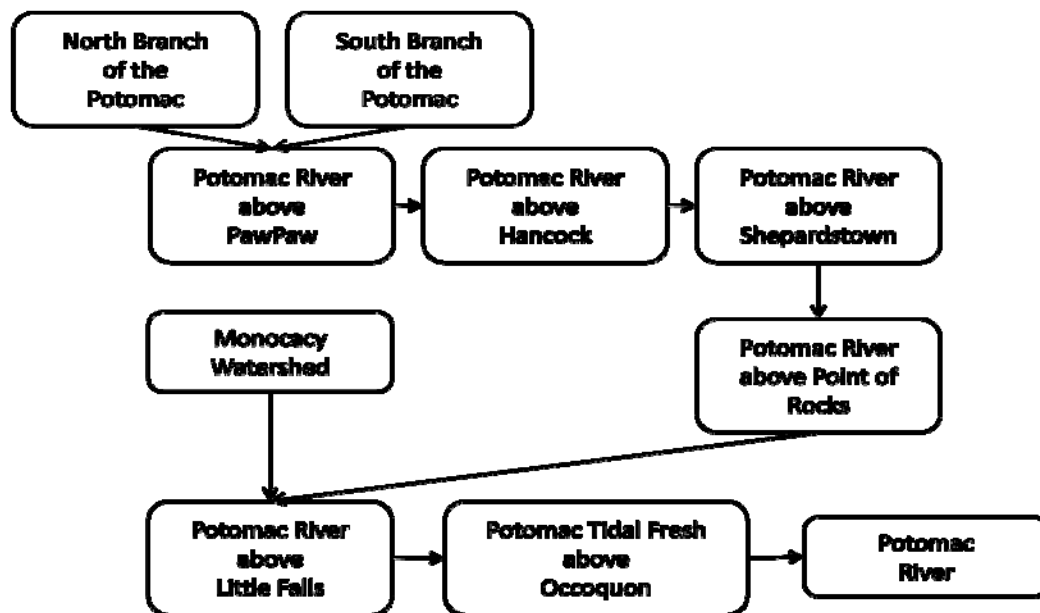


Figure 32. Drainage area flow diagram.

## 7 Conclusion

Conclusions presented in this study should be viewed as one possible indicator of potential trends and areas of concern regarding water consumption. The forecasts in this study were primarily business-as-usual. With the exception of the power sector scenario that considered a new plant and technological changes, these forecasts avoided predicting human behavior or public policy.

The rates of change in the withdrawal forecasts were less than 1.5 percent for the power, industry, and mining sectors. The rates of change for the irrigation, livestock, and domestic and public supply sectors were controlled by population and land use projections. Domestic and public supply was also controlled by the projected increase in withdrawal per person. This increase in withdrawal per person was a continuation of the trend from 2000 to 2005 into the future.

While the ratio of irrigated to total agricultural land increased, the agricultural withdrawal decreased because of land use change over time. The domestic and public supply sector increased primarily because of the per person withdrawal rate, and secondarily due to projected population increases. The industry, mining, and power sectors have slight increases projected, as would be expected with the small rates of change.

When comparing the sectors, most water is withdrawn by the power sector, but most is consumptively used by the domestic and public supply sector. This relationship was true for all years and scenarios. The scenarios clearly show that the per person withdrawal rate makes a sizeable difference. Fortunately, this is a factor that public policy can impact.

Trends in the monthly indoor versus outdoor withdrawals showed that water withdrawals were fairly evenly balanced between May and October and between November and April. The November to April time period represented 46 percent of all withdrawals. Outdoor water use is primarily confined to June through August.

The counties with the largest projected growth in withdrawals are adjacent to and immediately south of Washington, D.C. This provides an opportunity for public policy changes and communication to occur in a focused area, rather than the entire Potomac River basin.

The drought scenario showed an increase in withdrawals. This increase occurs at a time when streamflow is low — the summer months. Droughty weather is an opportune time for public education and increased communication about water use. Public policy developed to address crises can have substantial impacts.

The power sector is the largest growth sector in consumptive use. Regulatory forcing will result in cleaner air and protect against organism entrapment. Unfortunately, those same regulations also will result in increased power use, and therefore water withdrawal, to fuel the new technology. The power sector will also grow because of population increases. While a substantial portion of the region's power is generated outside of the basin, this may change in the future. Power plant siting analyses have already been conducted for locations in Frederick County, Maryland. Should a new

power plant be constructed that uses water, tremendous changes in withdrawal and consumption will be evident in the Potomac River or its tributaries.

Climate change is an important consideration in any analysis of future trends. In this study, climate change had little impact on water use. Climate change is anticipated to have a significant impact on water quality due to greater intensity storms, increased erosivity, sediment delivery and associated phosphorus.

The results of this study indicate that there will be impacts to the water resources in this region if future growth and water use continue along the same trend. The good news is that any impacts to the Potomac River from water demand likely can be ameliorated by management and policy options. It is recommended that policy options for decreasing the withdrawal used by the power sector and by domestic and public supply be developed now in anticipation of continued future growth.

## **8 Comparison of Results to Previous Studies**

### **8.1 MDE Wollman Report (2008)**

The state of Maryland created the Advisory Committee on the Management and Protection of the State's Water Resources, which was chaired by M. Gordon Wollman. This Committee issued a report in July 2008 that included water demand projections. This report was for the entire state of Maryland, as opposed to just the Potomac portion. Therefore, the specific water demands are not comparable. However, some comparisons are possible. The Wollman report was compared with this study's medium DP scenario results.

The Wollman report divided agriculture into livestock, irrigation, and aquaculture. Summing these categories showed an increase that was more than double the current withdrawal. ICPRB's projections for the Potomac showed a decrease in agriculture, primarily due to land use change. It is likely that the increase projected in the Wollman report is likely to occur on the Eastern Shore, which is outside the Potomac River basin.

The medium DP scenario shows a substantial increase in domestic and public supply while a more modest increase was reported in the Wollman report. This difference may be due to multiple factors. One factor could be that the ICPRB study assigns Washington, D.C.'s demand to Montgomery County, Maryland, where its intake is located. Other differences might be due to population projections or the projected amount of withdrawal per person.

In the power sector, the Wollman report shows a 14 percent increase while the ICPRB study reports a 24 percent water withdrawal increase under base conditions. Comparison with a new power plant in Frederick County and a change in water cooling systems to closed-loop, shows an increase of 46 percent.

The Wollman report did not provide projections for the industrial, livestock, mining or commercial sectors so the total increase could not be compared.

Overall, the reports were difficult to compare given the different geographical scale and sectors analyzed. The Wollman report provided a helpful framework for considering the issues affecting future demands.

### **8.2 ICPRB Section for Cooperative Operations on the Potomac Studies**

#### **8.2.1 Washington Metropolitan Area Water Supply Reliability 2010 Study**

The results of this study were also compared with those of ICPRB's Section for Cooperative Operations on the Potomac's (CO-OP) *2010 Washington Metropolitan Area Water Supply Reliability Study; Part 1: Demand and Resource Availability Forecast for the Year 2040* (Ahmed et al. 2010).

While seemingly attempting to answer the same question – how much water will be needed for human uses in the future – the two studies differ in many ways.

The CO-OP study specifically addressed this question for public water suppliers in the WMA. This differs from the study for the Middle Potomac project which analyzed future demands for all water uses throughout the entire Potomac watershed.

This section takes a look at the CO-OP results in comparison to the domestic and public supply withdrawal forecasts in the low DP scenario (Section 5.3). There is a significant difference in the assumptions about the growth rate of demands between the CO-OP study and the high DP scenario that is also discussed.

Below is a brief explanation of the demand forecasting methods used in the CO-OP study, a summary of results, and a comparison with the demand forecasts presented in this report.

#### **8.2.1.1 ICPRB CO-OP**

CO-OP provides technical assistance and coordination assistance to the WMA's three main water suppliers (Figure 33):

- Washington Aqueduct, serving the District of Columbia via DC Water, as well as Arlington County, the City of Falls Church, and the Town of Vienna, all in Virginia.
- Washington Suburban Sanitary Commission, serving Montgomery and Prince George's counties in Maryland. WSSC also provides a limited amount of water to Howard and Charles counties and is able to provide water on an emergency basis to the City of Rockville and DC Water.
- Fairfax Water, serving most of Fairfax County, Virginia, and the following wholesale customers: Dulles International Airport, Fort Belvoir, Town of Herndon, Loudoun Water, Prince William County Service Authority, and the Virginia American Water Company (serving the City of Alexandria and Dale City).

While sharing the Potomac River as the main source of raw water, these water suppliers have a long history of cooperation. CO-OP supports this cooperative effort by forecasting consumer demand and determining if the existing water supply system can meet these demands in the future. The most recent study was completed in 2010 and provided results for both 2030 and 2040.

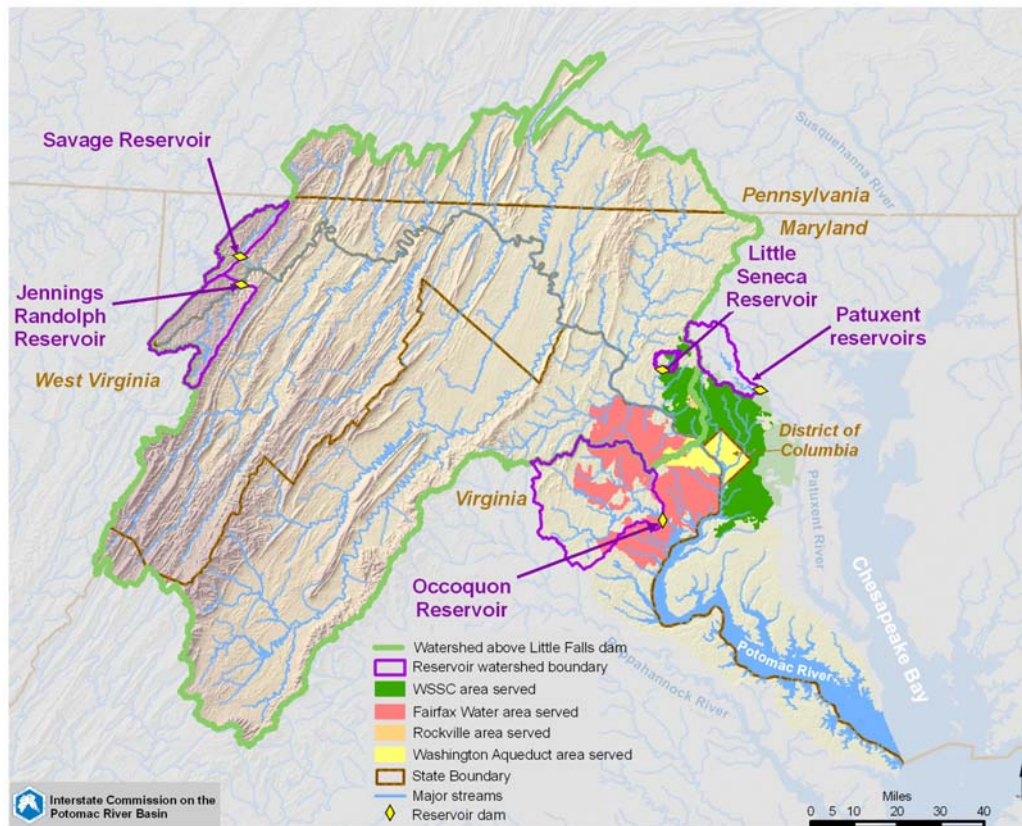


Figure 33. Map of the Potomac River basin, showing WMA water supply system resources and areas served by the WMA water suppliers. The CO-OP study was only concerned with water use WMA.

#### 8.2.1.2 Demand Forecasting Methods

Forecasts of average annual water demand were developed by combining recent water use information derived from billing data provided by the WMA suppliers and their wholesale customers, information on the current and future extent of the areas supplied with water from WMA suppliers and local planning agencies, and the most recent demographic forecasts from the Metropolitan Washington Council of Governments (MWCOG). Forecasts were also made for the City of Rockville.

Water use data was disaggregated into three categories for forecasting purposes: single family households, multi-family households (apartments), and employees (including commercial, industrial, and institutional use).

The MWCOG Round 7.2 Cooperative Forecast (MWCOG 2009) for the year 2040 projects that population in the WMA will increase from 2010 levels by approximately 1 million (24 percent) and total number of households will increase by approximately 480,000 (29 percent). The total number of employees is predicted to increase by approximately 1,100,000 (38 percent).

Water demand forecasts are notoriously inaccurate because of uncertainties in both demographic forecasts and in predictions of future water use behavior. To take these uncertainties into account, this study provided forecasts for two scenarios, the first using assumptions very similar to those of the past two WMA water supply studies by ICPRB, and the second assuming both higher population growth and higher unit use:

Scenario 1 – likely forecast, most consistent with recent studies:

- Based on MWCOG Round 7.2 growth forecasts.
- Assumes that both single family and multi-family household unit water use will decrease throughout the forecast period due to the increased use of low flow plumbing fixtures as mandated by the Energy Policy Act of 1992.

Scenario 2 – high demand forecast:

- Based on MWCOG Round 7.2 growth forecasts, with preliminary estimates of additional water demand due to potential growth in certain areas not considered in the Round 7.2 data.
- Assumes that only multi-family household unit water use will decrease throughout the forecast period and that no water use reductions will occur in single family households because reductions from the Energy Policy Act of 1992 and other indoor conservation measures will be offset by increases in summertime outdoor water use.

#### **8.2.1.3 Demand Forecasting Results**

Water use in the WMA has held relatively steady during the past two decades. Figure 34 shows total average annual, summer, and winter water production by the WMA suppliers, as well as peak-day production from 1990 through 2008. These data are derived from daily production data provided by the WMA suppliers.

Though there are slight upward trends in these data, only average summertime water use has increased at a rate that is statistically significant (at the 10 percent level). Over this same period, population in the WMA increased by about 10 percent, from approximately 3.9 to 4.3 million people.

The average annual demand of the WMA in 2010, including Rockville, was estimated to be approximately 503 MGD in Scenario 1 and 515 MGD in Scenario 2. By 2030, this is projected to increase to 593 MGD (18 percent) under Scenario 1 and 632 MGD (23 percent) under Scenario 2. By the year 2040, WMA demand is forecast to increase to 617 MGD (23 percent) for Scenario 1 or to 671 MGD (30 percent) for Scenario 2.

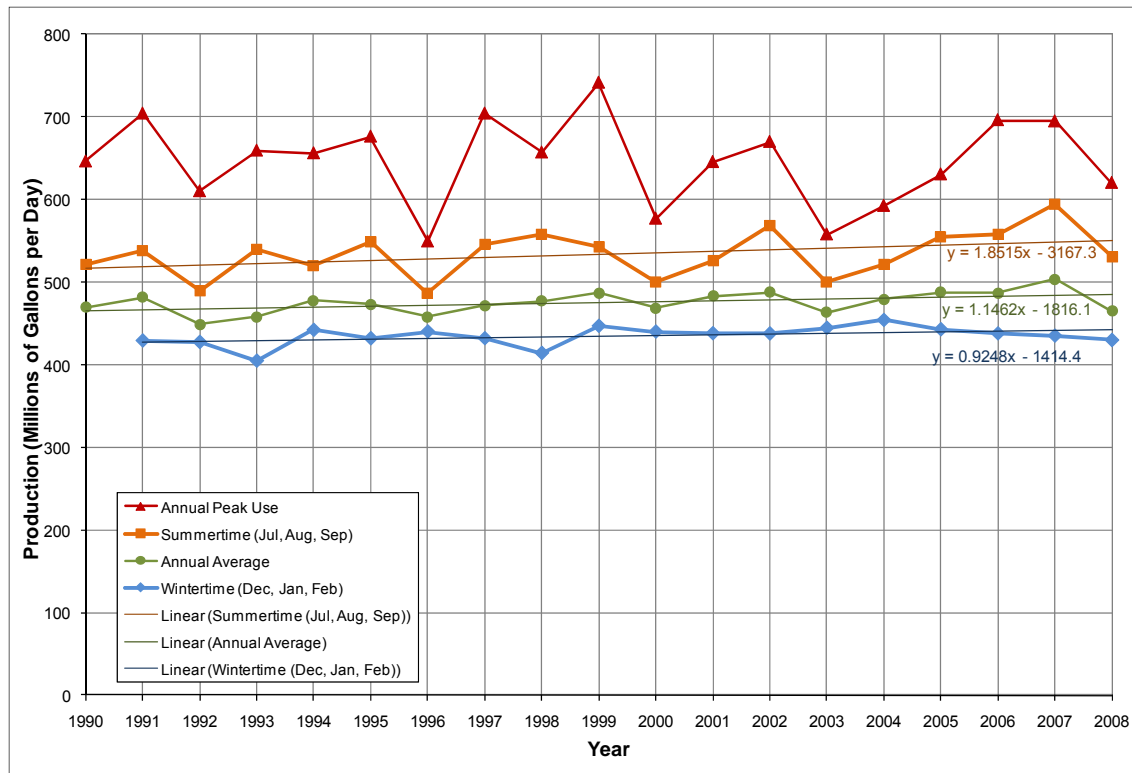


Figure 34. Average annual, summertime, wintertime, and peak day water use for the Washington, D.C., metropolitan area from 1990 through 2008.

#### 8.2.1.4 Study Comparison

A comparison of the 2005 withdrawal data shows that the WMA data for the two studies are consistent (Table 18). The Middle Potomac River Watershed Assessment's low DP scenario (DP1) and CO-OP's Scenario 2 were used for comparison because they had the most similar set of assumptions.

Table 19 shows both studies' forecasts for 2010 and 2030.

Table 18. Reported 2005 withdrawal data from the Middle Potomac River Watershed Assessment and CO-OP studies.

	<b>2005 (MGD)</b>	
	<b>MPRWA</b>	<b>CO-OP<sup>1</sup></b>
WSSC <sup>2</sup>	126.0	172
FW <sup>3</sup>	151.2	152
WAD	163.7	164
Total	440.9	488

<sup>1</sup> Reported values are production values from each utility. The amount of water billed to customers is less than this value.

<sup>2</sup> The WSSC figure from the Middle Potomac study is for their Potomac River withdrawal only. The value reported by CO-OP also includes water withdrawn from the Patuxent River reservoirs.

<sup>3</sup> Both figures for Fairfax Water include their Potomac River and Occoquan Reservoir withdrawals.

Table 19. Middle Potomac and CO-OP study forecasts for 2010 and 2030. The figures between the two studies are not directly comparable. The Middle Potomac study forecasts withdrawals and the CO-OP study forecasts demands.

	<b>2010</b>		<b>2030</b>	
	<b>Middle Potomac – Low DP (MGD)</b>	<b>CO-OP – Scenario 2 (MGD)</b>	<b>Middle Potomac – Low DP (MGD)</b>	<b>CO-OP – Scenario 2 (MGD)</b>
WSSC <sup>1</sup>	129.5	171.9	151.4	203.5
FW <sup>2</sup>	179.6	187.2	264.9	247.3
WAD	168.3	150.9	196.8	175.5
Total	477.4	510.0	613.1	626.3

<sup>1</sup> The WSSC figure from the Middle Potomac study is for their Potomac River withdrawal only. The value reported by CO-OP also includes water withdrawn from the Patuxent River reservoirs.

<sup>2</sup> Both sets of figures for Fairfax Water include their Potomac River and Occoquan Reservoir withdrawals.

A comparison of the demand forecasting methods, spatial scale, and data used in this study and those used in the 2010 CO-OP study is in Table 20 below.

Table 20. Comparison of CO-OP and Middle Potomac River Watershed Assessment methods for estimating future water demand.

	CO-OP Demand Study	MPRWA
Study purpose	Estimate of total demand in the WMA in 2030 and 2040 to assess system reliability; this demand is met through a combination of sources both within and outside the basin.	Estimate water withdrawal rates in the basin through 2030 for use in a flow-ecology relationship analysis
Geographic scope	Supplier service areas (metropolitan Washington area)	Potomac River basin
Geographic analysis unit	Area served and MWCOG's Traffic Analysis Zones	County and watershed
Water use data set	Amount of water sold by WMA suppliers and wholesale customers in 2008; daily WMA supplier production data	USGS and state withdrawal databases for 2005
Water uses considered	Public water supply	self-served domestic and public supply (DP), mining (MI), thermo-electric power (PO), industry (IN), livestock (LV), and irrigation (IR)
Water withdrawals considered	Fairfax Water, Washington Aqueduct, and WSSC.	All ground and surface withdrawals in study area.
Population/household/employee data and assumptions	MWCOG – population, household, and employee forecasts	Chesapeake Bay Program decadal projections interpolated for 5-year periods.
Time horizon – base year and forecast year	2008; 2030 and 2040	2005; 2030
Forecasting method and assumptions	<p>Unit use rates for single family, multi-family, and employees were separately calculated for each water supplier. Unit use rates for each utility from 1990 through 2008 were analyzed for trends. Rates from this analysis were used as the starting point for forecasting future demands.</p> <p>Two scenarios for unit consumption rates (steady or decreasing):  <u>Scenario 1</u> – likely forecast, most consistent with recent studies:  Household and employee numbers based on MWCOG Round 7.2 growth forecasts. Assumes that both single family and multi-family household unit water use will decrease throughout the forecast period due to the increased use of low flow plumbing fixtures as mandated by the Energy Policy Act of 1992.  <u>Scenario 2</u> – high demand forecast:  Household and employee numbers based on MWCOG Round 7.2 growth forecasts, with preliminary estimates of additional water demand due to potential growth in certain areas not considered in the Round 7.2 data.  Assumes that only multi-family household unit water use will decrease throughout the</p>	<p>The rate of change in water use across the basin between 2000 and 2005 was used as the basis.</p> <p>Water withdrawn in a given county is assumed to be used in that same county. For example, the Fairfax Water intake is in Loudoun County so it is attributed to Loudoun County population, not Fairfax County population. In the case of Washington Aqueduct and DC, the DC population was added to the Montgomery County population.</p> <p>Domestic and Public Supply Scenarios:  <u>High DP</u>: Withdrawal per person was calculated for each county and then an average over the counties was taken to get one value for the basin (USGS data). Average annual change in withdrawal per person in the basin between 2000 and 2005 (4.38%). Then USGS 2005 per person withdrawals were increased by 4.38% and multiplied by the projected population for each forecast year.</p> <p><u>Medium DP</u>: Removed outliers from base scenario and came up with a 1.82% increase in per capita withdrawals. Population projections remain the same as baseline.</p> <p><u>Low DP</u>: Assumed no increase in per capita</p>

	forecast period and that no water use reductions will occur in single family households because reductions from the Energy Policy Act of 1992 and other indoor conservation measures will be offset by increases in summertime outdoor water use.	withdrawal. Withdrawals remained the same as they were in 2005. Population projections remain the same as baseline.
--	---	---

#### 8.2.1.5 Annual Water Use Rates

For the most part, the different results between the two studies can be understood based on the specific question being asked and the data and methods used to arrive at an answer. That said, there is one major assumption – annual change in water use rates – that distinguishes the two studies.

The method used in the high DP scenario assumed that per capita water withdrawals for domestic and public supply increased by 4.38 percent each year. This differs to the CO-OP assumption that per household and per employee use rates were either holding steady or decreasing.

This difference can be understood by looking at the USGS withdrawal data (Table 21). This study's per capita water use rate was based on data after combining the withdrawals in the USGS domestic self-served and public supply sectors. To get the per capita rate for the basin, each county's rate was calculated and then an average of all county rates was taken. Because the CO-OP study is only concerned with public water supply, Table 21 also shows public water supply per capita use rates alone.

Calculating the per capita rates in this way shows why this study used an increasing rate of per capita use and why CO-OP's assumption that rates are holding steady or decreasing is also valid.

Table 21. Per capita water use estimates for the public supply sector and combined public supply and domestic self-served sectors. Per capita rates are shown as an average of the individual county rates and as a cumulative basin rate that summed population and withdrawals across all counties before determining the per capita rate. Data source: USGS – Kenny 2009.

	Per capita use estimate (gallons per day)		
	2005	2000	1995
Public supply - average of county rates	150.45	151.78	176.86
Public supply - cumulative basin rate	149.43	159.09	166.18
Public supply and domestic self-supplied - average of county rates	105.89	98.58	111.56
Public supply and domestic self-supplied - cumulative basin rate	138.02	143.24	148.73

### 8.2.2 2000 Water Supply Demands and Resources Analysis in the Potomac River Basin

In 2000, CO-OP quantified consumptive use rates in the basin in the report, *Water Supply Demands and Resources Analysis in the Potomac River Basin* (Steiner et al. 2000). Funding for this study was provided in part by the Maryland Department of Environment.

The results between the CO-OP study and the MPRWA one presented here are not directly comparable since the data and methods vary between the two. That said, the two studies offer similar predictions for future consumptive use rates in the basin.

For this comparison, the MPRWA Hot and Dry scenario (HD) assumptions were applied to the low domestic and public supply scenario (low DP or DP1). This was done to create a scenario that was most similar to the one used in the CO-OP study. These results were not part of the future scenarios used for the MPRWA.

The Steiner et al. study assessed current and future demands, consumptive use rates, and available resources through 2030. At the time the CO-OP study was conducted, the USGS estimates of consumptive use rates by use category (i.e. domestic, commercial, industrial, agricultural) were available. Additionally, both water use and consumptive use were estimated at the county and watershed level. The USGS has discontinued collecting consumptive use data and that by watershed; now only withdrawal rates are reported by county.

Because the USGS is no longer estimating consumptive use and is only providing water use data at the county level, the MPRWA's methods for forecasting withdrawals and consumptive use were more complicated. While this creates some challenges, it may allow the forecasts to better represent possible future conditions rather than relying on past trends.

Of specific interest is the consumptive use rate above the USGS gage at Little Falls dam. There are two reasons for this concern. First, at this location there is a recommended environmental flow-by of 100 MGD. Secondly, the WMA water utilities rely for the most part on the free-flowing river upstream of Little Falls to meet water demands and estimates of upstream consumptive use are used in CO-OP's long-term planning models. The WMA utilities have invested in upstream reservoirs that can augment the natural flow as needed during exceptionally dry periods. If there are significant changes to the available supply, such as an increase in consumptive uses in the basin, new resources may have to be built or management approaches may have to be altered.

This section lays out the different assumptions between the two studies and compares the results when practical.

Figure 35 shows the watershed area above Little Falls by HUC8.

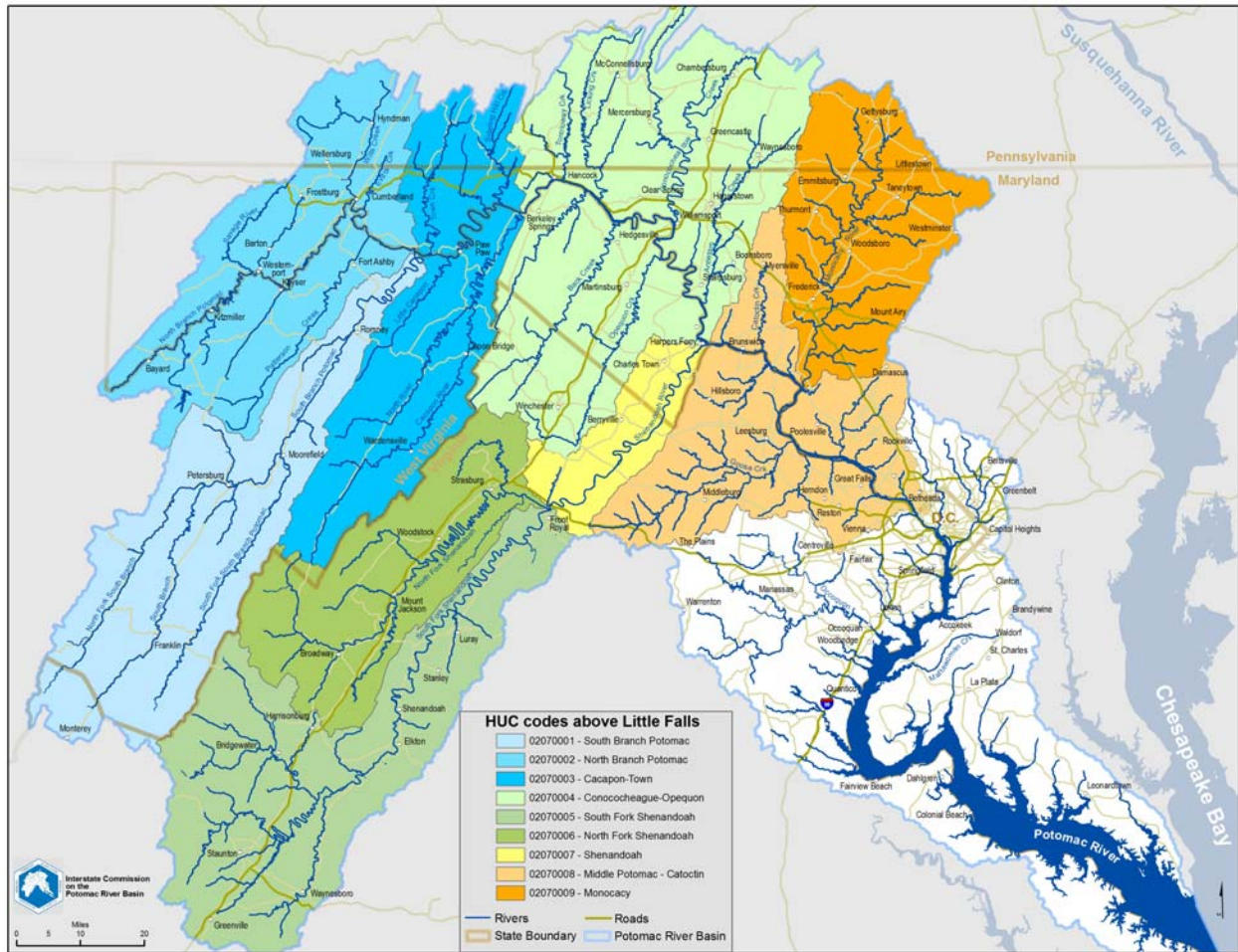


Figure 35. Portion of the basin that drains to Little Falls by sub-watershed (HUC8).

#### 8.2.2.1 2000 Consumptive Use Study Summary

Steiner et al. took two approaches for estimating consumptive use in the basin (Table 23). Both relied on 1995 USGS data as the starting point and made projections through 2030. At the time the USGS was reporting water use and consumptive use rates for the following sectors:

- Domestic,
- commercial,
- industrial,
- thermo-electric power,
- mining,
- livestock, and
- irrigation.

The first approach provided a summary of water use and consumptive use forecasts by state and District of Columbia. This resulted in annual average consumptive use rates through 2030 at a ten-year time step. This analysis did not attempt to evaluate use under hot and dry conditions.

The second approach provided consumptive use forecasts by HUC 8 watershed. The study area was the area above Little Falls and did not include the WMA water utilities. These results represented use in a typical stream flow year.

This forecast by HUC was developed to reflect seasonal use patterns as well as changes that could be expected under dry conditions, similar to the Hot and Dry scenario developed for the MPRWA. To do this, assumptions were made about water use in each sector.

In this second approach, it was assumed that the withdrawal or consumptive use rates for the commercial, industrial, thermoelectric, mining, or livestock sectors would remain constant, but that increases would be seen in the domestic and irrigation sectors. Since the USGS consumptive use estimates for 1995 are not reflective of a dry year where increased withdrawals would be experienced, other data had to be relied on to develop forecasts. This included production data from the WMA utilities and estimates of future number of households, population, and estimates of future irrigated acreage. The methods used to create the domestic and agriculture consumptive use estimates for the hot and dry scenario are outlined below.

The results for this approach focus on June, July, and August, since they are typically the driest months in the region.

#### *Domestic*

The domestic consumptive use rate in the Washington metropolitan area in 1999 was applied to all domestic water users in the basin. The year 1999 was a drought year, so the increases in use are representative of what might occur at a future time.

To determine the consumptive use rate in 1999, the assumption that the increase seen in single family water use rates in June, July, and August, over the winter minimum (experienced in February) represent outdoor water use. This additional amount was considered to be 100 percent consumptively used. Multi-family and employee water use, the other two sub-categories of domestic use, are assumed to remain steady regardless of temperature and precipitation conditions. (A complete explanation of the methods can be found in Steiner et al. 2000, Appendix H.)

This analysis resulted in an indoor water use rate of 71.1 thousand gallons per home and an outdoor rate of 22.7 thousand gallons per home in 1999.

The number of households was estimated using 1990 U.S. Census tract data and increased to represent growth through 1999.

To forecast domestic consumptive use, the average of June through August daily outdoor water use rates per single family household (163 gallons/day/household) was multiplied by the forecasted

number of single family households. As mentioned, this outdoor rate was assumed to be 100 percent consumptive.

### *Irrigation*

To estimate irrigation withdrawals in a hot and dry year, the USGS 1995 data was again used as the starting point. Because 1995 was not a particularly hot or dry year, the use rates were increased by 35 percent across an entire year to simulate conditions in a drought. A recognized method was used to apportion this annual figure to a monthly scale that would capture the peak use months between June and August (see Steiner et al. 2000, Appendix I).

For the purposes of this study, all irrigation was assumed to be 100 percent consumptive.

To forecast for future years, the estimate of consumptive use in June through August was applied to the expected number of irrigated acres in the future.

### *Results*

Based on these assumptions for a hot and dry year in 2030, the June through August consumptive use rate is expected to be 169.1 MGD for the drainage area above Little Falls (Table 22). This is approximately a 30 MGD, or one MGD per year, increase from the expected 2000 rate.

Table 22. Results from Steiner et al. (2000) for forecasts of average consumptive use in June through August of a hot and dry year by HUC (in Steiner et al, pg. 6).

	Consumptive Use Forecast (MGD)			
HUC 8 Name	2000	2010	2020	2030
South Branch Potomac	5.9	6.0	6.1	6.2
North Branch Potomac	24.5	24.6	24.7	24.7
Cacapon-Town	2.0	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	6.0	6.6	7.2	7.8
Middle Potomac-Catoctin <sup>a</sup>	13.8	15.6	17.0	18.5
Monocacy	24.1	27.9	30.4	33.5
<b>Totals</b>	<b>139.1</b>	<b>150.4</b>	<b>159.3</b>	<b>169.1</b>
<b>Totals excluding Mt. Storm<sup>b</sup></b>	<b>128.6</b>	<b>139.9</b>	<b>148.8</b>	<b>158.6</b>

Notes:

<sup>a</sup> The middle Potomac-Catoctin HUC only includes those totals for the non-metro portions of the Washington metropolitan area.

<sup>b</sup> 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.

### *Study Comparison*

The CO-OP and MPRWA studies differ in the data used to create the initial scenario and in the assumptions made to create a hot and dry scenario for 2030 (Table 23).

Because the USGS no longer estimates consumptive use rates or water use at the watershed level, the MPRWA used 2005 data from each of the basin states. This data was reported by monthly withdrawals rates for each individual withdrawal point. To estimate the consumptive use portion of these withdrawals, average rates for each water use sector were used (Table 4).

To adjust the MPRWA's DP1 scenario (no per capita increase in DP water use) to account of conditions in a hot and dry year, withdrawals were increased as follows:

- Domestic and public supply – increased by 15.21 percent from April through August
- Power – increased by 6.15 percent from May through September
- Agriculture – increased by 283.9 percent from May through September

The justification for each of these factors is explained in Section 5.6.

The consumptive use rates for each sector were assumed to remain the same throughout the forecast period.

This method is different from what the CO-OP study assumed. For consumptive use rates, CO-OP's domestic consumptive use was estimated applying the WMA outdoor water use rate expected in 2030 and both this rate and the irrigation withdrawals were assumed to be 100 percent consumptive.

While the MPRWA's study area was the entire Potomac River basin and not just the area above Little Falls, the results could be aggregated by HUC8 because the results were reported by individual withdrawal points. This allowed the results from both studies to be compared by subwatershed above Little Falls.

Table 23. Comparison of the methods used to create future withdrawal and consumptive use forecasts in the MPRWA and CO-OP studies.

	MPRWA				CO-OP			
	DP1		Hot and Dry		State analysis		Hot and Dry - HUC analysis	
	Withdrawals	Consumptive Use	Withdrawals	Consumptive Use	Withdrawals	Consumptive Use	Withdrawals	Consumptive Use
Agriculture (Livestock and Irrigation)	2005 state data; Irrigated land area projections (CBP, USDA)	82%	Increased DP1 283.9% May - September	No change	USGS 1995, Projections of % change in irrigated land cover for eastern U.S.; livestock withdrawals adjusted by population growth	USGS 1995, extrapolated trends	Increased irrigation withdrawals by 35%	Same, made irrigation 100% consumptive
Domestic and Public Supply	2005 state data; Population change (CBP)	11%	Increased DP1 15.21% April - August	No change	USGS 1995, state and county population forecasts, extrapolated existing trends; 2000 demand study	USGS 1995, extrapolated trends	USGS 1995, Population change (CBP)	Applied WMA rate of outdoor water use in June, July, and August, to projected number of households in basin, 100% consumptive
Power	2005 state data; National rate – 0.88%	3%	Increased DP1 6.15% May - September	No change	USGS 1995, extrapolated trends	USGS 1995, extrapolated trends	No change	Total increase capped at 2 MGD, because of Maryland Consumptive Use regulations
Mining	2005 state data; Appalachian rate – 0.30%	15%	No change	No change	USGS 1995, extrapolated trends	USGS 1995, extrapolated trends	No change	No change
Industry	2005 state data; National rate – 1.37%	9%	No change	No change	USGS 1995, extrapolated trends; increase proportional to population growth	USGS 1995, extrapolated trends	No change	No change
Commercial	N/A	N/A	N/A	N/A	USGS 1995, extrapolated trends; increase proportional to population growth	USGS 1995, extrapolated trends	Adjusted for population growth	No change

The consumptive use projections by HUC8 from the two studies are compared in Tables Table 24, Table 27, and Table 28. The tables only show average results for the peak water use months of June through August since that is the time period of greatest concern.

In the CO-OP study the Conococheague-Opequon watershed has the highest consumptive use rate in 2030 (43.5 MGD), whereas in the MPRWA the highest rate is seen in the North Branch (55.50MGD). The lowest 2030 rates are in the Cacapon-Town watershed for both the CO-OP and MPRWA study (2.4 and 0.04 MGD, respectively).

The two studies predict similar increases over their forecast periods. Essentially, the CO-OP study predicts that consumptive use will increase by about one MGD each year between 2000 and 2030. Similarly, the MPRWA shows a potential increase of 25 MGD (20%) between 2005 and 2030.

Clearly, the differences between the two 2030 projections results from the different assumptions made regarding how water use changes during hot and dry periods. The MPRWA assumes that withdrawals drastically increase during these periods, but that the portion consumptively used remains the same. CO-OP study assumes that in the domestic sector, 163 gallons per day will be used consumptively by each basin household in June through August, and that 100 percent of irrigation withdrawals during these months is also consumptive.

Table 24. Estimated average June through August consumptive use (MGD) for the initial year in the CO-OP and MPRWA studies.

<b>HUC8 Name</b>	<b>CO-OP Study – 1995 HD Average June-August Consumptive Use (MGD)</b>	<b>MPRWA Study – 2005 HD Average June-August Consumptive Use (MGD)</b>
South Branch Potomac	5.8	1.4
North Branch Potomac	24.5	45.2
Cacapon-Town	1.9	0.0
Conococheague-Opequon	33.6	18.0
South Fork Shenandoah	18.2	18.2
North Fork Shenandoah	8	5.6
Shenandoah	5.6	1.8
Middle Potomac-Catoctin <sup>a</sup>	12.8	22.9
Monocacy	21.9	11.9
<b>Totals</b>	<b>132.4</b>	<b>125.0</b>

<sup>a</sup>The middle Potomac-Catoctin HUC does not include Fairfax Water, WSSC, Washington Aqueduct, or City of Rockville consumptive use.

Table 25. Estimated 1995 HD average June through August consumptive use (MGD) by sector in the CO-OP study.

	<b>Domestic</b>	<b>Commercial</b>	<b>Industrial</b>	<b>Thermo-electric</b>	<b>Mining</b>	<b>Livestock</b>	<b>Irrigation</b>	<b>Total</b>
South Branch Potomac	1.5	1.0	2.4	0.0	0.0	0.9	0.0	5.8
North Branch Potomac	5.6	0.2	7.0	10.5	0.3	0.5	0.3	24.4
Cacapon-Town	1.2	0.0	0.0	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	33.7
South Fork Shenandoah	10.8	1.1	2.9	0.0	0.0	1.6	1.8	18.2
North Fork Shenandoah	3.1	0.5	0.4	0.0	0.0	2.6	1.4	8
Shenandoah	2.3	0.5	0.9	0.0	0.0	1.5	0.4	5.6
Middle Potomac - Catoctin	4.7	0.2	0.1	3.3	0.0	1.1	3.4	12.8
Monocacy	12.3	0.7	0.8	0.0	0.3	2.0	5.9	22
<b>Total</b>	<b>62.7</b>	<b>5.4</b>	<b>17.1</b>	<b>14.1</b>	<b>0.9</b>	<b>14.1</b>	<b>18.1</b>	<b>132.4</b>

Table 26. Estimated 2005 HD average June through August consumptive use (MGD) by sector in the MPRWA.

	<b>Domestic and Public Supply</b>	<b>Industry</b>	<b>Power</b>	<b>Mining</b>	<b>Agriculture</b>	<b>Total</b>
South Branch Potomac	0.6	0.6	0.0	0.0	0.2	1.4
North Branch Potomac	1.5	3.7	37.7	1.5	0.8	45.2
Cacapon-Town	0.0	0.0	0.0	0.0	0.0	0.0
Conococheague-Opequon	5.6	1.4	1.8	1.4	7.8	18.0
South Fork Shenandoah	3.5	1.4	0.0	0.1	13.2	18.2
North Fork Shenandoah	1.7	0.2	0.0	0.0	3.7	5.6
Shenandoah	0.7	0.0	0.0	0.0	1.1	1.8
Middle Potomac - Catoctin	3.4	0.1	13.2	0.0	6.2	22.9
Monocacy	4.0	0.2	0.0	1.2	6.5	11.9
<b>Total</b>	<b>21.0</b>	<b>7.6</b>	<b>52.7</b>	<b>4.2</b>	<b>39.5</b>	<b>125.0</b>

Table 27. Estimated average June through August consumptive use (MGD) in 2030 in the CO-OP and MPRWA studies.

HUC8 Name	CO-OP 2000 Study – 2030 June-August Average Consumptive Use (MGD)	MPRWA Study – 2030 June-August Average Consumptive Use (MGD)
South Branch Potomac	6.2	1.8
North Branch Potomac	24.7	55.5
Cacapon-Town	2.4	0.04
Conococheague-Opequon	43.5	19.9
South Fork Shenandoah	21.9	26.5
North Fork Shenandoah	10.6	5.7
Shenandoah	7.8	2.5
Middle Potomac-Catoctin <sup>a</sup>	18.5	27.2
Monocacy	33.5	10.6
<b>Totals</b>	<b>169.1</b>	<b>149.8</b>

<sup>a</sup> The middle Potomac-Catoctin HUC does not include Fairfax Water, WSSC, Washington Aqueduct, or City of Rockville consumptive use.

Table 28. Change in average consumptive use rates between the initial study year and 2030 in the CO-OP and MPRWA studies.

HUC8 Name	CO-OP Study – 2030 minus 1995 Average June-August Consumptive Use (MGD)	MPRWA Study – 2030 minus 2005 Average June-August Consumptive Use (MGD)	Percent change in CO-OP study results	Percent change in MPRWA study results
South Branch Potomac	0.4	0.4	7%	29%
North Branch Potomac	0.2	10.3	1%	23%
Cacapon-Town	0.5	0.0	26%	0%
Conococheague-Opequon	9.9	1.9	30%	11%
South Fork Shenandoah	3.7	8.3	20%	46%
North Fork Shenandoah	2.6	0.1	33%	2%
Shenandoah	2.2	0.7	39%	39%
Middle Potomac-Catoctin <sup>a</sup>	5.7	4.3	45%	19%
Monocacy	11.6	-1.3	53%	-11%
<b>Totals</b>	<b>36.7</b>	<b>24.8</b>	<b>28%</b>	<b>20%</b>

<sup>a</sup> The middle Potomac-Catoctin HUC does not include Fairfax Water, WSSC, Washington Aqueduct, or City of Rockville consumptive use.

## References

- Abler, D., J. Shortle, J. Carmichael, and R. Horan. 2002. Climate Change, Agriculture, and Water Quality in the Chesapeake Bay Region. *Climatic Change* 55: 339-359. doi:10.1023/A:1020570526499.
- Abler, D. Personal communication, 2010.
- Anon. n.d. Census of Agriculture, 2007.  
[http://www.agcensus.usda.gov/Publications/2007/Full\\_Report/usv1.pdf](http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf).
- Anon. n.d. IPCC - Intergovernmental Panel on Climate Change.  
[http://www.ipcc.ch/publications\\_and\\_data/publications\\_ipcc\\_fourth\\_assessment\\_report\\_wg1\\_report\\_the\\_physical\\_science\\_basis.htm](http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm).
- Ahmed, Sarah N., Karin R. Bencala, Cherie L. Schultz. 2010. *2010 Washington Metropolitan Area Water Supply Reliability Study; Part 1: Demand and Resource Availability Forecast for the Year 2040*. Interstate Commission on the Potomac River Basin, May.
- Atkins, John T. 2007. *Water-Use Estimates for West Virginia, 2004*. Open-File Report. USGS.
- Bates, Bryson C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof. 2008. *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change. Geneva Switzerland: IPCC Secretariat. <http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf>.
- Boland, John J. 1997. Assessing urban water use and the role of water conservation measures under climate uncertainty. *Climatic Change* 37: 157-176. doi:10.1023/A:1005324621274.
- Brekke, Levi D., Julie E. Kiang, J. Rolf Olsen, Roger S. Pulwarty, David A. Raff, D. Phil Turnipseed, Robert S. Webb, and Kathleen D. White. 2009. *Climate Change and Water Resources Management: A Federal Perspective*. Circular. Reston, Virginia: U.S. Geological Survey.  
<http://pubs.usgs.gov/circ/1331/>.
- Brow, T.C. 1999. *Past and Future Freshwater Use in the United States*. A technical document supporting the 2000 USDA Forest Service RPA Assessment. Fort Collins, CO: U.S.D.A.  
[http://www.fs.fed.us/rm/pubs/rmrs\\_gtr039.html](http://www.fs.fed.us/rm/pubs/rmrs_gtr039.html).
- Buchanan, Claire. Interstate Commission on the Potomac River Basin. Personal communication, 2010.
- Cooke, K. Personal communication, 2010.
- Devereux, Olivia H. 2009. *Estimates of County-Level nitrogen and Phosphorus Data for Use in Modeling Pollutant Reduction*. University of Maryland, College Park and Chesapeake Bay Program, June.  
[http://www.chesapeakebay.net/data\\_modeling.aspx](http://www.chesapeakebay.net/data_modeling.aspx).
- Downing, T. E., R. E. Butterfield, B. Edmonds, J. W. Knox, S. Moss, B. S. Piper, and E. K. Weatherhead. 2003. CCDeW: Climate Change and Demand for Water. *Stockholm Environment Institute, Oxford, England*: 200.

- Dziegielewska, B. and T. Bik. 2006. Water Use Benchmarks for Thermoelectric Power Generation (Project Completion Report). Southern Illinois University (SIU) Carbondale. 213.
- Eberly, M. Maryland Department of the Environment Water Supply. Personal communication, 2010.
- Elcock, Deborah. 2010. Future U.S. Water Consumption: The Role of Energy Production. *JAWRA Journal of the American Water Resources Association - Wiley InterScience* 46, no. 3: 447-460. doi:10.1111.
- Energetics Incorporated, Princeton Energy Resources International, and New West Technologies, LLC. 2009. *Maryland Comprehensive Energy Outlook*. Maryland Energy Administration, July 31.
- Erdman, R. Personal communication, 2010.
- Frederick, Kenneth D. 1997. *Water Resources and Climate Change*. Climate Issues Brief No. 3. Washington, DC: Resources for the Future, June. <http://www.rff.org/rff/documents/rff-ccib-03.pdf>.
- Goldstein, Robert. EPRI. Personal communication, 2010.
- Hagen, Erik R., Roland C. Steiner, and Jan Ducnuigen. 2000. *Water Supply Demands and Resource Analysis in the Potomac River Basin*. Interstate Commission on the Potomac River Basin, November.
- James, R.W. W.J. Moyer, A.J. Wagner, and G.T. Setzer. 2010. *Maryland and the District of Columbia: Floods and Droughts*. U.S. Geological Survey.
- Jarrett, Albert R. 2002a. Agricultural Water Needs and Sources Water Supply. Penn State, August.
- Jarrett, A. Personal communication, 2010.
- . 2002b. Consumptive Water Use Restrictions in the Delaware River Basin. Penn State, September.
- Jarrett, Albert R., and Megan Hamilton. 2002. Estimation of Agricultural Animal and Irrigated-Crop Consumptive Water Use in the Susquehanna River Basin for the Years 1970, 2000 and 2025. Penn State, April.
- Jarrett, Albert R., and Saed Sayyar Roudsari. 2007. Animal and Irrigation Water Use in Pennsylvania in 2002, 2010, 2020, and 2030. Penn State, February.
- Karl, T. R., J. M. Melillo, and T. C. Peterson. 2009. *Global climate change impacts in the United States*. U.S. Global Change Research Program. Cambridge Univ Pr.
- Kellogg, Robert L., Charles H. Lander, David C. Moffitt, and Noel Gollehon. 2000. Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States. USDA-NRCS-ERS, December.

- Kenny, Joan F., Nancy L. Barber, Susan S. Hutson, Kristin S. Linsey, John K. Lovelace, and Molly A. Maupin. 2009. *Estimated Use of Water in the United States in 2005*. Scientific Investigations Report. USGS. <http://pubs.usgs.gov/circ/1344/>.
- Kiang, Julie E., J. Rolf Olsen, Roger S. Pulwarty, David A. Raff, D. Phil Turnipseed, Robert S. Webb, Kathleen D. White, and Levi D. Brekke. 2009. Climate Change and Water Resources Management: A Federal Perspective. *Publications of the US Geological Survey* (January 1). <http://digitalcommons.unl.edu/usgspubs/44>.
- Klett, Michael G., Norma Kuehn, James R. Longanbach, Michael Rutkowski, Ronald L. Schoff, Gary J. Steigel, Vladimir Vaysman, and Jay S. White. 2007. *Power Plant Water Usage and Loss Study*. Environmental & Water Gasification. Washington, DC: U.S. Department of Energy, National Energy Technology Laboratory. [http://www.netl.doe.gov/technologies/coalpower/gasification/pubs/pdf/WaterReport\\_Revised%20May2007.pdf](http://www.netl.doe.gov/technologies/coalpower/gasification/pubs/pdf/WaterReport_Revised%20May2007.pdf).
- Kratovil, R. Personal communication, 2010.
- LaTour, John K. 1991. *Determination of Water Use in Rockford and Kankakee Areas, Illinois*. Water Resources Investigations Report. Urbana, Illinois: USGS.
- Lorie, Mark, and Erik R. Hagen. 2007. Placing Potomac River Droughts in Context Using Synthetic and Paleoclimatic Data. In *World Environment and Water Resources Congress*. American Society of Civil Engineers.
- Lovelace, John K. 2009. *Method for Estimating Water Withdrawals for Livestock in the United States, 2005*. Scientific Investigations Report. USGS. <http://pubs.usgs.gov/sir/2009/5041/pdf/sir2009-5041.pdf>.
- Lovelace, John K. 2009. *Methods for Estimating Water Withdrawals for Mining in the United States, 2005*. USGS.
- MD-DE-DC Water Science Center. 2012. Estimated Annual-Mean Streamflow Entering Chesapeake Bay, By Water Year. USGS. <http://md.water.usgs.gov/waterdata/chesinflow/wy>.
- Mideksa, Torben K., and Steffen Kallbekken. 2010. The impact of climate change on the electricity market: A review. *Energy Policy* 38, no. 7 (July): 3579-3585. doi:10.1016/j.enpol.2010.02.035.
- Mullaney, John R. 2004. *Water Use, Ground-Water Recharge and Availability, and Quality of Water in the Greenwich Area, Fairfield County, Connecticut and Westchester County, New York, 2000-2002*. Water Resources Investigations Report. East Hartford, CT: USGS.
- MWCOG. 2009. Round 7.2 Cooperative Forecasting: Employment, Population, and Household Forecasts to 2030 by Traffic Analysis Zone. Metropolitan Washington Council of Governments. Washington, D.C.
- Najjar, R. Personal communication, 2010.

North American Regional Climate Change Assessment Program, RCM3 and GCM3, last accessed August 2010.

Pachauri, Rajendra, A. Reisinger, and Intergovernmental Panel on Climate Change. 2007. *Climate change 2007: synthesis report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva Switzerland: IPCC.

Reilly, J., F. Tubiello, B. McCarl, D. Abler, R. Darwin, K. Fuglie, S. Hollinger, et al. 2003. U.S. Agriculture and Climate Change: New Results. *Climatic Change* 57, no. 1 (3): 43-67. doi:10.1023/A:1022103315424.

Shaffer, Kimberly H., and Donna L. Runkle. 2007. Consumptive Water-Use Coefficients for the Great Lakes Basin and Climatically Similar Areas. Scientific Investigations Report. USGS.

Steinhilber, P., J. Pease, and D. Hansen. Personal communication, 2010.

Shortle, J., D. Abler, S Blumsack, R Crane, Z Kaufman, M McDill, R Najjar, R Ready, Thorsten Wagener, and D Wardrop. 2009. *Pennsylvania Climate Impact Assessment: Report to the Department of Environmental Protection*. Environment & Natural Resources Institute, The Pennsylvania State University, June 29. <http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-75375/7000-BK-DEP4252.pdf>.

Shuster, Erik. 2009. *Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements*. <http://www.netl.doe.gov/energy-analyses/refshelf/detail.asp?pubID=278>.

Strebel, Don. Versar. Personal communication, 2010.

Sun, Ge, Steven G. McNulty, Jennifer A. Moore Myers, and Erika C. Cohen. 2008. Impacts of Multiple Stresses on Water Demand and Supply across the Southeastern United States. *JAWRA Journal of the American Water Resources Association* 44, no. 6 (12): 1441-1457. doi:10.1111/j.1752-1688.2008.00250.x.

Templin, W.E., R.A. Herbert, C. B. Stainaker, Marilee Horn, and W.B. Solley. 2010. *National Handbook of Recommended Methods for Water Data Acquisition -- Chapter 11 -- Water Use*. U.S. Department of the Interior, U.S.G.S., accessed. <http://pubs.usgs.gov/chapter11/chapter11J.html>.

U.S. Census Bureau. n.d. State and County QuickFacts. <http://quickfacts.census.gov/qfd/index.html>.

U.S. Department of Agriculture. 2009. *2007 Census of Agriculture, 2008 Farm and Ranch Irrigation Survey*. U.S.D.A. [http://www.nass.usda.gov/Surveys/Guide\\_to\\_NASS\\_Surveys/Farm\\_and\\_Ranch\\_Irrigation/index.asp](http://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Farm_and_Ranch_Irrigation/index.asp), [http://www.agcensus.usda.gov/Publications/2007/Online\\_Highlights/Fact\\_Sheets/fris.pdf](http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Fact_Sheets/fris.pdf).

U.S. Department of Energy. 2006. Energy Demands on Water Resources: Report to Congress on the Interdependency of Energy and Water. December.

U.S. Department of the Interior, U.S.G.S. 2009a. *2006 Minerals Yearbook, Pennsylvania*. USGS, August.

———. 2009b. 2006 Minerals Yearbook, West Virginia. USGS, July.

———. 2009c. 2006 Minerals Yearbook, Maryland. USGS, March.

———. 2009d. 2006 Minerals Yearbook, Virginia. USGS, July.

U.S. Energy Information Administration. 2009. *Annual Energy Outlook 2010: Early Release Overview*. Annual Energy Outlook 2010. U.S. EIA, December.

US EPA National Center for Environmental Assessment, Immediate Office, and Susan Julius. 2010. A Method to Assess Climate-Relevant Decisions: Application in the Chesapeake Bay (External Review Draft). DOCUMENT. June.

<http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=227483#Download>.

USDA. 2009. *Census of Agriculture, 2007*. USDA, December.

[http://www.agcensus.usda.gov/Publications/2007/Full\\_Report/index.asp](http://www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp).

Versar. 2010. Maryland Power Plants and the Environment (CEIR-15).

[http://esm.versar.com/pprp/ceir15/Report\\_C.htm](http://esm.versar.com/pprp/ceir15/Report_C.htm).

Vorosmarty, Charles J., Pamela Green, Joseph Salisbury, and Richard B. Lammers. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth. *Science* 289, no. 5477 (July 14): 284-288. doi:10.1126/science.289.5477.284.

Wolman, Markley Gordon. 2008. *Water for Maryland's Future: What We Must Do Today*. July 1.

[http://www.mde.state.md.us/assets/document/WolmanReport\\_Vol1.pdf](http://www.mde.state.md.us/assets/document/WolmanReport_Vol1.pdf).

## Supplemental Tables

Supplemental Table 1. Population of entire Potomac River basin and Middle Potomac study area.

See notes below end of table.

State	FIPS	Jurisdiction	Potomac watershed			Middle Potomac watershed		
		Name	2005	2010	2030	2005	2010	2030
DC	11001	District of Columbia	582,049	601,723	678,495	582,049	601,723	678,495
MD	24001	Allegany County	72,777	75,087	72,900	10,917	11,263	10,935
MD	24013	Carroll County	55,078	55,135	73,514	55,078	55,135	73,514
MD	24017	Charles County	131,133	139,996	193,761	0	0	0
MD	24021	Frederick County	219,381	233,319	334,946	219,381	233,319	334,946
MD	24023	Garrett County	4,946	5,015	5,374	0	0	0
MD	24031	Montgomery County	894,894	944,215	1,096,474	894,894	944,215	1,096,474
MD	24033	Prince George's County	556,209	572,974	644,067	528,399	544,325	611,864
MD	24037	St. Mary's County	72,709	78,846	93,594	0	0	0
MD	24043	Washington County	141,252	147,430	189,950	141,252	147,430	189,950
PA	42001	Adams County	46,293	47,460	83,277	46,293	47,460	83,277
PA	42009	Bedford County	6,548	6,569	7,037	3,929	3,941	4,222
PA	42055	Franklin County	123,077	134,385	148,134	123,077	134,385	148,134
PA	42057	Fulton County	11,824	12,031	12,645	11,824	12,031	12,645
PA	42111	Somerset County	1,853	1,835	1,876	0	0	0
VA	51013	Arlington County	199,761	207,627	238,335	199,761	207,627	238,335
VA	51015	Augusta County	64,390	68,808	80,349	64,390	68,808	80,349
VA	51043	Clarke County	14,011	14,034	18,492	14,011	14,034	18,492
VA	51059	Fairfax County	1,005,616	1,081,726	1,320,217	1,005,616	1,081,726	1,320,217
VA	51061	Fauquier County	37,865	38,402	76,944	37,865	38,402	76,944
VA	51069	Frederick County	68,555	78,305	114,539	68,555	78,305	114,539
VA	51091	Highland County	858	815	818	858	815	818
VA	51099	King George County	14,600	16,726	22,895	0	0	0
VA	51107	Loudoun County	253,631	312,311	467,693	253,631	312,311	467,693
VA	51133	Northumberland County	5,346	5,147	6,604	0	0	0
VA	51139	Page County	23,728	24,042	27,038	23,728	24,042	27,038
VA	51153	Prince William County	345,349	402,002	551,171	241,744	281,401	385,820
VA	51165	Rockingham County	71,639	76,314	91,450	71,639	76,314	91,450
VA	51171	Shenandoah County	38,927	41,993	56,927	38,927	41,993	56,927
VA	51179	Stafford County	78,351	86,698	139,805	0	0	0
VA	51187	Warren County	34,918	37,471	52,945	34,918	37,471	52,945
VA	51193	Westmoreland County	14,307	14,783	16,313	0	0	0
VA	51510	Alexandria city	137,602	139,966	169,185	137,602	139,966	169,185

State	FIPS	Jurisdiction	Potomac watershed			Middle Potomac watershed		
		Name	2005	2010	2030	2005	2010	2030
VA	51600	Fairfax city	22,030	22,565	26,270	22,030	22,565	26,270
VA	51610	Falls Church city	10,808	12,332	15,340	10,808	12,332	15,340
VA	51660	Harrisonburg city	42,689	48,914	57,026	42,689	48,914	57,026
VA	51683	Manassas city	36,898	37,821	41,244	36,898	37,821	41,244
VA	51685	Manassas Park city	11,593	14,273	16,798	11,593	14,273	16,798
VA	51790	Staunton city	23,402	23,746	22,235	23,402	23,746	22,235
VA	51820	Waynesboro city	21,123	21,006	28,015	21,123	21,006	28,015
VA	51840	Winchester city	25,640	26,203	32,458	25,640	26,203	32,458
WV	54003	Berkeley County	92,608	104,169	109,098	92,608	104,169	109,098
WV	54023	Grant County	11,591	11,937	13,853	5,796	5,969	6,927
WV	54027	Hampshire County	21,740	23,964	27,606	21,740	23,964	27,606
WV	54031	Hardy County	13,372	14,025	16,624	13,372	14,025	16,624
WV	54037	Jefferson County	48,542	53,498	74,419	48,542	53,498	74,419
WV	54057	Mineral County	26,856	28,212	29,045	2,686	2,821	2,905
WV	54065	Morgan County	15,869	17,541	21,035	15,869	17,541	21,035
WV	54071	Pendleton County	7,790	7,695	9,012	7,790	7,695	9,012
TOTAL			5,762,028	6,171,091	7,627,842	5,212,924	5,574,984	6,852,220

#### Notes on population estimates

1. 2010 population: U.S. Census blocks for counties and cities (by FIPS code) wholly or partly in the Potomac basin were assigned in or out of the Potomac and Middle Potomac watersheds based on block centroid location. Within watershed block level counts were summed to provide watershed population counts by FIPS code. This was deemed the most accurate estimate of watershed population and the fraction of within watershed population to total population by FIPS jurisdiction was used to adjust estimates of 2005 and 2030 population.
2. 2005 population. U.S. Census estimate of 2005 population by FIPS jurisdiction multiplied by the fraction of total FIPS population within watershed.
3. 2030 population. U.S. EPA Chesapeake Bay Program Office population projection for 2030 by FIPS jurisdiction (Peter Claggett, pers. communication, 5/18/2010), multiplied by the fraction of total FIPS population within watershed.
4. Potomac watershed includes the entire Potomac basin, including coastal plain. Middle Potomac watershed includes the area encompassed by the Middle Potomac River Watershed Assessment and does not include the North Branch.

Supplemental Table 2. Base Year scenario 2005.

Withdrawals and consumptive use estimates for the year 2005 by county for three regions: the entire Potomac River Basin (Potomac), the Middle Potomac River Watershed Assessment study area (MPRWA), and the Potomac River basin above the fall-line at Little Falls.

Units: million gallons per year

State	County	FIPS	Withdrawals 2005			Consumption 2005		
			Potomac	MPRWA	AFL	Potomac	MPRWA	AFL
Maryland	Allegany	24001	380	380	380	76	76	76
	Carroll	24013	1,572	1,572	1,572	244	244	244
	Charles	24017	358,155	-	-	13,917	-	-
	Frederick MD	24021	14,872	14,872	14,872	1,965	1,965	1,965
	Garrett	24023	4,649	4,649	4,649	679	679	679
	Montgomery	24031	249,397	249,397	249,327	112,342	112,342	112,288
	Prince George's	24033	499	150	-	270	139	-
	St. Mary's	24037	4,235	-	-	2,030	-	-
	Washington	24043	16,251	16,251	16,251	1,083	1,083	1,083
Pennsylvania	Adams	42001	2,629	2,629	2,629	329	329	329
	Bedford	42009	3,303	3,303	3,303	363	363	363
	Franklin	42055	3,637	3,637	3,637	750	750	750
	Fulton	42057	149	149	149	17	17	17
Virginia	Arlington	51013	47	-	-	27	-	-
	Augusta	51015	3,613	3,613	3,613	511	511	511
	Clarke	51043	245	245	245	43	43	43
	Fairfax	51059	507	397	178	504	393	178
	Fauquier	51061	908	908	78	100	100	9
	Frederick VA	51069	1,607	1,607	1,607	177	177	177
	King George	51099	249	-	-	27	-	-
	Loudoun	51107	41,285	41,285	41,258	4,557	4,557	4,535
	Northumberland	51133	37	-	-	6	-	-
	Page	51139	703	703	703	92	92	92
	Prince William	51153	90,669	25,234	-	4,755	2,791	-
	Rockingham	51165	8,738	8,738	8,738	1,061	1,061	1,061
	Shenandoah	51171	1,809	1,809	1,809	198	198	198
	Stafford	51179	4,538	-	-	508	-	-
	Warren	51187	3,715	3,715	3,715	630	630	630
	Westmoreland	51193	301	-	-	36	-	-
	Alexandria	51510	85,817	8	-	2,575	1	-
	Harrisonburg	51660	62	62	62	7	7	7

			Withdrawals 2005				Consumption 2005		
	Manassas	51683	49	49	-		5	5	-
	Manassas Park	51685	148	148	-		16	16	-
	Staunton	51790	15	15	15		4	4	4
	Waynesboro	51820	2,589	2,589	2,589		257	257	257
	Winchester	51840	54	54	54		5	5	5
West Virginia	Berkeley	54003	6,786	6,786	6,786		671	671	671
	Grant	54023	406,954	406,954	406,954		12,325	12,325	12,325
	Hampshire	54027	176	176	176		19	19	19
	Hardy	54031	1,462	1,462	1,462		169	169	169
	Jefferson	54037	1,990	1,990	1,990		257	257	257
	Mineral	54057	15,466	15,466	15,466		1,393	1,393	1,393
	Morgan	54065	832	832	832		101	101	101
	Pendleton	54071	601	601	601		57	57	57
Total			1,341,698	822,434	795,699		165,161	143,829	140,493

Supplemental Table 3. High Domestic and Public (DP3) scenario 2030.

A 4.38 percent per year increase in per capita withdrawal in domestic and public supply (referred to as “base” in Appendix B).

Units: million gallons per year

State	County	FIPS	Withdrawals 2030			Consumption 2030		
			Potomac	MPRWA	AFL	Potomac	MPRWA	AFL
Maryland	Allegany	24001	976	976	976	117	117	117
	Carroll	24013	3,654	3,654	3,654	450	450	450
	Charles	24017	455,044	-	-	27,055	-	-
	Frederick MD	24021	55,121	55,121	55,121	6,223	6,223	6,223
	Garrett	24023	5,977	5,977	5,977	838	838	838
	Montgomery	24031	553,342	553,342	553,316	382,994	382,994	382,975
	Prince George's	24033	804	308	-	568	305	-
	St. Mary's	24037	8,852	-	-	6,482	-	-
	Washington	24043	30,662	30,662	30,662	2,426	2,426	2,426
Penn-sylvania	Adams	42001	12,699	12,699	12,699	1,437	1,437	1,437
	Bedford	42009	10,343	10,343	10,343	1,138	1,138	1,138
	Franklin	42055	10,191	10,191	10,191	1,500	1,500	1,500
	Fulton	42057	463	463	463	52	52	52
Virginia	Arlington	51013	60	-	-	10	-	-
	Augusta	51015	11,077	11,077	11,077	1,408	1,408	1,408
	Clarke	51043	886	886	886	121	121	121
	Fairfax	51059	1,814	1,391	679	1,813	1,391	679
	Fauquier	51061	5,315	5,315	464	585	585	51
	Frederick VA	51069	7,735	7,735	7,735	851	851	851
	King George	51099	1,138	-	-	125	-	-
	Loudoun	51107	220,234	220,234	220,209	24,236	24,236	24,216
	Northumberland	51133	76	-	-	10	-	-
	Page	51139	2,043	2,043	2,043	242	242	242
	Prince William	51153	197,285	115,903	-	15,210	12,766	-
	Rockingham	51165	23,843	23,843	23,843	2,768	2,768	2,768
	Shenandoah	51171	5,867	5,867	5,867	642	642	642
	Stafford	51179	22,629	-	-	2,499	-	-
	Warren	51187	15,228	15,228	15,228	1,812	1,812	1,812
	Westmoreland	51193	983	-	-	111	-	-
	Alexandria	51510	106,705	11	-	3,202	1	-
	Harrisonburg	51660	231	231	231	25	25	25
	Manassas	51683	227	227	-	25	25	-
	Manassas Park	51685	626	626	-	69	69	-
	Staunton	51790	45	45	45	10	10	10
	Waynesboro	51820	6,341	6,341	6,341	659	659	659
	Winchester	51840	76	76	76	7	7	7

			Withdrawals 2030			Consumption 2030		
West Virginia	Berkeley	54003	15,654	15,654	15,654	1,616	1,616	1,616
	Grant	54023	506,438	506,438	506,438	15,367	15,367	15,367
	Hampshire	54027	651	651	651	72	72	72
	Hardy	54031	5,266	5,266	5,266	588	588	588
	Jefferson	54037	5,813	5,813	5,813	666	666	666
	Mineral	54057	21,807	21,807	21,807	1,966	1,966	1,966
	Morgan	54065	1,636	1,636	1,636	189	189	189
	Pendleton	54071	1,074	1,074	1,074	106	106	106
Total			2,336,929	1,659,154	1,536,465	508,289	465,667	451,217

Supplemental Table 4. Medium Domestic and Public (DP2) scenario 2030.

A 1.82 percent per year increase in per capita withdrawal in domestic and public supply.

Units: million gallons per year

State	County	FIPS	Withdrawals 2030			Consumption 2030		
			Potomac	MPRWA	AFL	Potomac	MPRWA	AFL
Maryland	Allegany	24001	535	535	535	69	69	69
	Carroll	24013	2,381	2,381	2,381	310	310	310
	Charles	24017	448,687	-	-	20,698	-	-
	Frederick MD	24021	31,307	31,307	31,307	3,603	3,603	3,603
	Garrett	24023	5,298	5,298	5,298	763	763	763
	Montgomery	24031	379,036	379,036	379,010	208,687	208,687	208,669
	Prince George's	24033	571	175	-	335	172	-
	St. Mary's	24037	6,057	-	-	3,687	-	-
	Washington	24043	23,431	23,431	23,431	1,630	1,630	1,630
Penn-sylvania	Adams	42001	6,967	6,967	6,967	807	807	807
	Bedford	42009	5,569	5,569	5,569	613	613	613
	Franklin	42055	6,015	6,015	6,015	1,040	1,040	1,040
	Fulton	42057	250	250	250	28	28	28
Virginia	Arlington	51013	35	-	-	7	-	-
	Augusta	51015	6,595	6,595	6,595	915	915	915
	Clarke	51043	493	493	493	77	77	77
	Fairfax	51059	992	765	366	992	764	366
	Fauquier	51061	2,868	2,868	250	316	316	27
	Frederick VA	51069	4,179	4,179	4,179	460	460	460
	King George	51099	612	-	-	67	-	-
	Loudoun	51107	118,820	118,820	118,796	13,081	13,081	13,061
	Northumberland	51133	57	-	-	8	-	-
	Page	51139	1,194	1,194	1,194	149	149	149
	Prince William	51153	143,973	62,604	-	9,346	6,903	-
	Rockingham	51165	15,247	15,247	15,247	1,822	1,822	1,822
	Shenandoah	51171	3,575	3,575	3,575	390	390	390
	Stafford	51179	12,300	-	-	1,363	-	-
	Warren	51187	8,288	8,288	8,288	1,049	1,049	1,049
	Westmoreland	51193	534	-	-	62	-	-
	Alexandria	51510	106,705	11	-	3,202	1	-
	Harrisonburg	51660	124	124	124	14	14	14
	Manassas	51683	122	122	-	13	13	-
	Manassas Park	51685	337	337	-	37	37	-

			Withdrawals 2030			Consumption 2030		
	Staunton	51790	27	27	27	8	8	8
	Waynesboro	51820	4,380	4,380	4,380	443	443	443
	Winchester	51840	76	76	76	7	7	7
West Virginia	Berkeley	54003	10,870	10,870	10,870	1,090	1,090	1,090
	Grant	54023	506,343	506,343	506,343	15,356	15,356	15,356
	Hampshire	54027	350	350	350	39	39	39
	Hardy	54031	2,841	2,841	2,841	322	322	322
	Jefferson	54037	3,750	3,750	3,750	439	439	439
	Mineral	54057	21,736	21,736	21,736	1,958	1,958	1,958
	Morgan	54065	1,211	1,211	1,211	142	142	142
	Pendleton	54071	888	888	888	85	85	85
Total			1,895,627	1,238,659	1,172,342	295,530	263,603	255,751

Supplemental Table 5. Low Domestic and Public (DP1) scenario 2030.

A 0 percent per year increase in per capita withdrawal in domestic and public supply (increase in total withdrawals is due solely to population growth).

Units: million gallons per year

State	County	FIPS	Withdrawals 2030			Consumption 2030		
			Potomac	MPRWA	AFL	Potomac	MPRWA	AFL
Maryland	Allegany	24001	348	348	348	48	48	48
	Carroll	24013	1,842	1,842	1,842	250	250	250
	Charles	24017	445,999	-	-	18,010	-	-
	Frederick MD	24021	21,238	21,238	21,238	2,496	2,496	2,496
	Garrett	24023	5,011	5,011	5,011	731	731	731
	Montgomery	24031	305,337	305,337	305,310	134,988	134,988	134,970
	Prince George's	24033	472	119	-	237	115	-
	St. Mary's	24037	4,876	-	-	2,506	-	-
	Washington	24043	20,373	20,373	20,373	1,294	1,294	1,294
Penn-sylvania	Adams	42001	4,544	4,544	4,544	540	540	540
	Bedford	42009	3,550	3,550	3,550	391	391	391
	Franklin	42055	4,249	4,249	4,249	846	846	846
	Fulton	42057	160	160	160	18	18	18
Virginia	Arlington	51013	24	-	-	6	-	-
	Augusta	51015	4,699	4,699	4,699	707	707	707
	Clarke	51043	327	327	327	59	59	59
	Fairfax	51059	644	500	233	644	499	233
	Fauquier	51061	1,833	1,833	159	202	202	18
	Frederick VA	51069	2,676	2,676	2,676	294	294	294
	King George	51099	390	-	-	43	-	-
	Loudoun	51107	75,942	75,942	75,917	8,364	8,364	8,344
	Northumberland	51133	48	-	-	7	-	-
	Page	51139	836	836	836	110	110	110
	Prince William	51153	121,432	40,068	-	6,866	4,424	-
	Rockingham	51165	11,612	11,612	11,612	1,422	1,422	1,422
	Shenandoah	51171	2,606	2,606	2,606	284	284	284
	Stafford	51179	7,933	-	-	882	-	-
	Warren	51187	5,354	5,354	5,354	726	726	726
	Westmoreland	51193	344	-	-	41	-	-
	Alexandria	51510	106,705	11	-	3,202	1	-
	Harrisonburg	51660	79	79	79	9	9	9
	Manassas	51683	78	78	-	9	9	-
	Manassas Park	51685	215	215	-	24	24	-
	Staunton	51790	20	20	20	7	7	7
	Waynesboro	51820	3,551	3,551	3,551	352	352	352
	Winchester	51840	76	76	76	7	7	7

			Withdrawals 2030			Consumption 2030		
West Virginia	Berkeley	54003	8,847	8,847	8,847	867	867	867
	Grant	54023	506,304	506,304	506,304	15,352	15,352	15,352
	Hampshire	54027	223	223	223	25	25	25
	Hardy	54031	1,816	1,816	1,816	209	209	209
	Jefferson	54037	2,878	2,878	2,878	343	343	343
	Mineral	54057	21,706	21,706	21,706	1,955	1,955	1,955
	Morgan	54065	1,032	1,032	1,032	122	122	122
	Pendleton	54071	810	810	810	77	77	77
Total			1,709,039	1,060,868	1,018,386	205,572	178,168	173,106

Supplemental Table 6. Hot and Dry (HD) scenario 2030.

Domestic and public supply sector withdrawals increased by 15.2 percent during April through August. Power sector withdrawals increased by 6.15 percent during May through September. Irrigation sector withdrawals increased by 284 percent during May through September. This scenario builds on the DP2 growth rate for domestic and public supply.

Units: million gallons per day

State	County	FIPS	Withdrawals 2030			Consumptive Use 2030		
			Potomac	MPRWA	AFL	Potomac	MPRWA	AFL
Maryland	Allegany	24001	602	602	602	99	99	99
	Carroll	24013	2,525	2,525	2,525	361	361	361
	Charles	24017	462,860	-	-	21,626	-	-
	Frederick MD	24021	33,346	33,346	33,346	4,009	4,009	4,009
	Garrett	24023	5,347	5,347	5,347	768	768	768
	Montgomery	24031	397,494	397,494	397,415	222,518	222,518	222,456
	Prince George's	24033	669	233	-	418	220	-
	St. Mary's	24037	6,300	-	-	3,926	-	-
	Washington	24043	24,701	24,701	24,701	1,797	1,797	1,797
Penn-- sylvania	Adams	42001	7,490	7,490	7,490	934	934	934
	Bedford	42009	5,925	5,925	5,925	652	652	652
	Franklin	42055	6,991	6,991	6,991	1,631	1,631	1,631
	Fulton	42057	268	268	268	32	32	32
Virginia	Arlington	51013	49	-	-	16	-	-
	Augusta	51015	7,763	7,763	7,763	1,630	1,630	1,630
	Clarke	51043	613	613	613	154	154	154
	Fairfax	51059	1,089	839	402	1,089	839	402
	Fauquier	51061	3,062	3,062	265	337	337	29
	Frederick VA	51069	4,451	4,451	4,451	489	489	489
	King George	51099	653	-	-	72	-	-
	Loudoun	51107	127,115	127,115	127,038	14,039	14,039	13,977
	Northumberland	51133	68	-	-	17	-	-
	Page	51139	1,340	1,340	1,340	219	219	219
	Prince William	51153	150,553	66,922	-	9,889	7,378	-
	Rockingham	51165	16,814	16,814	16,814	2,643	2,643	2,643
	Shenandoah	51171	3,808	3,808	3,808	458	458	458
	Stafford	51179	13,123	-	-	1,453	-	-
	Warren	51187	9,047	9,047	9,047	1,292	1,292	1,292
	Westmoreland	51193	580	-	-	74	-	-
	Alexandria	51510	110,014	11	-	3,301	1	-

		Withdrawals 2030				Consumptive Use 2030		
	Harrisonburg	51660	138	138	138	15	15	15
	Manassas	51683	130	130	-	14	14	-
	Manassas Park	51685	358	358	-	39	39	-
	Staunton	51790	48	48	48	23	23	23
	Waynesboro	51820	4,529	4,529	4,529	466	466	466
	Winchester	51840	76	76	76	7	7	7
West Virginia	Berkeley	54003	11,230	11,230	11,230	1,130	1,130	1,130
	Grant	54023	520,174	520,174	520,174	15,772	15,772	15,772
	Hampshire	54027	373	373	373	41	41	41
	Hardy	54031	3,058	3,058	3,058	369	369	369
	Jefferson	54037	4,019	4,019	4,019	545	545	545
	Mineral	54057	21,742	21,742	21,742	1,959	1,959	1,959
	Morgan	54065	1,243	1,243	1,243	146	146	146
	Pendleton	54071	901	901	901	87	87	87
Total		1,972,679	1,294,725	1,223,683	316,557	283,114	274,592	

Supplemental Table 7. Climate Change (CC) scenario 2030.

Applies Intergovernmental Panel on Climate Change (IPCC) projections for temperature increase and consequent changes in irrigation, power demand, and summer demand for domestic and public supply. This scenario builds on the DP2 growth rate for domestic and public supply.

Units: million gallons per year

State	County	FIPS	Withdrawal 2030			Consumption 2030		
			Potomac	MPRWA	AFL	Potomac	MPRWA	AFL
Maryland	Allegany	24001	1,006	1,006	1,006	126	126	126
	Carroll	24013	3,733	3,733	3,733	466	466	466
	Charles	24017	467,865	-	-	27,804	-	-
	Frederick MD	24021	56,509	56,509	56,509	6,422	6,422	6,422
	Garrett	24023	6,012	6,012	6,012	842	842	842
	Montgomery	24031	568,132	568,132	568,095	393,321	393,321	393,294
	Prince George's	24033	839	328	-	599	323	-
	St. Mary's	24037	9,023	-	-	6,652	-	-
	Washington	24043	31,784	31,784	31,784	2,520	2,520	2,520
Penn- sylvania	Adams	42001	13,042	13,042	13,042	1,493	1,493	1,493
	Bedford	42009	10,603	10,603	10,603	1,166	1,166	1,166
	Franklin	42055	10,660	10,660	10,660	1,728	1,728	1,728
	Fulton	42057	476	476	476	54	54	54
Virginia	Arlington	51013	65	-	-	12	-	-
	Augusta	51015	11,476	11,476	11,476	1,558	1,558	1,558
	Clarke	51043	925	925	925	137	137	137
	Fairfax	51059	1,894	1,452	708	1,893	1,452	708
	Fauquier	51061	5,460	5,460	476	601	601	52
	Frederick VA	51069	7,937	7,937	7,937	873	873	873
	King George	51099	1,167	-	-	128	-	-
	Loudoun	51107	226,617	226,617	226,580	24,948	24,948	24,919
	Northumberland	51133	79	-	-	12	-	-
	Page	51139	2,109	2,109	2,109	260	260	260
	Prince William	51153	202,670	119,134	-	15,630	13,121	-
	Rockingham	51165	24,501	24,501	24,501	2,959	2,959	2,959
	Shenandoah	51171	6,005	6,005	6,005	665	665	665
	Stafford	51179	23,274	-	-	2,570	-	-
	Warren	51187	15,734	15,734	15,734	1,937	1,937	1,937
	Westmoreland	51193	1,012	-	-	116	-	-
	Alexandria	51510	109,554	11	-	3,287	1	-
	Harrisonburg	51660	242	242	242	27	27	27
	Manassas	51683	232	232	-	26	26	-
	Manassas Park	51685	640	640	-	70	70	-
	Staunton	51790	50	50	50	12	12	12
	Waynesboro	51820	6,452	6,452	6,452	673	673	673

		Withdrawal 2030				Consumption 2030		
	Winchester	51840	76	76	76	7	7	7
West Virginia	Berkeley	54003	15,947	15,947	15,947	1,648	1,648	1,648
	Grant	54023	519,943	519,943	519,943	15,772	15,772	15,772
	Hampshire	54027	668	668	668	73	73	73
	Hardy	54031	5,416	5,416	5,416	609	609	609
	Jefferson	54037	5,972	5,972	5,972	711	711	711
	Mineral	54057	21,811	21,811	21,811	1,966	1,966	1,966
	Morgan	54065	1,659	1,659	1,659	191	191	191
	Pendleton	54071	1,083	1,083	1,083	107	107	107
Total		2,400,356	1,703,839	1,577,692	522,672	478,866	463,974	

Supplemental Table 8. Power (PO) scenario 2030.

New power plant on the Monocacy River in Frederick County, MD, and conversion from open cycle to closed cycle cooling at power plants (increased consumptive use but dramatically reduced withdrawals). This scenario builds on the DP2 growth rate for domestic and public supply.

Units: million gallons per year

State	County	FIPS	Withdrawals 2030			Consumption 2030		
			Potomac	MPRWA	AFL	Potomac	MPRWA	AFL
Maryland	Allegany	24001	535	535	535	69	69	69
	Carroll	24013	2,381	2,381	2,381	310	310	310
	Charles	24017	448,687	-	-	20,698	-	-
	Frederick MD	24021	80,377	80,377	80,377	20,718	20,718	20,718
	Garrett	24023	5,298	5,298	5,298	763	763	763
	Montgomery	24031	252,568	252,568	252,568	220,535	220,535	220,535
	Prince George's	24033	571	175	-	335	172	-
	St. Mary's	24037	6,057	-	-	3,687	-	-
	Washington	24043	14,240	14,240	14,240	2,491	2,491	2,491
Pennsylvania	Adams	42001	6,967	6,967	6,967	807	807	807
	Bedford	42009	5,569	5,569	5,569	613	613	613
	Franklin	42055	6,015	6,015	6,015	1,040	1,040	1,040
	Fulton	42057	250	250	250	28	28	28
Virginia	Arlington	51013	35	-	-	7	-	-
	Augusta	51015	6,595	6,595	6,595	915	915	915
	Clarke	51043	493	493	493	77	77	77
	Fairfax	51059	992	765	366	992	764	366
	Fauquier	51061	2,868	2,868	250	316	316	27
	Frederick VA	51069	4,179	4,179	4,179	460	460	460
	King George	51099	612	-	-	67	-	-
	Loudoun	51107	118,820	118,820	118,796	13,081	13,081	13,061
	Northumberland	51133	57	-	-	8	-	-
	Page	51139	1,194	1,194	1,194	149	149	149
	Prince William	51153	143,973	62,604	-	9,346	6,903	-
	Rockingham	51165	15,247	15,247	15,247	1,822	1,822	1,822
	Shenandoah	51171	3,575	3,575	3,575	390	390	390
	Stafford	51179	12,300	-	-	1,363	-	-
	Warren	51187	8,288	8,288	8,288	1,049	1,049	1,049
	Westmoreland	51193	534	-	-	62	-	-
	Alexandria	51510	1,382	11	-	1,194	1	-
	Harrisonburg	51660	124	124	124	14	14	14

			Withdrawals 2030			Consumption 2030		
	Manassas	51683	122	122	-	13	13	-
	Manassas Park	51685	337	337	-	37	37	-
	Staunton	51790	27	27	27	8	8	8
	Waynesboro	51820	4,380	4,380	4,380	443	443	443
	Winchester	51840	76	76	76	7	7	7
West Virginia	Berkeley	54003	10,870	10,870	10,870	1,090	1,090	1,090
	Grant	54023	506,343	506,343	506,343	15,356	15,356	15,356
	Hampshire	54027	350	350	350	39	39	39
	Hardy	54031	2,841	2,841	2,841	322	322	322
	Jefferson	54037	3,750	3,750	3,750	439	439	439
	Mineral	54057	21,736	21,736	21,736	1,958	1,958	1,958
	Morgan	54065	1,211	1,211	1,211	142	142	142
	Pendleton	54071	888	888	888	85	85	85
Total			1,703,715	1,152,070	1,085,753	323,346	293,427	285,575

Supplemental Table 9. Summary of withdrawals and consumptive use in the entire Potomac River basin, by sector, for the base year (2005) and six future scenarios (2030).

Units: million gallons per day (MGD)

Scenario		Agri- culture	Domestic & Public	Industry	Mining	Power	Total	
<b>2005</b>								
Current	Withdrawals	7	636	85	37	2,909	3,673	
	Consumption	6	346	8	5	87	452	
<b>2030</b>								%Change from 2005
DP1	Withdrawals	5	898	119	39	3,617	4,679	27%
	Consumption	4	433	11	6	109	563	24%
DP2	Withdrawals	5	1,409	119	39	3,617	5,190	41%
	Consumption	4	679	11	6	109	809	79%
DP3	Withdrawals	5	2,618	119	39	3,617	6,398	74%
	Consumption	4	1,262	11	6	109	1,392	208%
Hot and Dry	Withdrawals	17	1,504	119	39	3,722	5,401	47%
	Consumption	14	725	11	6	112	867	92%
Climate Change	Withdrawals	8	2,690	119	39	3,716	6,572	79%
	Consumption	7	1,296	11	6	111	1,431	216%
Power	Withdrawals	5	1,409	119	39	3,092	4,665	27%
	Consumption	4	679	11	6	185	885	96%

Supplement Table 10. Summary of withdrawals and consumptive use in the Middle Potomac River study area (and including the North Branch Potomac River), by sector, for the base year (2005) and six future scenarios (2030).

Units: million gallons per day (MGD)

Scenario		Agri- culture	Domestic & Public	Industry	Mining	Power	Total	
<b>2005</b>								
Current	Withdrawals	7	609	84	28	1,524	2,252	
	Consumption	5	331	8	4	46	394	
<b>2030</b>								%Change from 2005
DP1	Withdrawals	5	856	119	30	1,895	2,904	29%
	Consumption	4	411	11	4	57	488	24%
DP2	Withdrawals	5	1,343	119	30	1,895	3,391	51%
	Consumption	4	645	11	4	57	722	83%
DP3	Withdrawals	5	2,494	119	30	1,895	4,543	102%
	Consumption	4	1,199	11	4	57	1,275	224%
Hot and Dry	Withdrawals	16	1,433	119	30	1,947	3,545	57%
	Consumption	13	688	11	4	58	775	97%
Climate Change	Withdrawals	8	2,563	119	30	1,946	4,665	107%
	Consumption	6	1,231	11	4	58	1,311	233%
Power	Withdrawals	5	1,343	119	30	1,657	3,154	40%
	Consumption	4	645	11	4	138	803	104%

Supplemental Table 11. Summary of withdrawals and consumptive use in the Potomac River basin above the fall-line, by sector, for the base year (2005) and six future scenarios (2030).

Units: million gallons per day (MGD)

		Sector						
		Agri- culture	Domestic & Public	Industry	Mining	Power	Total	
Scenario								
2005								
Current	Withdrawals	6	538	84	27	1,524	2,179	
	Consumption	5	322	8	4	46	385	
2030								%Change from 2005
DP1	Withdrawals	5	741	118	29	1,895	2,788	28%
	Consumption	4	398	11	4	57	474	23%
DP2	Withdrawals	5	1,163	118	29	1,895	3,210	47%
	Consumption	4	624	11	4	57	700	82%
DP3	Withdrawals	5	2,160	118	29	1,895	4,207	93%
	Consumption	4	1,159	11	4	57	1,235	221%
Hot and Dry	Withdrawals	16	1,241	118	29	1,947	3,350	54%
	Consumption	13	666	11	4	58	752	95%
Climate Change	Withdrawals	8	2,219	118	29	1,946	4,319	98%
	Consumption	6	1,191	11	4	58	1,270	230%
Power	Withdrawals	5	1,163	118	29	1,657	2,973	36%
	Consumption	4	624	11	4	138	782	103%