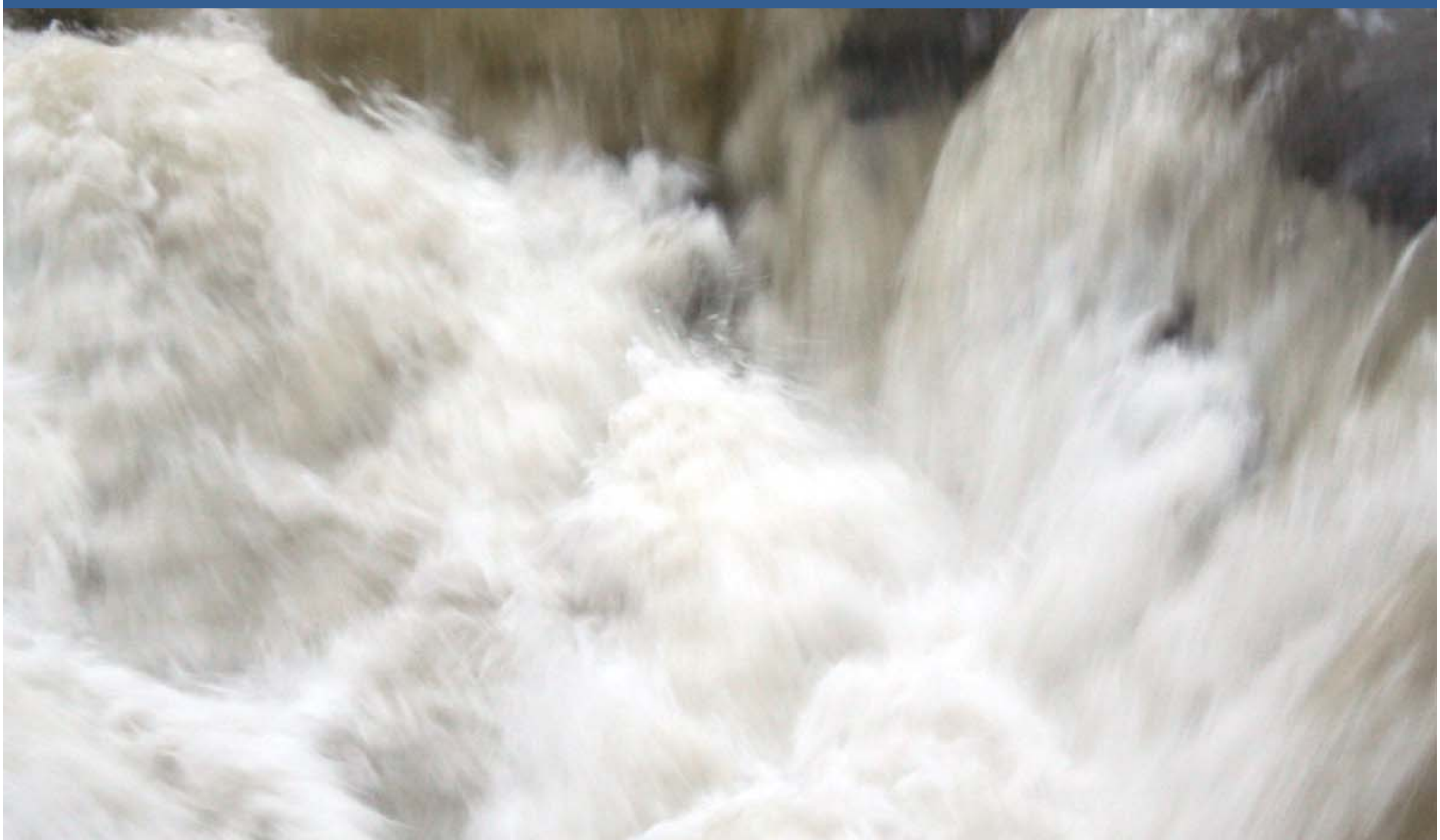
2010 Washington Metropolitan Area Water Supply Reliability Study

Part 1: Demand and Resource Availability Forecast for the Year 2040

Prepared by Sarah N. Ahmed, Karin R. Bencala, and Cherie L. Schultz



May 2010
ICPRB Report No. 10-01

The Section for Cooperative Water Supply Operations on the Potomac

Interstate Commission on the Potomac River Basin
51 Monroe Street, Suite PE-08 · Rockville, Maryland 20850

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Funds were provided for this report by the three major Washington, D.C., metropolitan area water suppliers: the Washington Suburban Sanitary Commission (WSSC); the Washington Aqueduct Division of the U.S. Army Corps of Engineers; and Fairfax Water.

This report would not have been possible without the many people who generously provided us with data and information. We thank the following individuals, as well as those whom we may have neglected to mention: Greg Prelewicz and Traci Kammer-Goldberg of Fairfax Water; Fatima Khaja and Sterling Wheeler of Fairfax County; Lloyd Stowe and Woody Peterson of Washington Aqueduct; Tim Hirrel, Roland Steiner, Elin Betanzo, Pedro Flores, Karen Wright, Todd Supple and John Kasprzak of WSSC; Dave Hundelt, Barbara Forbes and Elizabeth Craig of the Arlington Department of Environmental Services; Charles Kiely and Syed Khalil of D.C. WASA; Mary Ann Burke and Rodney Collins of the City of Falls Church; Thomas Lipinski, Thomas Bonacquisti and Craig Lees of Loudoun Water; Jill Allmon of Loudoun County; Beau Caire of Prince William County Service Authority; Frank Hunt and David McGettigan of Prince William County; Susan Strauss, Ilene Lish and Jason Zimmerman of the City of Rockville; Salah Jaro and Dana Heiberg of the Town of Herndon; Marion Serfass and Julie Morris of the Town of Vienna; Jim Downs and Michael Youshock of Virginia American Water Company; Angie de la Barrera and Elizabeth Rodgers of Arlington County; Ralph Rosenbaum of the City of Alexandria, Mayra Bayonet and Manisha Tewari of the City of Rockville; Kimberly Driggins, Joy Phillips and Art Rodgers of the District of Columbia; Wayne Koempel, Patrick Callahan, Jacquelin Philson and Joseph Valenza of the Maryland National Capital Park and Planning Commission; and Paul DesJardin and Greg Goodwin of the Metropolitan Washington Council of Governments.

We would especially like to thank Greg Prelewicz and Traci Kammer-Goldberg of Fairfax Water, Roland Steiner of WSSC, and Lloyd Stowe of Washington Aqueduct for their advice and guidance and for taking the time to answer our many questions. We would also like to thank them, along with Elin Betanzo of WSSC, for editorial assistance in the preparation of this document. We would like to thank Greg Goodwin of the Metropolitan Washington Council of Governments for his help with navigating and interpreting the Round 7.2 Cooperative Forecast results. We would like to thank Bill Haines, Barry Flickinger and Julie Fritz of the Baltimore District Office of the U.S. Army Corps of Engineers for their invaluable assistance in documenting North Branch reservoir operations. Finally, we would like to express our appreciation to Erik Hagen, Ani Kame'enui and Julie Kiang, formerly of ICPRB CO-OP, for their careful work and documentation of analyses done in the previous study.

Disclaimer

Executive Summary

This study provides forecasts of water demand and availability in the Washington, D.C., metropolitan area (WMA) through the year 2040. Long-term water supply forecasts aid managers in meeting future needs, since the time required to develop new resources is lengthy. This report is the fifth in a series of periodic reviews by the Section for Cooperative Water Supply Operations on the Potomac (CO-OP) of the Interstate Commission on the Potomac River Basin (ICPRB) of the ability of the WMA water supply system to meet future demands. The study consists of two parts: Part 1, the subject of this report, includes the demand forecast, analysis of current resources, and summary of potential resource alternatives. Part 2 of this study, which will be documented in a separate report, will assess the potential impact of global climate change on WMA water supply and demand.

Background

The three major WMA water suppliers, Washington Aqueduct Division of the U.S. Army Corps of Engineers (Washington Aqueduct), Fairfax County Water Authority (Fairfax Water), and Washington Suburban Sanitary Commission (WSSC), have a long history of cooperation. This cooperative approach was formalized in a set of agreements signed in the late 1970s and early 1980s. These agreements include the Low Flow Allocation Agreement (LFAA), which allocates the amount of water each supplier can withdraw from the Potomac River in the event that total flow is not sufficient to meet all needs, and the Water Supply Coordination Agreement (WSCA), which provides for coordinated operations of the major water supply facilities in the region during periods of low flow. During periods when Potomac River flows are low, as may occur in times of drought, the WMA suppliers coordinate their operations with the assistance of CO-OP in order to optimize use of available resources and maintain adequate flow downstream of their Potomac intakes to protect aquatic habitats. In addition, every five years beginning in 1990, CO-OP has conducted a forecast of WMA water demand and resource availability, as specified in the WSCA and LFAA as amended by Modification No. 1, on behalf of the WMA suppliers. The specified 20-year forecast horizon has been extended in the current study to 30 years to provide assistance to the Northern Virginia Regional Commission in its development of the Northern Virginia Regional Water Supply Plan in fulfillment of Virginia water supply regulations, 9 VAC 25-780.

The majority of WMA residents obtain their water from one of the three major suppliers, either directly or via their wholesale customers:

- Washington Aqueduct serves the District of Columbia via the D.C. Water and Sewer Authority (D.C. WASA), as well as Arlington County, the City of Falls Church, and the Town of Vienna, all in Virginia.
- WSSC serves Montgomery and Prince George’s counties in Maryland, and provides a limited amount of water to Howard and Charles counties. Water is also provided on an emergency basis to the City of Rockville and D.C. WASA.
- Fairfax Water serves 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).

The Potomac River is the primary source of raw water for the WMA suppliers, providing approximately 78 percent of the total water used. The Occoquan Reservoir in Virginia and the Patuxent River reservoirs in Maryland provide the remaining 22 percent. The WMA water suppliers jointly pay the capital and operating costs to reserve a portion of the water stored in two reservoirs to augment the natural flow of the Potomac River: Jennings Randolph Reservoir, located on the North Branch of the Potomac River approximately 200 miles upstream of Washington, D.C., and Little Seneca Reservoir, located in Montgomery County, Maryland. The combined water supply storage capacity of the Occoquan, Patuxent, Jennings Randolph and Little Seneca reservoirs is approximately 35 billion gallons. The WMA water suppliers also contribute to the operating costs of Savage River Reservoir, which supplements Jennings Randolph water supply augmentations.

Water use in the WMA has held relatively steady during the past two decades. Figure ES-1 shows total average annual, summer, and winter water production by the WMA suppliers, as well as peak-day production, from 1990 through 2008. 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.

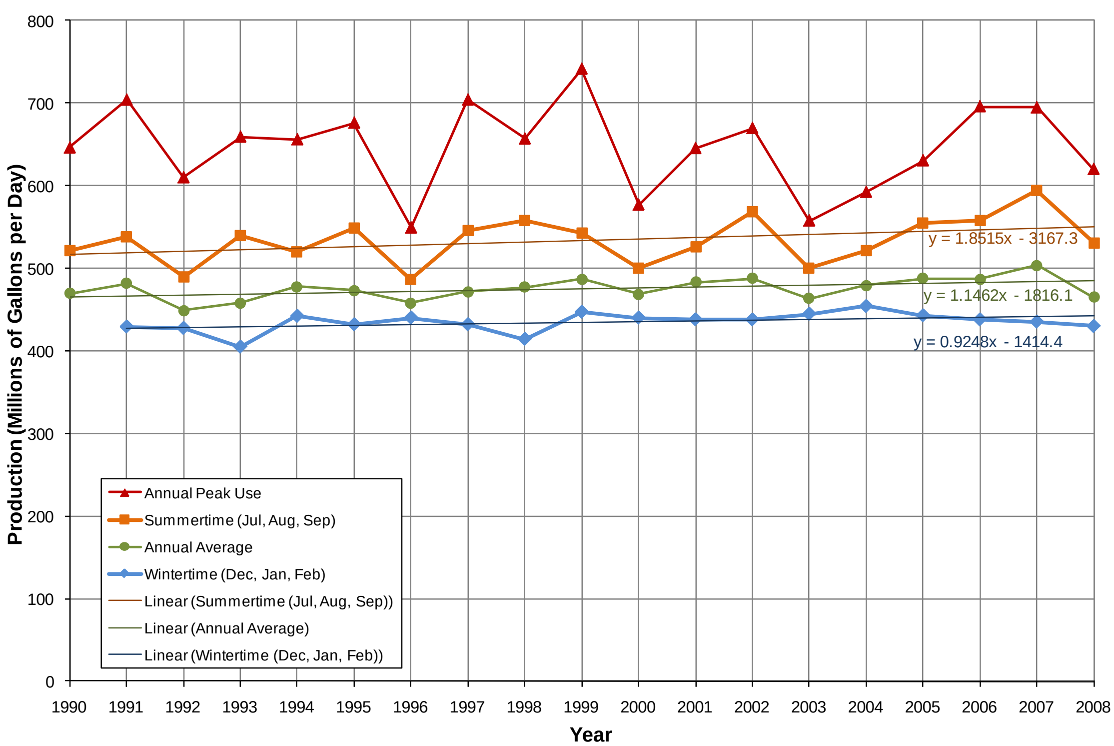


Figure ES-1: Average annual, summertime, wintertime, and peak day water use for the Washington, D.C., metropolitan area from 1990 through 2008.

Demand Forecasts

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). Total number of employees is predicted to increase by approximately 1,100,000 (38 percent). In all of these categories, the areas served by Fairfax Water and its wholesalers are projected to have the highest percent increases, as can be seen from Table ES-1. Areas served by WSSC are projected to have the lowest population increase (17 percent) but the second highest increase in the number of employees (42 percent).

Table ES-1: MWCOG growth predictions between the years 2010 and 2040, by areas currently served by a water supplier.

	Additional Households (percent)	Additional Population (percent)	Additional Employees (percent)
Fairfax Water retail and wholesale customers	206,297 (36%)	491,256 (32%)	448,178 (54%)
Aqueduct wholesale customers	122,738 (28%)	254,474 (26%)	276,175 (24%)
WSSC retail customers	140,980 (22%)	286,317 (17%)	332,151 (42%)
Totals (plus Rockville)	478,417 (29%)	1,049,078 (24%)	1,078,791 (38%)

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 provides 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.

Table ES-2 contains forecasted demand for both Scenario 1 and Scenario 2 at five year intervals for the period, 2010 through 2040. These values include all water supplied by each of the three WMA suppliers, including water supplied to wholesale customers, in units of million gallons per day (mgd).

Table ES-2: WMA demand forecasts, including demand from wholesale customers, for Scenario 1 – most likely demands, and Scenario 2 – high demands (mgd).

	2010	2015	2020	2025	2030	2035	2040
Scenario 1 - Fairfax Water	175.2	186.9	199.4	210.2	218.2	223.8	228.9
Scenario 2 - Fairfax Water	187.2	201.7	217.8	234.2	247.3	259.0	269.1
Scenario 1 - Washington Aqueduct	150.9	157.7	164.8	168.7	172.2	174.2	177.8
Scenario 2 - Washington Aqueduct	150.9	158.6	166.6	171.4	175.5	178.1	182.4
Scenario 1 – WSSC	171.9	177.5	186.7	191.6	197.1	201.1	203.8
Scenario 2 – WSSC	171.9	179.6	190.4	196.9	203.5	208.7	212.5
Scenario 1 - WMA Supplier Subtotal	497.9	522.1	551.0	570.6	587.5	599.1	610.5
Scenario 2 - WMA Supplier Subtotal	509.9	540.0	574.8	602.5	626.3	645.7	664.0
Scenario 1 - City of Rockville DPW	4.8	5.0	5.3	5.6	5.8	6.1	6.3
Scenario 2 - City of Rockville DPW	4.8	5.0	5.4	5.7	6.0	6.3	6.5
Scenario 1 - TOTAL WMA Suppliers plus Rockville	**502.7**	**527.1**	**556.3**	**576.2**	**593.3**	**605.1**	**616.8**
Potential additional demand from growth areas	12	13	15	19	23	28	32
Additional demand assuming constant SFH unit use	0.0	4.9	8.9	13.0	16.0	18.9	21.7
Scenario 2 - TOTAL WMA Suppliers plus Rockville	**514.7**	**545.0**	**580.2**	**608.2**	**632.3**	**652.0**	**670.5**

Note: SFH = single family home

Average annual demand in the WMA, including Rockville, is estimated to be approximately 503 mgd in year 2010 for Scenario 1, or 515 mgd for Scenario 2, and this is projected to increase to 593 mgd (18 percent) in 2030 under the assumptions of Scenario 1, or 632 mgd (23 percent) for 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.

In Figure ES-2, the forecasted WMA supplier demands shown in Table ES-2 are compared with results from past studies by ICPRB (Kame'enui *et al.*, 2005; Hagen and Steiner, 2000; Mullusky *et al.*, 1996; Holmes and Steiner, 1990) and other organizations (USACE, 1975; 1983). It is clear from Figure ES-2 that demand forecasts have consistently fallen over time. Throughout most of the past four decades, population has continued to grow in the WMA, but unit use values have fallen. However, current results indicate that these decreasing trends in unit use may be leveling off. The demand forecast lines in Figure ES-2 for ICPRB's 2005 and 2010 studies are close to one another. The similarity in these results is due to overall similarities in MWCOG demographic forecasts and the fact that unit use values have remained relatively constant throughout the past decade, with the exception of the values for multi-family households, which continue to decrease.

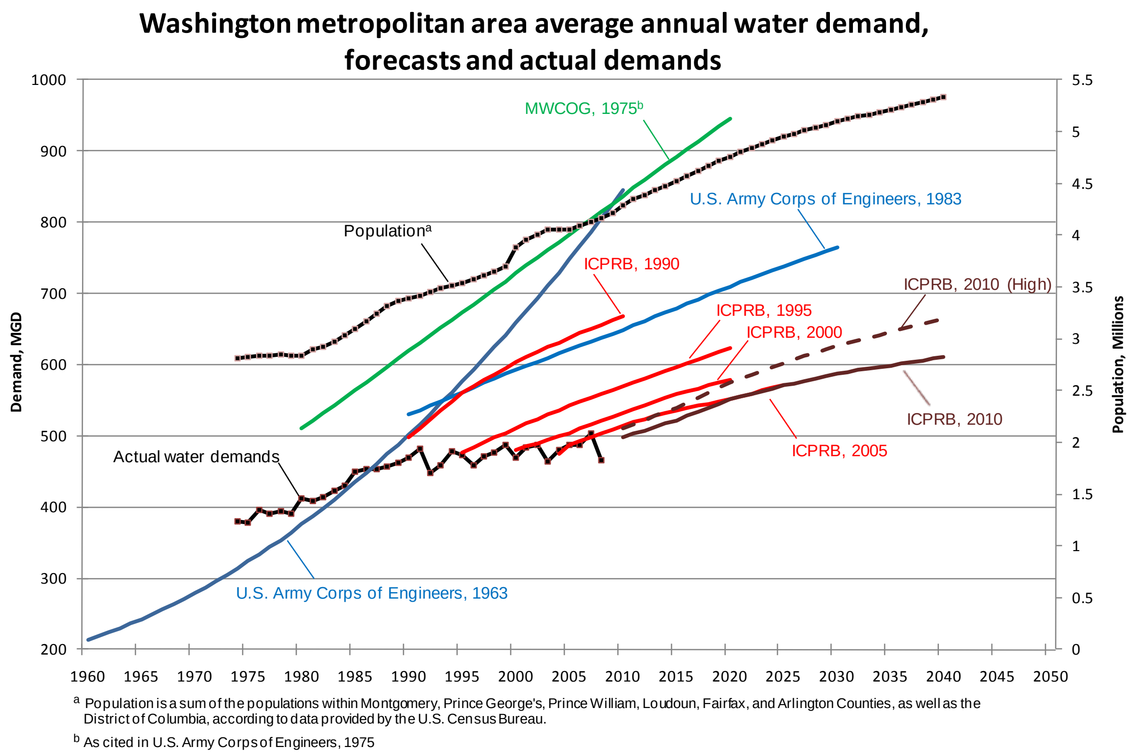


Figure ES-2: Comparison of Washington metropolitan area water supplier average annual demand forecasts from current (labeled ICPRB, 2010) and past studies.

Resource Analysis

The resource analysis was conducted using the Potomac Reservoir and River Simulation Model (PRRISM) to simulate future water demand and availability in the WMA water supply system based on forecasted demands and the historical record of hydrologic and meteorological conditions. PRRISM simulates on a daily basis the processes that govern water supply and demand in the WMA system: flows in the Potomac River; inflows, storage, and releases from the WMA system of reservoirs; and water withdrawals by the three major WMA suppliers. PRRISM was used to evaluate how the current WMA system would respond to forecasted water demands under the range of hydrologic conditions that occurred from 1929 through 2007.

PRRISM has undergone several enhancements since the CO-OP's last WMA water supply study was conducted. These changes (Chapter 6 and Appendix E) reflect recently adopted reservoir operating procedures for Jennings Randolph and Savage reservoirs and revised estimates of Jennings Randolph sedimentation rates. The new operating rules were developed by the U.S. Army Corps of Engineers, Baltimore District, with assistance from ICPRB, following recommendations from the North Branch Potomac River Advisory Committee. This committee was formed in 2005 by the agencies collectively responsible for the operations and management of the two North Branch reservoirs.

Model results are presented for both the typical 20-year demand forecast for the year 2030, and for the 30-year demand forecast for the year 2040. The 30-year forecast has been included in this study to assist the Northern Virginia Regional Commission in their concurrent water supply planning effort.

Model simulations predict that the WMA's current water supply system is likely adequate to meet future demands forecasted through the year 2030, but might be strained by 2040 demands. In the year 2030, the model indicates that the system could meet demands with no shortfalls and no need for emergency water use restrictions under a range of hydrologic conditions similar to the 78-year period of record. By the year 2040, for the higher demand forecasts of Scenario 2, model simulations indicate that if conditions experienced during the worst drought of record were to reoccur, emergency water use restrictions would be required, combined water supply storage in Little Seneca and Jennings Randolph reservoirs would fall below one billion gallons, and water supply shortfalls would occur at Occoquan Reservoir.

Conclusions and Recommendations

The following conclusions and recommendations can be made based on the results of this analysis:

Conclusions

1. The resource analysis conducted for this study indicates that the WMA's current water supply system will continue to be able to meet demands over the 20-year forecast period, to the year 2030, under a range of hydrologic conditions similar to the 78-year period of historical record, with no water supply shortfalls and no emergency water use restrictions.

2. By the year 2040, however, the current system may have difficulty meeting the region's demands during periods of drought without water use restrictions, and/or the development of additional supply capabilities.

3. Summertime outdoor water use may be increasing in some areas of the WMA, offsetting the benefits of adoption of more water efficient indoor fixtures and appliances.

4. The system's largest reservoir, Jennings Randolph, appears to be losing storage capacity due to sedimentation at a rate that is higher than estimated in the past.

Recommendations

1. Completion of the evaluation of water supply alternatives to determine the most beneficial and cost-effective resources to meet future demands, including an improved methodology for optimizing existing and potential water supply resources.

2. A new hydrographic survey to measure current storage capacity of Jennings Randolph Reservoir. New surveys of Savage Reservoir and Little Seneca Reservoir may also be warranted.

3. Consideration of new watershed protection efforts to reduce watershed erosion and thus loss of storage in system reservoirs, potentially under the auspices of the Potomac River Basin Drinking Water Source Protection Partnership.

4. Investigation in the next WMA water supply study of changes and impacts of summertime outdoor water use.

1 Study Objective and Background

1.1 Objective

The objective of the 2010 Water Supply Reliability Forecast is to aid long-range water resource planning for the Washington, D.C., metropolitan area (WMA) by

a) Forecasting average annual water supply demands for the WMA through the year 2040, taking into account projected demographic and societal changes that may affect future water use.
b) Evaluating the ability of current resources to meet these projected demands.
c) Assessing the potential impact of global climate change on WMA system reliability.

The study is being conducted in two parts. Part 1, which is the subject of this report, addresses the forecasting of demand and evaluation of regional resources, items a) and b) above. Part 2, which is documented in a separate report, addresses the potential impact of future climate change on system reliability, item c) above.

This study satisfies a requirement specified in both the Low Flow Allocation Agreement (LFAA), as amended by Modification 1, signed by the United States, the state of Maryland, the Commonwealth of Virginia, the District of Columbia, the Washington Suburban Sanitary Commission, and Fairfax County Water Authority (Fairfax Water), and the Water Supply Coordination Agreement (WSCA), signed by the United States, Fairfax County Water Authority, the Washington Suburban Sanitary Commission, the District of Columbia, and the Interstate Commission on the Potomac River Basin. As stated in the WSCA, it is agreed that "In April 1990 and in April of each fifth year thereafter… the Aqueduct, the Authority, the Commission and the District shall review and evaluate the adequacy of the then available water supplies to meet the water demands in the Washington Metropolitan Area which may then be expected to occur during the succeeding 20 year period." The specified 20-year forecast horizon has been extended in the current study to 30 years to provide assistance to the Northern Virginia Regional Commission in its development of the Northern Virginia Regional Water Supply Plan in fulfillment of Virginia water supply planning regulations, 9 VAC 25-780.

1.2 Introduction

Demand forecasting and resource assessments are necessary tools for water resource planning because the time required to plan and develop new resources is lengthy. The current study is the fifth in a series of periodic reviews by the Interstate Commission on the Potomac River Basin (ICPRB) of the ability of the WMA water supply system to meet future demands. Previous studies were published in 1990, 1995, 2000, and 2005 (Holmes and Steiner, 1990; Mullusky, *et al*., 1996; Hagen and Steiner, 2000; Kame'enui *et al*., 2005). This five-year time interval allows each study to incorporate the most up-to-date regional demographic forecasts, published by the Metropolitan Washington Council of Governments (MWCOG), along with recent data on water use in the WMA. Successive studies have also made use of new information on the characteristics of the physical system – the streams and reservoirs that provide water to the WMA – and have taken advantage of continuing improvements in data availability and in simulation and analysis tools. In addition to allowing for updates and refinements to forecasts and analyses, this iterative approach to water supply planning helps increase the visibility of regional water supply issues and helps foster communication between regional stakeholders (Hagen *et al*., 2005).

Part 1 of the 2010 study follows the methodology developed in past ICPRB studies. As in the past, forecasts of average annual water demand are developed by combining recent water use data provided by the CO-OP water suppliers and their wholesale customers, information on the current and future extent of the areas served by water suppliers and local planning agencies, and the most recent demographic forecasts from MWCOG. Seasonal and daily variations in demand, dependent on the time of year and meteorological conditions, are simulated using statistical regression and stochastic modeling techniques following the methodology used by Kame'enui *et al*. (2005; Steiner, 1984). The resource analysis is conducted using the Potomac Reservoir and River Simulation Model (PRRISM), which simulates Potomac River flows, water withdrawals, and reservoir levels on a daily basis. System resource availability, determined by reservoir inflows and daily flows in the Potomac River, are evaluated based on historical hydrologic and meteorological records extending from October 1929 through September 2007.

PRRISM has undergone several enhancements since the 2005 study was conducted. These changes, documented in this report, reflect recently adopted reservoir operating procedures for Jennings Randolph and Savage reservoirs and revised estimates of Jennings Randolph sedimentation rates. The new operating rules were developed by the U.S. Army Corps of Engineers, Baltimore District, with assistance from ICPRB, following recommendations from the North Branch Potomac River Advisory Committee (NPS, 2008). This committee was formed in 2005 by the agencies collectively responsible for the operations and management of the two North Branch reservoirs. These updated rules include an improved representation of water quality operating procedures in the North Branch Potomac which affect downstream flow.

This study also summarizes four potential water supply alternatives for the WMA:

- Potomac estuary intake/pumping station near head-of-tide below Little Falls, with discharge to Washington Aqueduct's Dalecarlia Reservoir.
- Occoquan estuary membrane treatment plant operated by Fairfax Water.
- Use of two quarries located in Fairfax County to augment Fairfax Water storage.
- Use of two Loudoun County quarries as pumped storage reservoirs for Loudoun Water, with one quarry potentially serving to augment Potomac River flow during droughts.

Part 2 of this study, documented in a separate report, investigates the potential impact of global climate change on system resources. The climate change assessment makes use of available watershed modeling results and other analytical tools to devise sets of PRRISM input data that reflect the range of possible changes in both demand and basin stream flows.

1.3 Water Suppliers

The Potomac River is the primary water supply source for residents, businesses, and government facilities located in the WMA, which is comprised of the District of Columbia and the District's Maryland and Virginia suburbs. The three major water suppliers in the WMA are:

- Washington Aqueduct Division of the U.S. Army Corps of Engineers (Aqueduct), serving the District of Columbia via the D.C. Water and Sewer Authority (D.C. WASA), and parts of Virginia
- Washington Suburban Sanitary Commission (WSSC), serving parts of Maryland
- Fairfax Water (FW), serving Fairfax County and providing wholesale water to other suppliers in northern Virginia

These suppliers (interchangeably the CO-OP or WMA suppliers) obtain approximately 78 percent of their water from the Potomac River and jointly own water stored in two upstream reservoirs. These reservoirs, Jennings Randolph and Little Seneca, can be used to augment natural river flow during times of drought. In addition, Fairfax Water and WSSC rely on water stored in reservoirs which are outside of the drainage area above their Potomac River intakes, on the Occoquan River and the Patuxent River, respectively. The WMA suppliers provide treated water either directly to customers or through independent wholesale suppliers.

1.4 History of Cooperation

The first regional approaches to water supply management began in the 1960s. The population of the WMA was expected to grow to 5 million by 1985 (USACE, 1963), after having grown from 672,000 in 1930 to two million in 1960. During this same time period, drought-induced rationing was a very real threat in the WMA, as demand was forecasted to exceed the low flow of the largely unregulated (meaning few dams) Potomac River (Potomac Basin Reporter, 1982).

A number of potential measures for increasing water supply were studied during this period. The U.S. Army Corps of Engineers conducted a study that identified 16 potential dam sites on the Potomac River upstream of Washington, D.C., whose reservoirs could augment supply during low-flow periods (USACE, 1963). There was significant public opposition to many of these sites and only one, Jennings Randolph Reservoir near Bloomington, Maryland, was constructed. Other alternatives that were studied included estuary treatment plants, interconnections in the distribution systems, and inter-basin transfers (Ways, 1993).

In reality, the actual WMA population realized in 1985, at approximately 3.1 million people (United States Census Bureau, 2004), was lower than that forecasted by the U.S. Army Corps of Engineers. Drought rationing in the WMA did not occur during this period only because no serious droughts threatened the water supply system in the 1970s. However, WMA demand levels exceeded the 1966 low flow of the Potomac River 41 times during the period between 1971 and 1982 (Ways, 1993).

Given the opposition to constructing reservoirs, the water suppliers and local governments searched for other solutions. By the late 1970s, researchers at Johns Hopkins University had developed the basis for using stored water in a way that would allow the system to meet growing demands and allow for better reliability during droughts through cooperative operations by the utilities (Palmer *et al*., 1979; 1982; Sheer, 1977). This research indicated that the management of the Jennings Randolph Reservoir in coordination with the existing Occoquan and Patuxent reservoirs could meet the region's projected demand and maintain adequate environmental flows through about 2020. Increased system reliability stems from operating rules which specify that

WMA water suppliers depend more heavily on the free-flowing Potomac River during winter and spring months of low-flow years in order to preserve storage in the Patuxent and Occoquan reservoirs. This strategy is possible because even during droughts, the winter and spring Potomac flow is more than adequate to meet water supply demand. This operating policy ensures that the Patuxent and Occoquan reservoirs remain available for use during the summer low-flow season and reduces the probability of system failure. Thus, a regional consensus emerged, minimizing the need for new dams or other costly and controversial structural measures.

Following this consensus, key agreements governing this cooperative approach were forged. In 1978, the states and the WMA water suppliers signed the Low Flow Allocation Agreement, which allocates the amount of water each supplier can withdraw from the river in the event that the total flow is not sufficient to meet the needs of each supplier. These allocations are set annually, based on winter water use.

In 1982, the WMA water suppliers and ICPRB signed the Water Supply Coordination Agreement. This agreement provides for the coordination of the major water supply facilities in the region, including those on the Patuxent and Occoquan rivers, as a means of minimizing the potential of triggering the LFAA's low flow allocation mechanism. In doing this, the WMA water suppliers cooperate by operating as one entity that shares water across the Potomac, Patuxent, and Occoquan basins during periods of low flow. This cooperative work is coordinated by a special section of ICPRB, the "Section for Cooperative Water Supply Operations on the Potomac" (CO-OP), as described in the WSCA agreement.

The WMA water suppliers jointly pay the capital and operating costs to reserve a portion of the water stored in the Jennings Randolph and Little Seneca reservoirs for augmenting the natural flow of the Potomac River. Together, these sources provide over 17 billion gallons of storage. The WMA water suppliers also contribute to the operating costs of Savage River Reservoir.

As specified in the WSCA, CO-OP is to assume a direct role in managing water supply resources and withdrawals in the WMA. The agreement provides for an Operations Committee, consisting of representatives from the Aqueduct, Fairfax Water, and WSSC, that is responsible for overseeing CO-OP activities. It binds all parties to joint operations during times of low flow in the Potomac River. In addition, it assigns the responsibility for scheduling water supply releases from Jennings Randolph and Little Seneca reservoirs to CO-OP. This portion of the agreement was driven by the realization that by making cooperative operating decisions, each supplier could meet their own demand and collectively meet the demand of the region. This decision to seek a joint solution to potential water supply shortages through ICPRB CO-OP has made it possible to provide adequate water supply to the WMA in a far less expensive way, as compared to other proposed solutions.

Since the completion of Jennings Randolph Reservoir in 1982, water supply releases to augment the natural flow of the Potomac River for water supply purposes have been made in only two years.. Water supply releases were made from Jennings Randolph and Little Seneca reservoirs during low flow periods in the summers of 1999 and 2002. In both years, cooperative operations between ICPRB and the WMA water suppliers ran smoothly, and the augmented flow of the Potomac provided the required water.

2 General Description of the WMA Water Supply System

2.1 Introduction

The Washington, D.C. metropolitan area (WMA) water supply system includes both the physical water resources and the entities that treat and distribute the water for consumption. Understanding this system, from the headwaters of the Potomac River to the wastewater discharge locations, is essential to quantifying both future demand and system reliability. This chapter aims to describe the basics of the system (see Figure 2-1 for a summary), including the available water resources (Section 2.2) and the production of water for consumption (Section 2.3).

2.2 WMA Water Resources

2.2.1 Study Area

In general, the study area for this report is the Potomac River watershed, but the two parts of the analysis cover different portions of the watershed. For the development of the demand forecast, the study considers the physical extent of the areas served by the WMA water suppliers and their wholesale customers. WSSC serves Prince George's and Montgomery counties, Washington Aqueduct sells water to wholesale customers that provide water to the District of Columbia and portions of northern Virginia, and Fairfax Water serves Fairfax County and other suburbs in northern Virginia. The major wholesale customers of the WMA suppliers include Loudoun Water, Prince William County Service Authority, Virginia American (City of Alexandria and Dale City), Vienna Department of Public Works, District of Columbia Water and Sewer Authority, Arlington County Department of Environmental Services, and Falls Church Department of Environmental Services. Together the WMA water suppliers and their wholesale customers currently provide water to nearly 4.3 million WMA residents.

In terms of determining the availability of water resources, the extent of the study area is the non-tidal Potomac River, including storage in Jennings Randolph and Little Seneca reservoirs, as well as reservoirs on the Occoquan and Patuxent rivers.

2.2.2 Water Supply Sources

The non-tidal Potomac River is the main source of drinking water for the majority of people living in the WMA. The area of the Potomac River watershed upstream of the major water supply intakes comprises 11,560 square miles of the total basin (14,670 square miles). The average flow of the river over a year is about 7 billion gallons per day (bgd), with higher flows typically occurring in the winter months and lower flows in the summer months. For the most part throughout the year, water supply withdrawals from the Potomac are a small fraction of the river's flow. The average summer demand for water from the Potomac by the WMA suppliers is approximately 500 million gallons per day (mgd), or 0.5 bgd. An assessment of demand relative to flow can be found in Chapter 7.

On average, the Potomac River accounts for approximately 78 percent of the water treated by the WMA water suppliers. The natural flow of the Potomac is augmented during times of low flow by storage from Jennings Randolph and Little Seneca reservoirs. In addition to these resources, Fairfax Water and WSSC have their own reservoirs outside of the non-tidal Potomac watershed, the Occoquan and Patuxent reservoirs, respectively. These resources are able to supply the remaining 22 percent of demand for water.

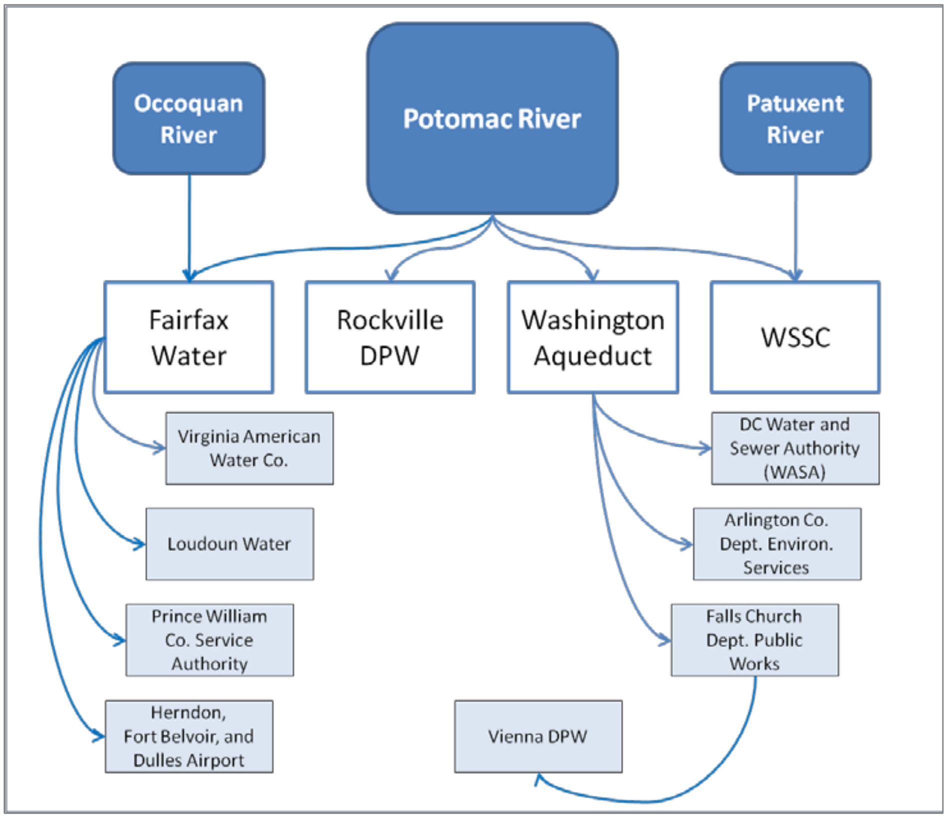


Figure 2-1: Schematic of the available water resources and water suppliers for the Washington metropolitan area.

2.2.3 Shared Resources

Per the Water Supply Coordination Agreement discussed in Section 1.4, the CO-OP utilities have agreed to share a number of water storage resources. The three major regional water suppliers collaborated to pay for storage in Jennings Randolph and Little Seneca reservoirs, at an initial cost of more than $96 million dollars, plus annual operation and maintenance costs. Figure 2-2 shows the extent of the Potomac River basin, including the tidal portion, and the locations of the water storage resources. A description of each reservoir follows below.

<u>Jennings Randolph Reservoir</u>: This reservoir can be viewed as the area's "savings account." It provides 13.4 billion gallons (bg) of water supply storage that is available to the WMA water suppliers. Releases are directed by ICPRB CO-OP based on existing and projected water demand, status of other reservoirs, and weather conditions. The reservoir is approximately 200 miles upstream of the WMA water suppliers' intakes, and releases take more than a week to travel to them during times of low flow. The drainage area of Jennings Randolph is about 263 square miles.

<u>Little Seneca Reservoir</u>: This smaller reservoir can be viewed as the region's "checking account" and is about a day's travel time from Montgomery County, Maryland, to the furthest downstream intake. It stores approximately 3.9 bg for the benefit of the WMA water suppliers and is used to "fine tune" the larger releases from Jennings Randolph Reservoir, which can then be operated more conservatively. Little Seneca's drainage area is about 21 square miles.

<u>Savage Reservoir</u>: This reservoir is located on the Savage River in the headwaters of the basin near Jennings Randolph Reservoir. The dam is owned by the Upper Potomac River Commission (UPRC). The UPRC operates the dam with guidance from the U.S. Army Corps of Engineers, Baltimore District, and also operates a downstream wastewater treatment facility. Water quality releases from Savage Reservoir are made concurrently with releases from water supply storage in Jennings Randolph Reservoir. The drainage area of Savage Reservoir is about 105 square miles. The releases from Savage and Jennings Randolph reservoirs are used to meet a flow target (set by ICPRB CO-OP as needed during low flows) at Luke, Maryland.

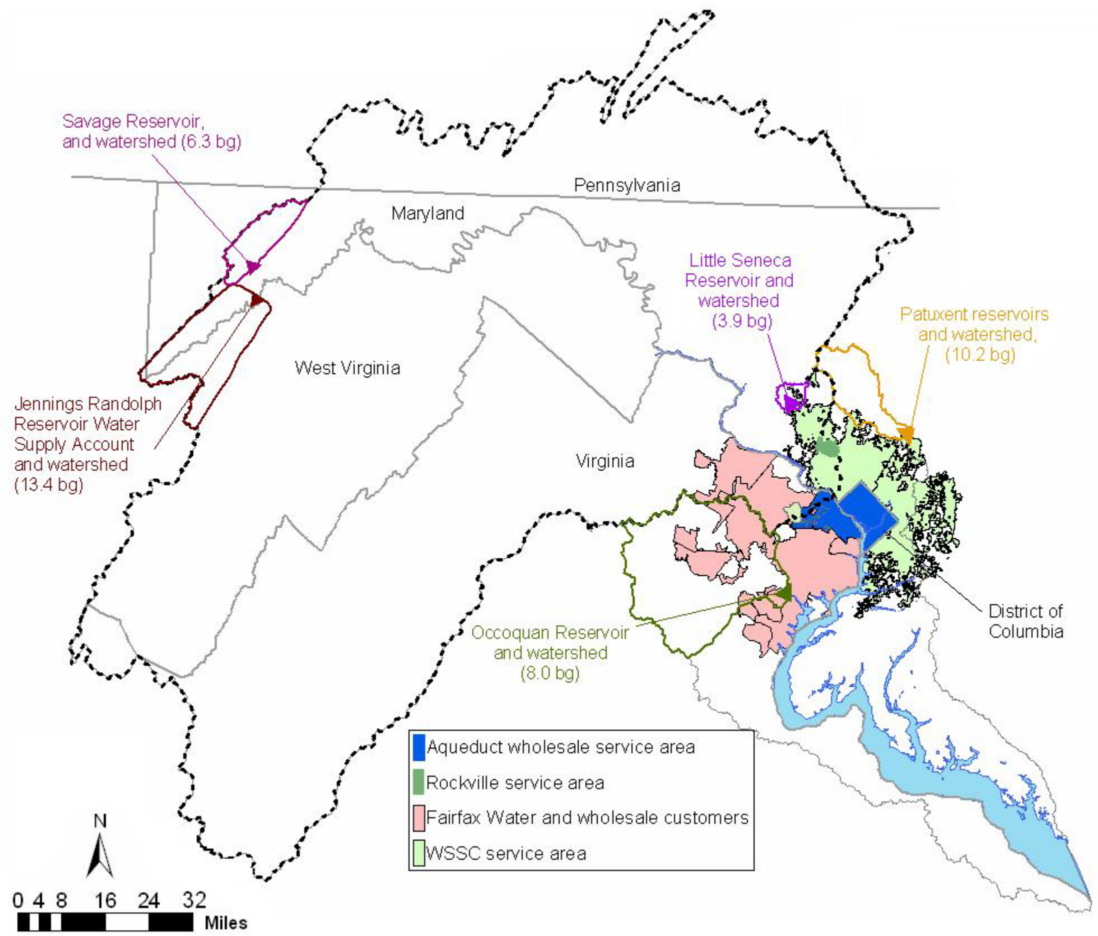


Figure 2-2: CO-OP reservoir sites, watersheds, and storage capacities in relation to the Potomac basin and areas served by the Washington metropolitan area water suppliers.

2.2.4 Additional Resources

Patuxent Reservoirs: WSSC operates two reservoirs in the neighboring Patuxent River watershed. Total usable storage in these reservoirs is about 10.2 bg. WSSC uses this stored water in tandem with Potomac withdrawals throughout the year. The combined drainage area of these reservoirs is about 132 square miles.

Occoquan Reservoir: Fairfax Water operates this reservoir on the Occoquan River. The reservoir contains about 8.0 bg of total usable storage, which is used in tandem with Potomac River withdrawals. The drainage area of the Occoquan is about 592 square miles.

2.3 Water Production by WMA Suppliers

Average annual water production for the WMA suppliers has been increasing modestly over the past two decades. Production is the amount of water treated by the suppliers and distributed to retail or wholesale customers. Figure 2-3 shows total average annual, summertime, and wintertime use, as well as daily peak use for the WMA suppliers from 1990 through 2008. Production in the summer months is significantly higher than in the winter months due to demand driven by outdoor water use.

Washington Aqueduct and WSSC treated an average of 157.6 mgd and 162.7 mgd, respectively, in 2008, the most recent year for which data were available for this study. Fairfax Water production was slightly less, averaging 144.7 mgd in 2008. (Data for 2008 includes the months of January through December.) A significant portion of the WSSC and Fairfax Water production is satisfied by the Patuxent and Occoquan reservoirs, respectively. In 2008, 31 percent of WSSC's production came from the Patuxent reservoirs and 42 percent of Fairfax Water's production came from the Occoquan Reservoir.

Over the time period represented in Figure 2-3, 1990 through 2008, WSSC's peak-day production of 263.4 mgd occurred on June 8, 1999; this can be compared to WSSC's historical peak-day production of 267.3 mgd, which occurred on July 8, 1988. Fairfax Water's historical peak-day production of 254.5 mgd occurred on July 9, 2007. The Aqueduct's historical peak-day production of 281.1 mgd occurred on July 7, 1999. The historical peak-day combined production of the three suppliers was 741.4 mgd, which occurred on June 8, 1999.

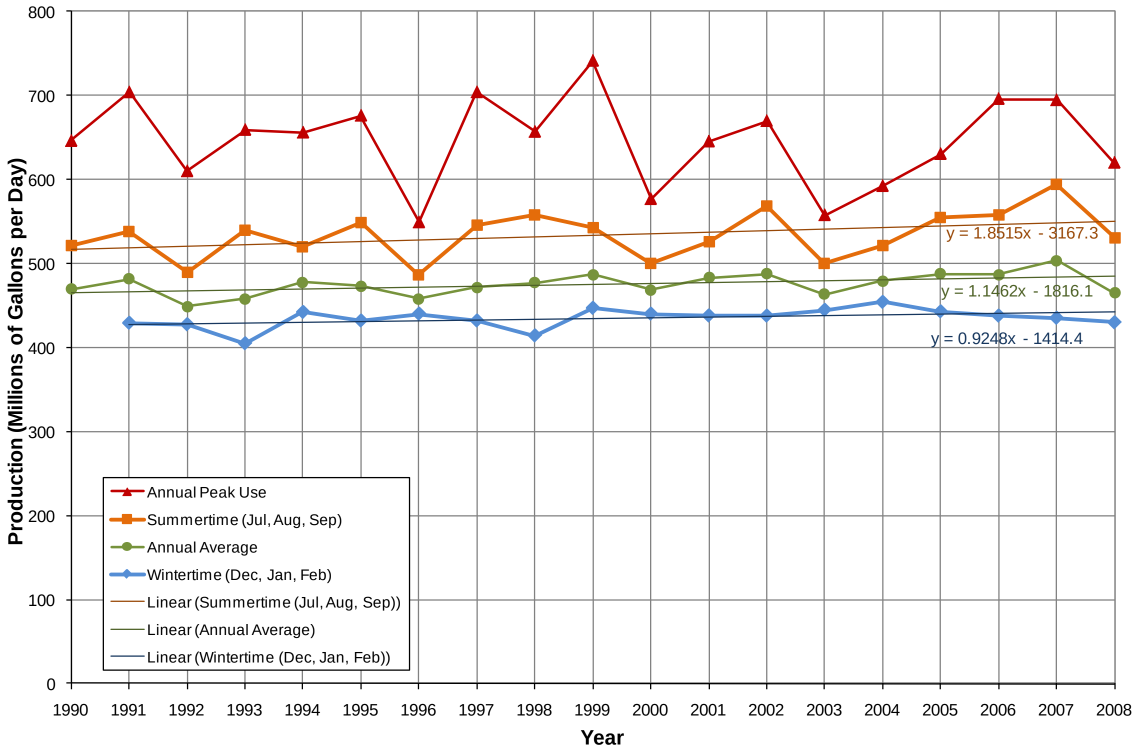


Figure 2-3: WSSC, Aqueduct, and Fairfax Water combined total annual average, summertime, wintertime (by water year), and peak-day production.

Figure 2-3 is a graph of average annual, summer months, and winter months total water production by WMA suppliers, as well as annual peak-day production. This graph illustrates that both summertime and peak-day production can be significantly greater than the annual average production. For the period 1995 through 2008, the annual peak-day production was on average 36 percent higher than the annual average production and a maximum of 52 percent higher than the annual average demand (1999). Though there are slight upward trends in these data, only summertime water use has increased, on average, at a rate that is statistically significant (at the 10 percent level). Over this same period, population in the WMA increased from approximately 3.9 million people to approximately 4.3 million. Chapter 5 provides additional detail on current patterns of water production for the WMA water suppliers.

3 Method for Developing the Annual Demand Forecast

3.1 Introduction

Forecasting of annual average water demand for the 2010 study is a multi-step process. It requires water use and demographic data along with assumptions regarding changes in water use patterns in the region. Billing data and maps of the area served are collected from each utility, and the current and future demographic projections are provided by the Metropolitan Washington Council of Governments (MWCOG), a regional planning agency. Growth, development, and changes in water use, such as the use of more efficient appliances, are also considered. Using this information, in conjunction with discussions with the utilities and the area's water resource planners, a forecast of water use out to year 2040 is developed. This process includes the derivation of areas served by each water supplier (Section 3.3), dwelling unit ratios (Section 3.4), demographic information (Section 3.5), and unit use and unmetered water calculations (Section 3.7).

3.2 Method

The determination of current and future water demand for the Washington metropolitan area requires disaggregated water use billing data from each utility and demographic data specific to the area served by a given water supplier. The process of estimating demand can be tracked in Figure 3-1 below and is detailed in the discussion that follows. The estimate of future demand is based on aggregating all water use types into three categories of water uses: single family household use, multi-family (apartment) household use, and employee use (*e.g.* commercial, industrial, and institutional). Billing data from the WMA water suppliers and their wholesale customers was gathered from 2005 through the most current year of available data, either 2007 or 2008. The utilities do not necessarily collect or report this data in the same format. Data were either received as an annual number or aggregated into one from billing cycle data that are collected on a quarterly or fiscal year basis. The number and type of end user categories varied widely between utilities. Some only had a residential and a commercial category; whereas, others may have had categories for different types of residences and commercial activities. When possible, the data was categorized into single family use, multi-family use, and employee use. An estimate of unmetered water use was also developed by taking the difference between the amount of water produced or purchased and the amount billed to customers. When each utility's total demand was calculated, unmetered water less than 10 percent was assumed to be 10 percent to provide a conservative planning-level estimate of future demand that accounts for increased losses as infrastructure ages. This assumption was made for some or all years of data for Fairfax Water retail customers, Dulles Airport, Fort Belvoir, Prince William County Service Authority, City of Falls Church, Town of Vienna, and Rockville. An average of the recent years' unmetered water use percentages was used to estimate future unmetered amounts. A detailed description of the billing data received from each utility and the methods used for analysis is given in Appendix B.

Household, employment, and population projections for the area served by each water supplier are based on the MWCOG Round 7.2 Cooperative Forecast (MWCOG, 2009) and on a delineation of the current and future areas served by water suppliers using GIS tools.

Additionally, the number of single family and multi-family households in each jurisdiction was obtained when available. This information was used to calculate the dwelling unit ratio (the number of single family households divided by the number of multi-family households) by county for each area served, and then to separate the MWCOG household forecasts into the number of single family and multi-family households.

The billing and demographic data were then used to calculate unit use factors, in gallons per day (gpd), in order to describe average daily water use by user category. Unit use factors are determined by dividing the total amount of water used per user category by the number of units (single family households, multi-family households, or employee). Future unit use factors were estimated by taking into account the fact that per household water use may in some cases be lower in the future than it is today due to the installation of water conserving fixtures and fittings as prescribed in the Energy Policy Act of 1992.

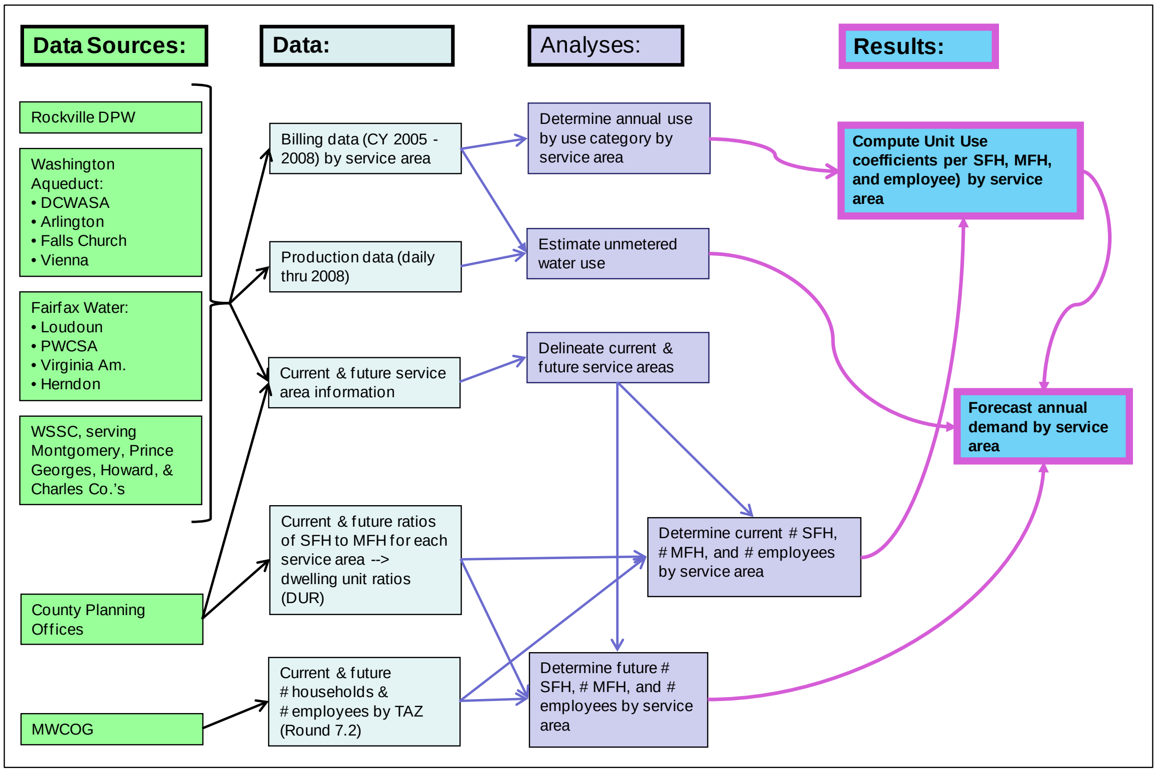


Figure 3-1: Schematic of process used to determine unit use values.

3.3 Delineation of Areas Served by Water Suppliers

The current (2010) and projected (2040) areas served by metropolitan Washington, D.C. water suppliers are shown in Figure 3-2 and Figure 3-3. Delineating the area served is critical to determining demographic changes expected for each water supplier. Demographic information (households, employment, and population) for each water supplier was compiled by extracting MWCOG demographic data by traffic analysis zone (TAZ), based on the geographic extent of areas served by the WMA water suppliers. Traffic analysis zones are used throughout the country as geographic units for analyzing traffic patterns. GIS ArcMap™ (ESRI) was used for this analysis, as described in Section 3.5, and Google Earth aerial photographs were used to reconcile overlapping areas and to refine area boundaries.

The area served by Loudoun Water experienced the largest expansion since the 2005 study, with the current area already extending beyond the 2035 forecasted area reported in that study. The areas served by other water suppliers showed little to no expansion from what was reported in the 2005 study. Due to improved mapping and analysis tools, some of the areas served by the other water suppliers may appear slightly different from previous studies even if there was no reported change.

Each water supplier provided a map of the area that they serve (Figure 3-2). This was different from the 2005 study, when many of the areas had to be developed by ICPRB based on information such as water line maps from county planning offices. These maps were reviewed by ICPRB by superimposing them on satellite imagery available from Google Earth. As a result of this review, a few maps were modified.

The map of the area served by WSSC was modified to include gaps within the main extent of the area, and to exclude areas that overlapped with the District of Columbia and the City of Rockville. WSSC's original map was created by placing a buffer around their distribution network. The holes in this map were often sparsely populated areas such as roads, barren land, forest, wetlands, or water, which when included, provided a more complete estimate of the area's demographics, as explained in Section 3.5. These gaps were also filled in to capture many customer-owned pipes that connect to the larger WSSC pipe system to which the buffer did not extend; for example, the University of Maryland and Andrews Air Force Base. On the other hand, regions that overlapped with the District of Columbia and Rockville were removed because it is known that WSSC does not serve these areas. These types of small overlaps are common when mapping at a fine scale. This map does not include Howard and Charles counties, which receive a small amount of water on a wholesale basis from WSSC.

Overlaps between the areas served by Fairfax Water and Prince William County and the City of Alexandria were assumed to be errors. Each map of the areas served by these water suppliers was clipped to the corresponding political boundaries. Dulles Airport was extracted from the area served by Fairfax Water and made its own entity because it is a wholesale customer of Fairfax Water. In contrast to other overlapping areas, areas served by both Fairfax Water and the City of Falls Church were unaltered because both utilities do supply water to those areas. In this instance, demographic figures were assumed equally divided between the two water suppliers.

The future extent of each area served by water suppliers is difficult to predict (Figure 3-3). These estimations can be based on known physical constraints of the water supply system or on county zoning maps and comprehensive plans. Only WSSC provided ICPRB with their own approximation of the future area served by their facilities as based on pressure zones. The remaining water suppliers indicated little to no anticipated changes to the current area served. To verify this, ICPRB compared the boundaries of each area served with MWCOG forecasts of new growth areas. For the most part, these areas are predicted to be outside of the current area served by WMA suppliers and have alternative water sources. For example, Leesburg, in Loudoun

County, gets its water from the town's own water service system, which draws mainly from the Potomac River, in addition to wells.

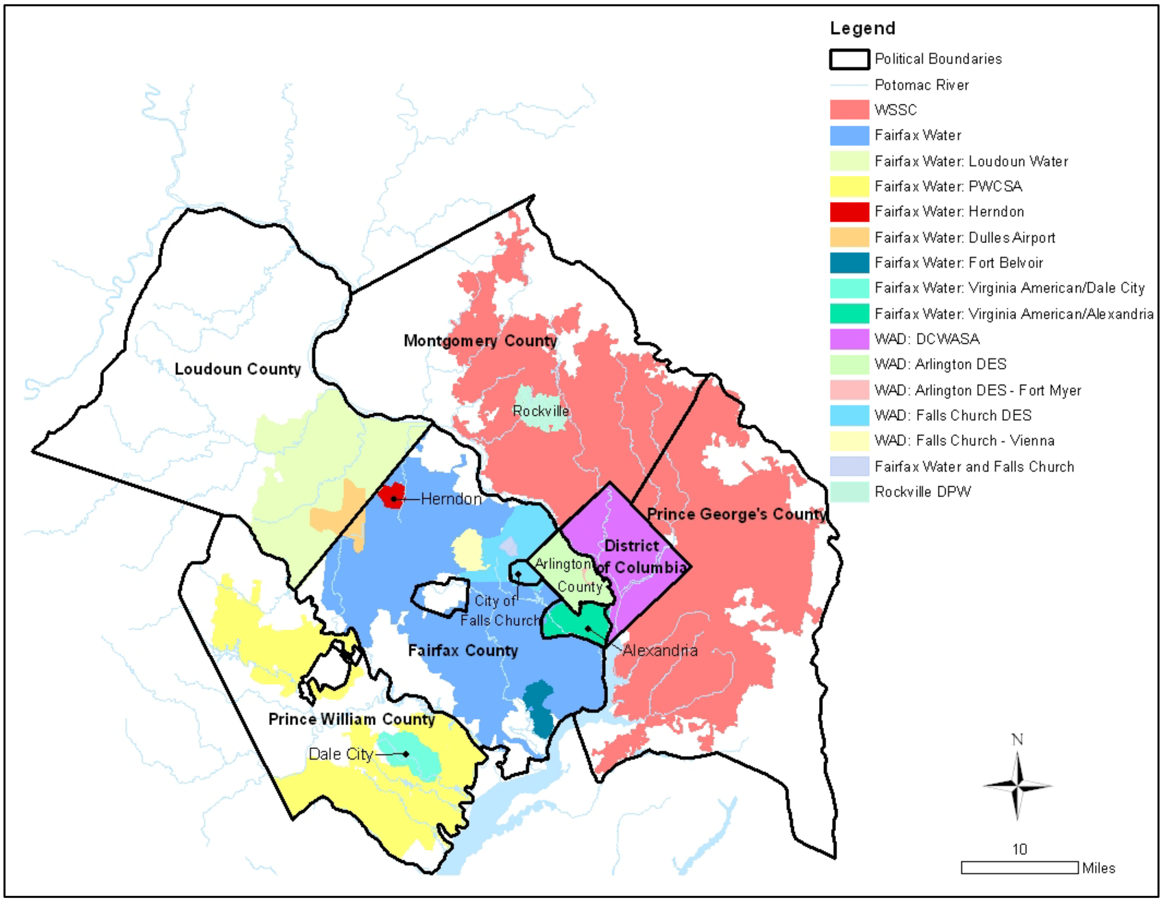


Figure 3-2: Areas served by water suppliers in the Washington metropolitan area, 2010.

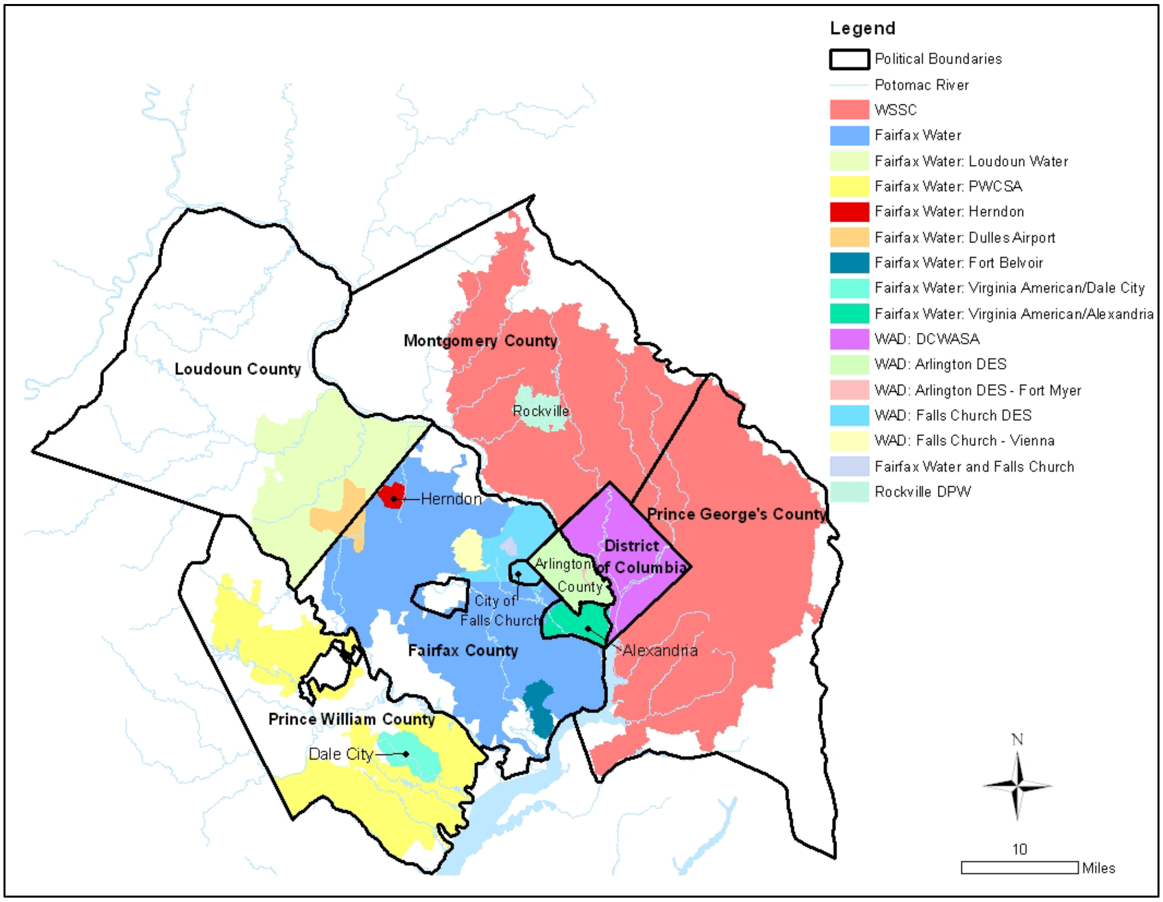


Figure 3-3: Areas served by water suppliers in the Washington metropolitan area, 2040 forecasts.

3.4 Dwelling Unit Ratios

Dwelling unit ratios, defined as the number of single family households divided by the number of multi-family households, were calculated by county for the WMA suppliers and their wholesale customers. The number of single family and multi-family (*e.g.* apartment) households (specifically, occupied housing units) was obtained from each jurisdiction's planning agency. For water suppliers that serve more than one county or that serve a portion of a county, only the households within the areas served by WMA water suppliers were used to develop the ratio. Dwelling unit ratios for the area served by each WMA supplier were used to separate the MWCOG household forecasts into single family and multi-family households, which are in turn used to calculate unit use factors. Dwelling unit ratios for the major jurisdictions in the WMA are shown in Table 3-1 below. The ratios were compiled using information from the City of Alexandria Department of Planning and Zoning; Arlington County Department of Community Planning, Housing and Development; City of Rockville Community Planning and Development Services; District of Columbia Office of Planning; Fairfax County Department of Planning and Zoning; Falls Church Planning Division; Town of Herndon, Department of Community Development; Montgomery and Prince George's offices of the Maryland National Capital Park and Planning Commission; and Loudoun County Department of Management and Financial Services.

Table 3-1: Dwelling unit ratios for each jurisdiction served by a WMA water supplier (portions of the jurisdictions not served by Fairfax Water, WSSC, Washington Aqueduct, or one of their wholesale customers are excluded from this analysis).

	2005	2008	2010	2015	2020	2025	2030	2035	2040
Arlington County[1]	0.67	0.60	0.59	0.52	0.47	0.46	0.44	0.44	0.44
City of Alexandria[2]	0.47	0.46	0.45	0.43	0.41	0.39	0.37	0.36	0.35
City of Rockville[3]	1.90	1.69	1.59	1.23	1.09	1.03	1.02	0.87	0.80
Dale City	3.14	2.80	2.60	1.67	1.29	1.13	0.98	0.89	0.84
District of Columbia[4]	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Fairfax County[5]	2.93	2.89	2.83	2.62	2.42	2.26	2.15	2.08	1.88
Falls Church	1.90	1.92	1.88	1.70	1.69	1.67	1.65	1.64	1.56
Loudoun County[6]	5.21	5.28	5.17	4.40	3.55	3.18	2.91	2.73	2.55
Montgomery County	2.07	1.83	1.99	1.77	1.61	1.49	1.39	1.33	1.29
Prince George's County	1.98	2.04	2.00	2.00	1.95	1.89	1.84	1.81	1.79
Prince William County	4.03	3.94	3.82	2.68	2.07	1.73	1.54	1.42	1.36
Vienna[7]	12.03	11.64	11.65	11.31	10.63	10.00	9.56	9.28	8.78
Town of Herndon[8]	2.09	2.07	2.06	1.90	1.72	1.71	1.67	1.60	1.53

[1]Data was provided by housing unit (all houses, including those not occupied). The county vacancy rate was applied to these numbers to calculate the number of occupied households.
[2]2005, 2008, 2035, and 2040 were extrapolated from the provided data.
[3]Rockville's household projections for 2006 through 2030 were provided as the annual change in the number of households from a baseline number from the 2000 Census. Household figures for 2035 and 2040 were extrapolated.
[4]The District of Columbia does not track the number of single family or multi-family households. U.S. Census data from 2007 was used to derive the dwelling unit ratio. This value was assumed for all years, as has been done in previous reports.
[5]The number of housing units was provided for 2008, 2009, 2010-2035, 2037 by TAZ. The vacancy rate was applied by TAZ to calculate the number of single and multi-family occupied households. 2005 and 2040 values were extrapolated.
[6]The number of single family and multi-family households by TAZ was not available for 2008. The 2008 value was interpolated for the areas of Loudoun County served by Loudoun Water.
[7] The area served by Vienna extends beyond the town's boundaries; therefore, the demographic figures for within the area and the town are not necessarily the same.
[8]The number of 2008 single family and multi-family housing units were provided, along with estimates for the total number of units in 2010, 2020, and 2030. An estimate of the number of single family units in 2030 was also provided. 2020 values were assumed to be half way between 2010 and 2030 values. The others values were extrapolated.

3.5 MWCOG Cooperative Forecast

Estimates of population, households, and employees in the WMA for 2005 through 2040 are based on the Metropolitan Washington Council of Governments' (MWCOG) Round 7.2 Cooperative Forecast (MWCOG, 2009). This forecast is developed through a cooperative process involving MWCOG and local government agencies. The Cooperative Forecasting Program, established in 1975 and administered by MWCOG, allows for coordinated local and regional planning using common assumptions about future growth and development. The forecast available at the beginning of this study, Round 7.2, for the period between 2005 and 2040, was completed in fall 2008, and approved by the MWCOG Board of Directors in July 2009.

The development of the MWCOG forecast uses both a regional econometric model and bottom-up approach undertaken by local planning agencies. The econometric model is based on national and local economic and demographic trends, while the local planning agencies rely more on development and transportation plans, in addition to local economic and demographic trends. After these two forecasts have been independently completed, they are reconciled through MWCOG's Cooperative Forecasting and Data Subcommittee and approved by MWCOG's Board of Directors. The final product is an estimate of population, employees, and households as distributed by traffic analysis zone (TAZ). Each county has several hundred TAZs, which allows for a forecast of water demand at the TAZ level by areas served by each water supplier. In the WMA there are currently 1,972 TAZs of varying size. TAZs tend to be smaller closer to the urban core (*i.e.* D.C. has the most TAZs of all jurisdictions in the area). More information on the development of this forecast can be found at MWCOG's website*: www.mwcog.org.*

MWCOG provided ICPRB with the Round 7.2 dataset by county. Data was extracted from the county datasets in order to determine the population, number of households, and number of employees in a given area served by a WMA water supplier. To do this, GIS ArcMap™ (ESRI) was used to estimate a ratio of the area within a TAZ served by a water supplier. For the TAZs that were not completely within an area served by one of the WMA water suppliers, it was assumed that the number of units (households, employees, or population) was allocated based on the area ratio. For example, if 50 percent of the area in a TAZ was within the area served by WSSC, then 50 percent of its households, employees, and population were assumed to be customers of WSSC. In order to verify this assumption and to make corrections when needed, footprints of areas served were exported to Google Earth and overlaid on satellite imagery in order to survey area boundaries. For example, if a TAZ was only partially within an area boundary, the satellite image was used to estimate the percentage of households within the TAZ that were actually within the area. This was done for WSSC, Fairfax Water, Loudoun Water, Prince William County Service Authority, Falls Church DEP, and Rockville DPW. Finally, the data associated with each TAZ were multiplied by the percentage of supplier coverage in the given TAZ. While most TAZs were covered 100 percent by the areas, perimeter TAZs ranged in coverage. This second step followed similar imaging techniques adopted by ICPRB during the 2005 WMA water supply study, and allowed for more precise demographic estimates.

Once this process was complete, the population, household, and employee data for each area were extracted from the county data (Table 3-2). Overall, Round 7.2 indicates continued growth throughout the area served by the WMA suppliers and their wholesale customers (Table 3-3). Fairfax Water is predicted to experience the most growth of all the suppliers over the next 30 years. The largest expected gain is in the number of employees, which is predicted to grow by 54 percent by 2040. Overall, the WMA forecast indicates an increase in the number of households by 29 percent, population by 24 percent, and employment by 38 percent.

Table 3-2: Projected MWCOG Round 7.2 figures for households, population, and employees by WMA water supplier.

	2010			2040		
Areas Served	**Households**	**Population**	**Employees**	**Households**	**Population**	**Employees**
Fairfax Water - Dulles International Airport	23	57	16,268	23	57	20,844
Fairfax Water - Fort Belvoir	504	1,309	17,892	665	1,804	21,279
Fairfax Water - Town of Herndon	7,580	22,972	24,733	8,400	25,405	27,334
Fairfax Water - Loudoun Water	67,750	192,356	115,309	109,621	296,052	225,145
Fairfax Water - Prince William County Service Authority	95,114	276,820	85,743	154,651	418,105	185,262
Fairfax Water - Current retail area	307,256	834,922	456,687	386,624	1,037,719	620,677
Fairfax Water/Virginia American - City of Alexandria	70,434	142,420	109,109	93,006	178,128	164,844
Fairfax Water/Virginia American - Dale City	21,903	66,166	9,950	23,871	71,008	18,484
Fairfax Water subtotal	570,564	1,537,022	835,691	776,861	2,028,278	1,283,869
Aqueduct - Arlington County DES	99,581	208,808	212,380	122,107	245,048	278,972
Aqueduct - City of Falls Church DES	52,050	129,794	140,469	67,203	164,728	180,417
Aqueduct - Vienna PWD[1]	9,662	26,832	14,105	11,306	31,408	15,079
Aqueduct - D.C. Water and Sewer Authority	275,963	610,732	788,162	359,378	789,456	957,162
Aqueduct - D.C. WASA - Fort Meyer	305	2,594	2,121	305	2,594	1,782
Aqueduct subtotal	437,561	978,760	1,157,237	560,299	1,233,234	1,433,412
WSSC - Prince George's County	307,034	841,431	353,588	364,280	951,971	507,534
WSSC – Montgomery County	331,130	881,436	437,556	414,864	1,057,213	615,761
WSSC subtotal[2]	638,164	1,722,867	791,144	779,144	2,009,184	1,123,295
Fairfax Water, Aqueduct, WSSC total	1,646,289	4,238,649	2,784,072	2,116,304	5,270,696	3,840,576
City of Rockville DPW	17,880	46,014	64,893	26,282	63,045	87,180
Fairfax Water, Aqueduct, WSSC, Rockville total	1,664,169	4,284,663	2,848,965	2,142,586	5,333,741	3,927,756

[1] The area served by Vienna extends beyond the town's boundaries; therefore, the demographic figures for the area served and the town are not necessarily the same.

[2] These numbers reflect the expansion in the area served that is anticipated for WSSC.

Table 3-3: Predicted net increase in demographics for WMA water suppliers from 2010 to 2040.

	Additional Households (percent)	Additional Population (percent)	Additional Employees (Percent)
Fairfax Water retail and wholesale customers	206,297 (36%)	491,256 (32%)	448,178 (54%)
Aqueduct wholesale customers	122,738 (28%)	254,474 (26%)	276,175 (24%)
WSSC retail customers	140,980 (22%)	286,317 (17%)	332,151 (42%)
Totals (plus Rockville)	478,417 (29%)	1,049,078 (24%)	1,078,791 (38%)
Totals - 2000 WMA water supply study - (Shown for comparison, projected for period 2000 to 2020)	343,092 (22%)	792,524 (19%)	831,919 (32%)

While Round 7.2 continues to indicate growth in the region, a comparison of the estimate for 2005 in the Round 6.4a forecast (used in the 2005 study) and actual 2005 numbers in Round 7.2 shows a few significant changes in the forecast (Table 3-4). Most notably, the 2005 estimates for Prince William County were lowered – households and population by 11 percent and employment by 13 percent (Table 3-5). The 2005 figures for Fairfax County were slightly lowered, and Prince George's County and Montgomery County either saw a minor decrease or no change. Loudoun County is the only jurisdiction where a significant increase between projected and experienced figures (14 percent) in 2005 employment is seen. These differences are attributed to the 2005 numbers in Round 6.4a being a forecasted number, whereas in Round 7.2 they are the base number, and therefore are a better reflection of the actual growth (Greg Goodwin, personal communication, 7/16/09).

Table 3-4: Comparing Round 6.4a and Round 7.2 demographics for 2005. Round 6.4a was used in the 2005 demand forecast, and Round 7.2 is used in the 2010 demand forecast.

	Round 6.4a 2005 Forecasted Households	Round 7.2 2005 Estimated Households	Round 6.4a 2005 Forecasted Population	Round 7.2 2005 Estimated Population	Round 6.4a 2005 Forecasted Employees	Round 7.2 2005 Estimated Employees
Prince George's County	303,646	305,057	853,953	846,829	357,636	347,301
Montgomery County	347,846	347,768	944,606	931,424	520,295	500,584
District of Columbia	263,937	253,379	606,998	582,164	720,407	750,260
Loudoun County	86,275	87,478	243,528	247,311	114,478	130,304
Prince William County	133,104	118,939	396,443	354,276	130,406	113,532
Fairfax County	395,000	375,353	1,078,000	1,027,502	635,248	600,017

Table 3-5: Difference between Round 7.2 and Round 6.4a demographics for 2005. Round 6.4a was used in the 2005 demand forecast and Round 7.2 is used in the 2010 demand forecast.

	Difference from Round 6.4a Households (percent)	Difference from Round 6.4a Population (percent)	Difference from Round 6.4a Employees (percent)
Prince George's County	1,411 (0%)	-7,124 (-1%)	-10,335 (-3%)
Montgomery County	-78 (0%)	-13,182 (-1%)	-19,711 (-4%)
District of Columbia	-10,558 (-4%)	-24,834 (-4%)	29,853 (4%)
Loudoun County	1,203 (1%)	3,783 (2%)	15,826 (14%)
Prince William County	-14,165 (-11%)	-42,167 (-11%)	-16,874 (-13%)
Fairfax County	-19,647 (-5%)	-50,498 (-5%)	-35,231 (-6%)

3.6 Other Potential Demographic Changes

In addition to the changes considered in the MWCOG forecast, there are a few areas that are expected to experience growth that were not considered in Round 7.2. For instance, there are areas in Fairfax County where amendments to the county's comprehensive plan are being reviewed that could lead to significant growth. Additionally, there are changes to the region's transportation infrastructure that could also lead to growth in certain areas. An overriding development that will affect multiple portions of the region is the military's Base Realignment and Closure (BRAC) process. MWCOG Round 7.2 projections account for the confirmed changes that will occur due to BRAC, but are unable to assess additional plans that are not yet finalized by the counties. Note that some of the changes described below will likely serve to shift growth from within the WMA to other areas outside the WMA, and in these cases, impacts on total WMA water demand should not be large. Other potential changes may have a significant impact on water demand, and are considered in the high demand scenario explained in Section 4.2 of Chapter 4.

In 2005, MWCOG reviewed BRAC recommendations and analyzed changes in population, households, and employment in 2010 and 2020 as compared to figures from Round 6.2a (MWCOG, 2005). The report indicated that in 2010 there is likely to be a loss of approximately 15,000 jobs in the WMA, but that by 2020 there will likely be an increase of 13,700 jobs, as based on Round 6.2a figures. Table 3-6 shows which areas are predicted to experience changes in employment.

Table 3-6: Regions of the WMA that are expected to see changes in the number of employees due to BRAC.

	2010	2020
Increase	I-95/Springfield Area; Bethesda/Friendship Heights, Fort Belvoir (increase of 15,000 jobs)	I-95/Springfield Area; Bethesda/Friendship Heights; Fort Belvoir (increase of 16,000 jobs)
Decrease	Pentagon/Reagan Airport/Alexandria; Rosslyn/Ballston Corridor; Baileys Crossroads Area; Silver Spring/Takoma Park/Wheaton	Pentagon/Reagan Airport/Alexandria; Rosslyn/Ballston Corridor; Silver Spring/Takoma Park/Wheaton; D.C.

In addition to these developments, there are also potential changes that have yet to be finalized, but which could have a significant effect on regional water use. For example, there have been discussions about closing Walter Reed Hospital in D.C. and possibly building a naval hospital in conjunction with the National Institutes of Health in Montgomery County, Maryland (Greg Goodwin, personal communication, 7/16/09).

In Fairfax County a number of land development initiatives are currently being considered prior to undergoing more formal evaluation as proposed amendments to the county's Comprehensive Land Use Plan (Greg Prelewicz, personal communication, 7/7/09). Included among the areas of interest are:

Fort Belvoir BRAC Initiated Development

- Lorton - South Rt. 1 Suburban Center
- Richmond Highway Corridor
- I-95 Corridor Industrial Area
- Beltway South Industrial Area
- Springfield Central Business District
- Kingstowne Central Business District

Urbanization & Redevelopment

- Baileys Crossroads Revitalization Area
- Reston - Lake Anne Village Center Redevelopment Area
- INOVA Fairfax Hospital Special Study Area
- Merrifield Revitalization Area

Transportation Oriented Development

- Tysons Corner Urban Center
- Reston - Herndon Suburban Center
- Huntington Metro Transportation Study Area
- Franconia - Springfield Metro Transportation Study Area
- Van Dorn Street Metro Transportation Study Area
- Fairfax-Vienna Metro Transportation Study Area

Any of these potential increases in land use density will result in a corresponding increase in water use. The associated additional water demand is difficult to estimate until the scope of individual development projects is better defined. Fairfax Water has provided some preliminary estimates of potential additional demand, which are incorporated into this study's high demand scenario forecasts, discussed in Chapter 4.

Montgomery County and Prince George's County in Maryland have been undergoing significant changes to their transportation infrastructure. The Intercounty Connector, a freeway running east-west that will connect other existing transportation corridors, was discussed in the 2005 report. The first portion of the project is scheduled to be completed in the fall of 2010, with an anticipated completion date for the entire project of late 2011 (*http://www.iccproject.com*, 7/9/09).

Additionally, these two counties are exploring the addition of a rapid transit line that would connect with existing regional transportation infrastructure as another means of improving east-west travel (*http://www.purplelinemd.com*, 7/9/09). The form of this project is still being explored; construction would not begin until 2012 at the earliest. While this project was not considered in the Round 7.2 forecast, a Round 7.2a is being developed that will account for this development. Provisionally it is expected to add approximately 3,000 new jobs between 2020 and 2030 to both the Prince George's and Montgomery county Round 7.2 estimates. Table 3-7 shows the new numbers as submitted by the two counties (no other jurisdictions participated in Round 7.2a).

Table 3-7: Round 7.2a figures for Prince George's and Montgomery counties, reflecting the development of a rapid transit line in the region.

	Montgomery County			Prince George's County		
	Households	**Population**	**Employee**	**Households**	**Population**	**Employee**
2005	347,000	929,100	500,000	306,014	849,333	347,885
2010	362,000	966,000	510,000	317,881	872,014	362,886
2015	386,000	1,025,000	547,000	331,243	899,192	379,393
2020	408,000	1,075,000	590,000	344,789	924,788	399,211
2025	425,200	1,113,500	631,500	356,841	945,710	424,429
2030	440,400	1,142,000	673,000	367,834	966,852	454,932
2035	451,400	1,161,000	703,000	375,627	985,064	488,946
2040	460,000	1,174,000	723,000	380,375	995,372	524,292

3.7 Calculation of Unit Use Values

The average daily water consumption by single family household (SFH), multi-family household (MFH), and employee (EMP) users was calculated in terms of gallons per unit (household or employee) per day for each of the four years (2005, 2006, 2007, 2008) for which data were available for this study (Table 3-8). The unit use values were calculated based on the aforementioned dwelling unit ratios, MWCOG housing and employment data, and water consumption as billed by the WMA water suppliers. Current unit use factors are a primary input for the long-term water demand forecasts presented in Chapter 4.

Billing data from the regional water suppliers was requested in terms of single family households, multi-family households, and commercial categories. The availability of such disaggregated data was dependent on the individual water suppliers' billing system. Instances where these data were not available are noted in Appendix B. The total amount of water consumed by each category was divided by the number of single or multi-family households or the number of employees. In addition, unmetered water was calculated. This is the difference between the water produced (or purchased at the wholesale level) and the water billed to customers. When each water suppliers' total demand was calculated, if the amount of unmetered water was less than 10 percent, it was assumed to be 10 percent to allow for a conservative estimate of demand. These values are also included in each water supplier summary in Appendix B.

Table 3-8: Unit use values by area served by water supplier (gallons per unit per day). (A detailed description of unit use calculations can be found in Appendix B.)

	2005			2006			2007			2008		
Area Served	**SFH**	**MFH**	**EMP**	**SFH**	**MFH**	**EMP**	**SFH**	**MFH**	**EMP**	**SFH**	**MFH**	**EMP**
Fairfax Water - Dulles International Airport[1]	(206.4)	(170.0)	61.5	(211.2)	(167.5)	55.7	(227.6)	(167.8)	49.5	(199.9)	(165.6)	43.8
Fairfax Water - Fort Belvoir[1]	(206.4)	(170.0)	85.1	(211.2)	(167.5)	108.4	(227.6)	(167.8)	99.9	(199.9)	(165.6)	73.3
Fairfax Water - Town of Herndon[2]	157.5		43.7	157.9		42.6	157.0		42.0	[157.5]		[42.8]
Fairfax Water - Loudoun Water	216.9	173.8	47.6	236.2	188.9	52.1	254.3	203.0	54.5	220.6	176.2	45.3
Fairfax Water - Prince William County Service Authority[1,2]	270.8	(173.8)	(47.6)	277.3	(188.9)	(52.1)	290.0	(203.0)	(54.5)	[279.4]	[188.6]	[51.4]
Fairfax Water - Area currently served by retail	206.4	170.0	41.8	211.2	167.5	42.3	227.6	167.8	44.4	199.9	165.6	40.0
Fairfax Water/Virginia American - City of Alexandria[1,2]	164.7	167.8	(41.8)	177.0	148.4	(42.3)	183.4	143.8	(44.4)	[175.0]	[153.3]	[42.9]
Fairfax Water/Virginia American - Dale City[1,2]	245.2	172.6	(41.8)	275.5	274.0	(42.3)	255.9	233.4	(44.4)	[258.9]	[226.7]	[42.9]
Aqueduct - Arlington County DES	164.7	103.3	42.5	168.0	100.4	41.3	170.4	96.6	42.0	158.8	93.3	39.7
Aqueduct - City of Falls Church DES	136.6	118.0	18.6	221.8	159.8	35.0	220.0	157.1	34.3	199.9	163.3	30.4
Aqueduct - Vienna PWD	207.7	148.6	29.7	197.7	133.7	28.0	204.6	132.3	27.0	196.8	130.9	26.0
Aqueduct - D.C. Water and Sewer Authority	177.5	140.4	58.6	174.7	137.9	61.5	169.9	132.9	60.2	161.9	122.5	58.9
Aqueduct - D.C. WASA - Fort Meyer[1]	(206.4)	(170.0)	92.1	(211.2)	(167.5)	107.8	(227.6)	(167.8)	129.3	(199.9)	(165.6)	115.2
WSSC - Montgomery County and Prince George's County	179.6	162.6	49.0	185.7	154.2	44.0	186.9	152.2	42.5	189.3	142.0	40.8
City of Rockville DPW	154.6	139.1	16.6	183.7	165.3	22.3	186.9	168.2	24.2	161.1	145.0	23.8
Weighted Average (WSSC, Fairfax Water retail, and D.C. WASA only)	**187.5**	**156.0**	**51.2**	**191.9**	**150.8**	**50.5**	**196.8**	**148.1**	**49.8**	**188.5**	**139.2**	**47.8**

Note: SFH = single family home; MFH = multi-family home; EMP = employees

[1] Values in parenthesis are assumed, based on values from another utility.

[2] Values in brackets are averages of the previous years' values.

3.8 Trend Analyses of Calculated Unit Use Values

The forecasts of average annual demand for the years 2010 through 2040 require estimates of unit use factors throughout this time period. Calculated unit use values, such as those appearing in Table 3-8, fluctuate from year to year due to factors such as weather, demographic and economic conditions, and minor variations in estimation methods. Unit use factors are also expected to exhibit long-term trends because of changes in customer use behavior. In recent ICPRB demand forecasts for the WMA, unit use factors for the beginning of the forecast period were generally approximated by the values calculated for the most recent year in which data were available, which for the current study is 2008, with minor adjustments made to account for weather effects. Future unit use factors for employee use were assumed to remain constant over the forecast period, but factors for both single and multi-family household use were assumed to decline due to installation of low-flow plumbing fixtures resulting from the Energy Policy Act of 1992.

Calculated unit use factors from current and past studies for the WMA were compiled and analyzed to determine values for use in the water demand forecasts. Unit use factors calculated in the current study and past studies are given in Table 3-9 and graphed in Figure 3-4. Visual inspection of the graphs indicates that employee unit use has remained relatively constant throughout the past two decades for all three utilities. Within the same time period, the graphs suggest that household unit use has dropped for both Washington Aqueduct and WSSC.

Table 3-9: Unit use factors calculated in past and current studies.

	Fairfax Water (retail)			Washington Aqueduct (D.C.WASA)			WSSC (retail)		
	SFH	**MFH**	**EMP**	**SFH**	**MFH**	**EMP**	**SFH**	**MFH**	**EMP**
1990[1]	240	177	44	325	315	50	241	224	58
1995[2]	229.0	156.0	47.0	237.0	237.0	50.0	249.0	233.0	53.0
1998[3]	218.6	191.8	45.8	304.4	304.4	44.8	181.8	183.8	44.2
1999[3]							161.0	171.1	42.9
2000[4]	227	165	44	279.0	279.0	60.7	179.0	184.0	45.0
2002[5]	241.5	171.1	49.9	168.2	172.9	58.1	185.0	173.4	45.9
2003[5]	207.1	167.5	47.8	184.7	156.8	55.8	183.7	174.3	44.1
2004[5]	206.4	158.9	45.1	169.6	159.8	56.9	178.9	175.3	46.6
2005[6]	206.4	170.0	41.8	177.5	140.4	58.6	179.6	162.6	49.0
2006[6]	211.2	167.5	42.3	174.7	137.9	61.5	185.7	154.2	44.0
2007[6]	227.6	167.8	44.4	169.9	132.9	60.2	186.9	152.2	42.5
2008[6]	199.9	165.6	40.0	161.9	122.5	58.9	189.3	142.0	40.8

Note: SFH = single family home; MFH = multi-family home; EMP = employees

[1] 1990 study results (Holmes and Steiner, 1990), based primarily on 1988 data.

[2] 1995 study results (Mullusky *et al*., 1996), based primarily on 1993 or 1994 data (WSSC results are for existing housing units).

[3] From 2000 study spreadsheet.

[4] Revised 2000 value reported in 2005 study (Kame'enui *et al*., 2005).

[5] 2004 results from 2005 study (Kame'enui *et al*., 2005); 2002 and 2003 results from 2005 study spreadsheet.

[6] Current study results

Both parametric and non-parametric statistical tests were used to identify significant trends in unit use values for the three major WMA suppliers over the past decade. Linear regression models were fit to the unit use time series appearing in Table 3-9 for the time period, 2000 through 2008, with results summarized in Table 3-10 and Table 3-11. For Washington Aqueduct, the regressions were done on 2002 through 2008 values, because the 2000 values were clearly outside of the linear portion of the data. The Student's T-test was used as a parametric method to test for the statistical significance of the slopes appearing in Table 3-10.

For the Student's T-test, the null hypothesis was that the slope coefficient is zero; the alternative hypothesis was that the slope coefficient is not zero. Typically, the null hypothesis is rejected if the P-value associated with the T statistic is less than the significance level. Results in Table 3-10 show that at the five percent significance level, unit use was decreasing for multi-family household use for both Washington Aqueduct and for WSSC. A somewhat weaker trend was identified for single family household unit use for WSSC, which was found to be increasing at the 10 percent significance level.

The Mann-Kendall test for trends (*e.g.* Gilbert, 1987) was also applied to the 2000 through 2008 unit use values in Table 3-9. This non-parametric test is based on a statistic, S, constructed from the signs of the differences of all pairs of successive values in a time series. Table 3-12 contains a summary of Mann-Kendall test results and associated *P*-value, the probability associated with the absolute value of *S*. The test indicates a downward trend (upward trend) if *S* is negative (positive) and if the *P*-value is less than the significance level; A *P*-value greater than the significance level indicates no trend. The Mann-Kendall test results support the results of the linear regression tests. At the five percent significance level, Mann-Kendall indicates that multi-family unit use has fallen since 2000 for both Washington Aqueduct and WSSC, whereas single family unit use has increased for WSSC.

Though only a weakly increasing trend was found for WSSC single family household unit use from the least squares regression analysis, the Mann-Kendall test indicated that the increasing trend was more significant. The existence of an increasing trend in this case is consistent with results of a WSSC demand study completed in 2006 (WSSC, 2006). This study found that single family household unit use was higher for new units (added after 2005) than for older units in the area served by WSSC.

Table 3-10: Linear regression analysis of recent unit use values.

	SFH		MFH		Employees	
	Intercept	**Slope**	**Intercept**	**Slope**	**Intercept**	**Slope**
Fairfax Water – retail (2000 - 2008)						
Coefficients	5272	-2.52	-156	0.16	1294	-0.62
Standard Error	3776	1.88	1138	0.57	744	0.37
***T* Statistic**	1.40	-1.34	-0.14	0.28	1.74	-1.68
***P*-value**	0.21	0.23	0.90	0.79	0.13	0.14
Lower 95%	-3969	-7.13	-2942	-1.23	-528	-1.53
Upper 95%	14514	2.09	2629	1.55	3117	0.29
Washington Aqueduct – D.C. WASA (2002 - 2008)						
Coefficients	3292	-1.56	15969	-7.89	-1066	0.56
Standard Error	2720	1.36	1768	0.88	610	0.30
***T* Statistic**	1.21	-1.15	9.03	-8.95	-1.75	1.84
***P*-value**	0.28	0.30	0.00	0.00	0.14	0.12
Lower 95%	-3700	-5.04	11424	-10.16	-2635	-0.22
Upper 95%	10286	1.93	20514	-5.62	502	1.34
WSSC - retail (2000 - 2008)						
Coefficients	-1766	0.97	10454	-5.13	949	-0.45
Standard Error	908	0.45	1304	0.65	681	0.34
***T* Statistic**	-1.94	2.15	8.01	-7.89	1.39	-1.33
***P*-value**	0.10	0.08	0.00	0.00	0.21	0.23
Lower 95%	-3987	-0.14	7262	-6.73	-716	-1.28
Upper 95%	456	2.08	13646	-3.54	2615	0.38

Note: SFH = single family home; MFH = multi-family home

Table 3-11: Regression statistics from analysis of 2000-2008 unit use values.

Regression Statistics	SFH	MFH	Employees
Fairfax Water – retail (2000 - 2008)			
***R* Square**	0.23	0.01	0.32
Standard Error	13.31	4.01	2.62
Relative Stand. Error	0.95	1.07	0.89
Washington Aqueduct – D.C. WASA (7 Observations)			
***R* Square**	0.21	0.94	0.40
Standard Error	7.18	4.67	1.61
Relative Stand. Error	1.06	0.25	1.06
WSSC – retail (2000 - 2008)			
***R* Square**	0.43	0.91	0.23
Standard Error	3.20	4.60	2.40
Relative Stand. Error	1.04	0.36	0.87

Note: SFH = single family home; MFH = multi-family home

Table 3-12: Results of Mann-Kendall Tests for Trends.

	SFH	MFH	Employees
Fairfax Water (2000 - 2008)			
Mann-Kendall *S*	-10	2	-14
***P*-value**	0.14	0.45	0.054
Washington Aqueduct (7 Observations)			
Mann-Kendall *S*	-5	-19	11
***P*-value**	0.28	0.00	0.07
WSSC (2000 - 2008)			
Mann-Kendall *S*	16	-22	-12
***P*-value**	0.03	0.00	0.09

Note: SFH = single family home; MFH = multi-family home

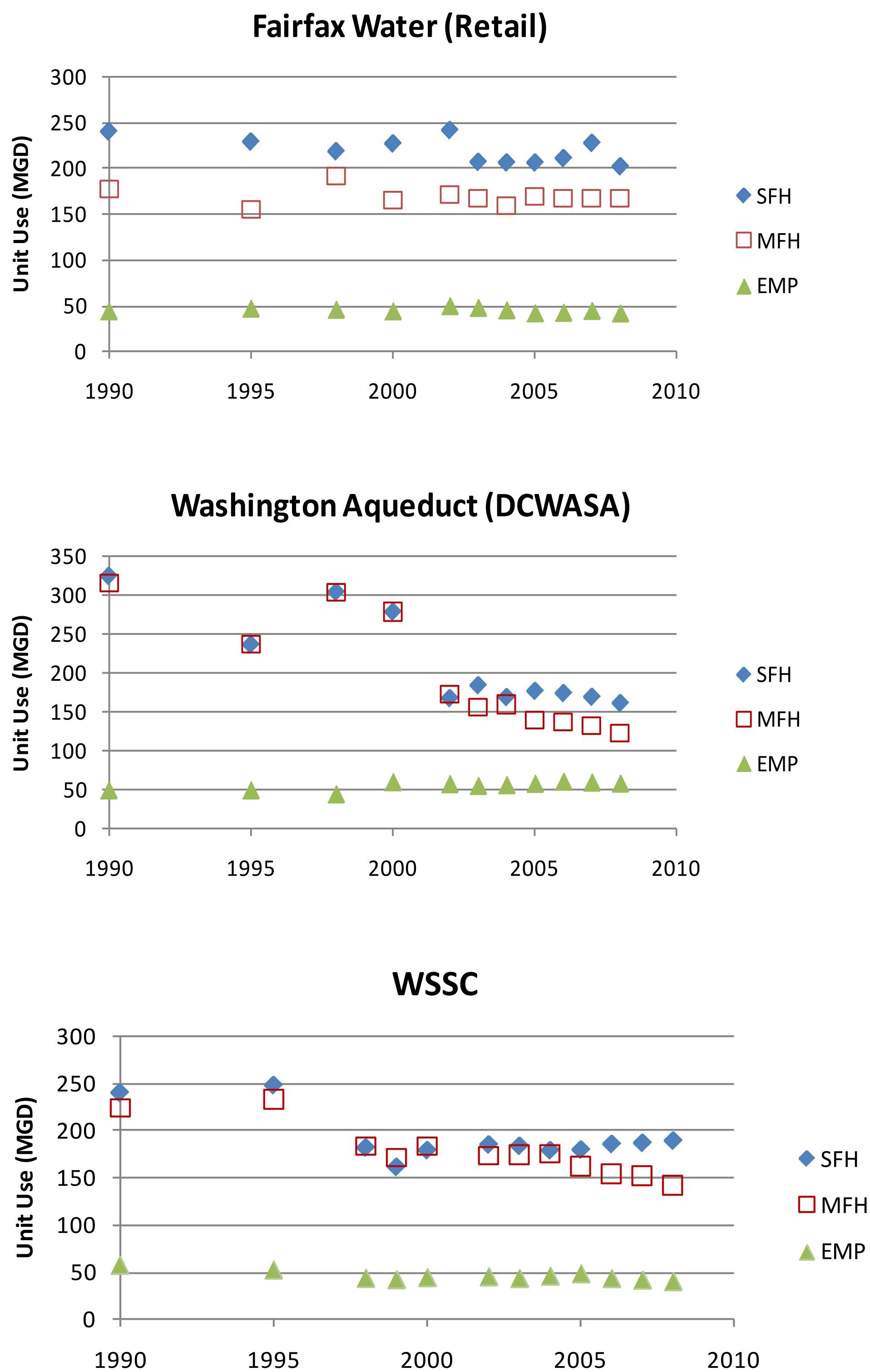


Figure 3-4: Unit use factors for the three major WMA suppliers from 1990 through 2008.

Summertime outdoor water use, which is a significant component of demand in the WMA, is influenced by weather conditions. Summer temperature and precipitation data in the WMA over recent years were examined for trends that may have occurred during the study period and influenced single family household unit use. Average temperature and precipitation data for the WMA for the four months with highest water use – June, July, August, and September – are summarized in Table 3-13 and graphed in Figure 3-5. Regression analyses did not indicate any trends at the five percent significance level in precipitation or temperature for the period from 1995 to 2008, nor for the shorter period of 2000 through 2008. Thus, the trends identified for recent unit use are not likely due to trends in WMA summertime weather conditions.

Table 3-13: Total precipitation and average temperature in the WMA for June, July, August, and September.

Year	Total Precipitation (inches)	Average Temperature (degrees F)
1995	12.9	86.1
1996	24.4	83.8
1997	11.3	85.1
1998	10.2	85.8
1999	19.1	85.8
2000	15.1	80.8
2001	20.0	83.0
2002	12.1	87.0
2003	25.6	82.1
2004	17.4	82.3
2005	12.3	86.3
2006	21.6	84.1
2007	8.4	86.1
2008	13.9	86.3

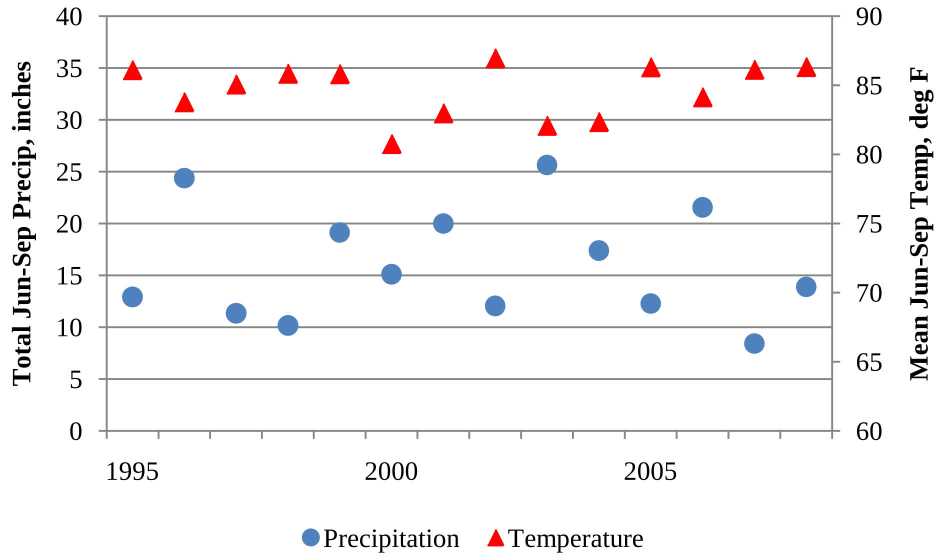


Figure 3-5: Average June through September WMA weather conditions for 1995 through 2008.

3.9 Unit Use Factors for Beginning of Demand Forecast Period

Based on the results of the analyses described in the previous section, unit use factors for the beginning of the forecast period were estimated. To minimize the effects of year-to-year fluctuations in calculated unit use value on the demand forecasts, the values for the forecast are derived from the set of values computed for 2000 through 2008, rather than from the 2008 values alone. This approach was used to take advantage of the availability of unit use values over time. Additionally, there are indications that water demand data were somewhat anomolous in 2008, possibly because of the very unusual economic conditions experienced during that year. In the cases where significant trends were identified for this period by both least squares regression and Mann-Kendall tests (Washington Aqueduct and WSSC multi-family household unit use), the forecasts are based on unit use factors predicted by the linear regression models for the year 2008. In cases where no significant trends were found by either method, the forecasts are based on the simple mean of calculated 2000 through 2008 unit use values (or 2002 through 2008 for Washington Aqueduct). In cases where there were mixed results from the two tests, the conservative (*i.e.* higher) value was chosen. The unit use factors used for the beginning of the forecast period are given in Table 3-14, along with a summary of the trend analysis results and a comparison of unit use estimates from the regression models and the 2000 through 2008 means. For comparison purposes, calculated unit use values for 2008 are also included in Table 3-14.

Table 3-14: Estimates of current unit use factors.

	FW (retail)			WA (D.C. WASA)			WSSC (retail)		
	SFH	MFH	EMP	SFH	MFH	EMP	SFH	MFH	EMP
Significant trend[1]	no/no	no/no	no/–	no/no	–/–	no/no	no/+	–/–	no/–
2008 predicted by regression	207	168	42	168	122	60	187	146	43
2000-2008 mean	216	167	45	172	146	59	184	165	45
2008 calculated	202	168	42	162	123	59	189	142	41
Unit Use used in forecasts	**216**	**167**	**45**	**172**	**122**	**59**	**187**	**146**	**45**

Note: SFH = single family home; MFH = multi-family home; EMP = employees
[1] "+" = increasing, "–" = decreasing, and "no" = not significant, at five percent significance level, from results of least squares regression/Mann-Kendall.

3.10 Potential Changes in Customer Demand

Changes in water use behavior over a 30-year forecast period are difficult to predict, and are a source of significant uncertainty in the demand forecasts. To reflect this uncertainty, this study considers two potential changes in unit use in the two demand forecast scenarios considered in Chapter 4. The first assumes reductions in both single family and multi-family household unit use values will be seen throughout the forecast period. The second assumes reductions for multi-family households only.

Changes in use over time can be attributed to a number of factors. For example, weather, retail rate structures, and government policies and regulations impact how much water is used. Block rate structures that increase charges as customers use more water can reduce the amount consumed. Policies, such as the Energy Policy Act of 1992, that require the use of more efficient plumbing fixtures can reduce water demand without requiring consumers to change their behavior. Government programs promoting voluntary water conservation may also affect consumer water use behavior. Long-term trends in regional temperature and precipitation which may result from global climate change could also have an impact on summertime outdoor water use, which is a significant component of annual average demand. A detailed investigation of the potential impacts of global climate change on WMA water demand and resources is the subject of a separate report, Part 2 of this study.

It is assumed that some of the reduction in unit use that has occurred in the WMA since the early 1990s can be attributed to the Energy Policy Act of 1992. This bill called for the use of more efficient plumbing fixtures. This study made assumptions based on this policy and on consumer behavior literature to estimate reductions in household unit use factors in the WMA (see Appendix C for details). Specifically, estimated reductions were based on assumptions about residential water use rates (Mayer *et al*., 1999), the number of existing households with remodeled bathrooms, bathroom fixture replacement rates, and the number of new houses with associated low flush toilets and low flow showerheads. Table 3-15, below, summarizes the estimated savings per household.

Table 3-15: Summary of estimated effects of the Energy Policy Act of 1992 on WMA household water use in 2010 and 2040, assuming current Federal standard flow rates.

	2010	2040	Savings
Toilet water use, gallons, per household, per day	33	20	13
Shower water use, gallons, per household, per day	34	31	3

In addition to the water savings prompted by the Energy Policy Act of 1992, other conservation efforts in the WMA will likely contribute additional savings in coming years. For example, MWCOG runs the "Water Use It Wisely" education campaign that promotes wise water use in the region. The first water demand scenario considered in this study assumes that household unit use factors will drop throughout the forecast period for a total reduction of 16 gallons per day from 2010 to 2040 for both single family and multi-family households. This assumption is consistent with that used in ICPRB's past two WMA demand forecasts (Hagen and Steiner, 2000; Kame'enui *et al*., 2005). These estimated reductions may be conservative, because they do not include the effects of other water conservation efforts likely to reduce demand.

The second demand scenario assumes that only multi-family household unit use factors will decrease over the forecast period from reductions due to the Energy Policy Act of 1992. Here the assumption is that single family household unit use will not drop because other changes in water use behavior will offset reductions related to the Energy Policy Act. This alternative scenario is based on a review of the trend analysis results in Section 3.8, information from the water suppliers, and indications that summertime outdoor water use may be increasing in parts of the WMA. A review of the regression analysis results in Table 3-10 shows that multi-family household unit use has significantly decreased in two of the major areas served by WMA water suppliers (WSSC – retail and D.C. WASA), and that the observed annual decreases are greater than the predicted decrease based on the Energy Policy Act between 2000 and 2008. In the third area served by WMA water suppliers, Fairfax Water – retail, annual reductions in multi-family household unit use from the regression analysis are not inconsistent with this predicted reduction. However, the trend analyses found no significant decreases in single family household unit use, and found that single family unit use has been rising significantly for WSSC. Consistent with this result, a recent WSSC study found that water use in newer single family homes served by WSSC is higher than use in older homes (WSSC, 2006). Finally, anecdotal reports from WMA water suppliers indicate that summertime outdoor water use may be increasing in some areas. This is consistent with the slight but persistent increase in August water production in the past two decades, discussed in Chapter 5.

3.11 Effects of Water Use Restrictions

As mentioned, water use restrictions are temporary reductions in water use during times of drought or other serious conditions. Restrictions can be voluntary or mandatory, depending on the severity of the drought. Such restrictions typically include the banning of lawn watering, filling of swimming pools, and operation of ornamental fountains.

In 2000, the MWCOG board of directors endorsed a regionally coordinated public response plan that sets trigger levels for water use restrictions (MWCOG Board Task Force on Regional Water Supply Issues, 2000). Voluntary restrictions are triggered when combined Jennings Randolph and Little Seneca reservoir storage drops below 60 percent full. This trigger level for voluntary restrictions was implemented in the computer model, PRRISM, used for the resource assessment (see Chapter 6). The MWCOG trigger level for mandatory restrictions is more complex and was not implemented in PRRISM, since it would have required excessive computational demand in the daily timestep simulation model. Instead, “mandatory” restrictions are simulated in PRRISM when either Jennings Randolph or Little Seneca storage drops below 25 percent full, and “emergency” restrictions are simulated when storage in either of these reservoirs drops below 5 percent full.

Demand reduction levels are estimated based on recent regional experience and are provided in Table 3-16. The City of Frederick assumes a five to ten percent demand reduction goal for voluntary restrictions per the City of Frederick Water Conservation and Drought Response Plan (2002). A five percent reduction in demand is consistent with that experienced by Fairfax Water in March of 1993 during the Colonial Oil Co. pipeline spill. Fairfax Water had to temporarily shut down its Potomac intake, taking all of its water instead from the Occoquan Reservoir. Fairfax Water asked its customers to voluntarily reduce their water use. Average demand from February 1 through March 28 was 97.6 mgd, and was reduced to 92.6 mgd during March 29 through April 7, a five percent reduction in demand. It is likely that even greater reductions in demand are possible during higher demand summer months with more discretionary outdoor water uses, but to be conservative a reduction in demand of five percent is assumed for summer months and three percent for other months.

Based on WSSC’s experience during the drought of 1999, mandatory restrictions are assumed to have an associated reduction in demand of 9.2 percent in June through September (Kame’enui *et al.*, 2005).

Emergency demand reduction percentages of 15 percent are chosen because they are consistent with mandatory restriction levels experienced in the nearby City of Frederick. Mandatory demand reduction measures were in place in October of 2002, and the City of Frederick achieved a demand reduction of 15.3 percent as compared to the prior October of 2001 (Jennifer P. Dougherty, Mayor of Frederick, 10/11/02 Mayor’s Message). (In the WMA, detrended demand increased by 0.3 percent from October 2001 to October of 2002, so the demand reduction in the City of Frederick is likely real and not due to differences in weather patterns.)

Table 3-16: Demand reduction percentages assumed for restrictions in model runs.

PRRISM Restriction status	Restriction trigger	Percent reduction in system demand, June through September	Percent reduction in system demand, October through May
Voluntary[1]	Combined storage in Jennings Randolph and Little Seneca less than 60 percent full	5%	3%
Mandatory	Jennings Randolph or Little Seneca storage of less than 25 percent full	9.2%	5%
Emergency	Jennings Randolph or Little Seneca storage empty	15%	15%

[1]As defined in the Metropolitan Washington Water Supply and Drought Awareness Response Plan: Potomac River System (MWCOG Board Task Force on Regional Water Supply Issues, 2000).

4 Forecasting Future Water Demand

4.1 Introduction

The forecasts of the WMA's future average annual water demand are presented in this chapter. Here, demand is primarily derived from water billing data and includes unmetered water use. This is done to track trends in water use behavior. In Chapter 5, demand is represented slightly differently by the amount of water produced by utilities at treatment plants to meet consumer demand. Forecasts are given for each area served by a WMA supplier. Because of the uncertainties in both demographic projections and predictions of future unit use, forecasts are provided for two scenarios, the first of which uses assumptions very similar to those of past studies, and the second of which assumes increased population growth and higher unit use. A more detailed breakdown of each forecast is available in Appendix D.

4.2 Forecasts of Water Demand

Forecasts of average annual water demand, including unmetered water use, for the WMA water suppliers are given in Table 4-1. To take into account the uncertainties in both demographic forecasts and in predictions of future water use behavior, this study provides forecasts for the following two scenarios:

<u>Scenario 1</u> – likely demand scenario, and most consistent with recent studies:

- Based on MWCOG Round 7.2 growth forecasts.
- Assumes that both single family household and multi-family household unit use will decrease throughout the forecast period due to the effects of the Energy Policy Act of 1992, as detailed in Appendix C.

<u>Scenario 2</u> – high demand forecast:

- Based on MWCOG Round 7.2 growth forecasts, with preliminary estimates of additional water demand due to potential growth in certain special growth areas not considered in Round 7.2.
- Assumes that only multi-family household unit use will decrease throughout the forecast period. Here, the assumption is that net single family unit use will not decrease due to increases in summertime outdoor water use that will offset decreases from the Energy Policy Act of 1992.

Scenario 2, which results in a higher demand forecast, takes into account additional growth that may occur over the forecast period in Fairfax County in certain special areas. These are areas in which county plans are not yet finalized and are thus not taken into account in the MWCOG Round 7.2 demographic forecasts, as discussed in Section 3.6. Potential additional water demand for the special growth areas was provided by Fairfax Water (Greg Prelewicz, personal communication, 8/5/09). These additional demands were developed based on preliminary conceptual information obtained from Fairfax County (Department of Planning and Zoning) related to potential urbanization, transportation oriented development, and BRAC related development in the Reston, Tysons, Springfield, and Bailey's Crossroads areas of Fairfax

County. The county is in the initial stages of study and analysis associated with these areas and as such any potential modifications to growth or population projections have not been fully developed for consideration through the county's formal processes.

Scenario 2 also includes additional demand resulting from the assumption that no unit use decreases will occur over the forecast period for single family households. In this scenario, it is assumed that water use reductions due to the Energy Policy Act of 1992 and other indoor conservation measures will be offset by increases in summertime outdoor water use by single family households (see Section 3.10 for discussion).

Results reported in Table 4-1 and Table 4-2 show that the WMA suppliers' (not including Rockville) average annual water use during normal years is predicted to be between 498 and 510 mgd in 2010 and to be between 611 and 664 mgd in 2040, depending on the demand scenario. The overall WMA water supplier and wholesale customer average annual demand is forecast to increase between 113 and 154 mgd by 2040 (again excluding Rockville). Of this total, Fairfax Water demand is forecast to increase between 54 and 82 mgd, the Aqueduct between 27 and 32 mgd, and WSSC between 32 and 41 mgd. Growth in annual average demand from 2010 to 2040 by areas served by a water supplier and water use category is shown in Table 4-2.

Table 4-1: Forecast of average annual water demand for the WMA from 2010 to 2040 (mgd).

Areas Served	2010	2015	2020	2025	2030	2035	2040
Fairfax Water - Area currently served by Retail	90.0	93.6	96.9	100.6	103.4	105.5	107.1
Fairfax Water - Dulles	0.8	0.8	0.9	0.9	1.0	1.0	1.0
Fairfax Water - Fort Belvoir	1.6	1.8	1.8	1.8	1.8	1.8	1.8
Fairfax Water - Herndon	2.6	2.7	2.7	2.7	2.7	2.7	2.7
Fairfax Water - Loudon Water	23.3	26.5	31.1	34.1	35.5	36.4	37.2
Fairfax Water - Prince William Co. Service Authority	32.1	35.5	38.9	41.9	44.6	46.7	48.7
Fairfax Water/Virginia American - City of Alexandria	18.2	19.0	20.1	21.1	22.1	22.6	23.2
Fairfax Water/Virginia American - Dale City	6.7	6.9	7.0	7.0	7.0	7.1	7.1
Total Fairfax Water (Scenario 1[1])	**175.2**	**186.9**	**199.4**	**210.2**	**218.2**	**223.8**	**228.9**
Potential demand from "special growth areas"	12	13	15	19	23	28	32
Added demand assuming constant SFH[2] unit use	-	1.9	3.4	5.0	6.1	7.2	8.2
TOTAL Fairfax Water (Scenario 2[3])	**187.2**	**201.7**	**217.8**	**234.2**	**247.3**	**259.0**	**269.1**
Aqueduct - Arlington County DES	25.0	26.7	28.2	28.5	28.6	28.7	28.6
Aqueduct - District of Columbia WASA	107.4	111.3	116.4	119.6	122.6	124.2	127.5
Aqueduct - Falls Church DES	15.6	16.8	17.3	17.8	18.2	18.5	18.7
Aqueduct - Fort Meyer	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Aqueduct - Vienna PWD	2.5	2.5	2.6	2.6	2.6	2.6	2.7
TOTAL Washington Aqueduct (Scenario 1)	**150.9**	**157.7**	**164.8**	**168.7**	**172.2**	**174.2**	**177.8**
Added demand assuming constant SFH unit use	-	1.0	1.8	2.6	3.3	3.9	4.6
TOTAL Washington Aqueduct (Scenario 2)	**150.9**	**158.6**	**166.6**	**171.4**	**175.5**	**178.1**	**182.4**
WSSC – Served by Retail	168.7	174.3	180.3	185.2	190.7	194.7	197.4
WSSC – Howard County[4]	2.5	2.5	5.0	5.0	5.0	5.0	5.0
WSSC – Charles County	0.7	0.7	1.4	1.4	1.4	1.4	1.4
WSSC (Scenario 1)	**171.9**	**177.5**	**186.7**	**191.6**	**197.1**	**201.1**	**203.8**
Added demand assuming constant SFH unit use	-	2.0	3.7	5.3	6.4	7.6	8.7
WSSC (Scenario 2)	**171.9**	**179.6**	**190.4**	**196.9**	**203.5**	**208.7**	**212.5**
WMA Suppliers Subtotal (Scenario 1)	**497.9**	**522.1**	**551.0**	**570.6**	**587.5**	**599.1**	**610.5**
Potential demand from "special growth areas"	12	13	15	19	23	28	32
Added demand assuming constant SFH unit use	0.0	4.9	8.8	12.9	15.8	18.7	21.5
WMA Suppliers Subtotal (Scenario 2)	**509.9**	**540.0**	**574.8**	**602.5**	**626.3**	**645.7**	**664.0**
City of Rockville DPW (Scenario 1)	4.8	5.0	5.3	5.6	5.8	6.1	6.3
Added demand assuming constant SFH unit use	0.0	0.0	0.1	0.1	0.2	0.2	0.2
City of Rockville DPW (Scenario 2)	4.8	5.0	5.4	5.7	6.0	6.3	6.5
WMA TOTAL plus Rockville (Scenario 1)	**502.7**	**527.1**	**556.3**	**576.2**	**593.3**	**605.1**	**616.8**
Potential demand from "special growth areas"	12	13	15	19	23	28	32
Added demand assuming constant SFH unit use	0.0	4.9	8.9	13.0	16.0	18.9	21.7
WMA TOTAL plus Rockville (Scenario 2)	**514.7**	**545.0**	**580.2**	**608.2**	**632.3**	**652.0**	**670.5**

[1]Scenario 1 predictions are based on calculations of demand that account for reductions due to the Energy Policy Act being applied to both single family and multi-family households, starting in 2015.

[2]SFH = single family households

[3]Scenario 2 predictions are based on calculations of demand that account for reductions due to the Energy Policy Act being applied to multi-family households only, starting in 2015. The values for single family household unit use are assumed to be constant from 2010 on. In the case of Fairfax Water, the Scenario 2 prediction also accounts for estimated additional demand from special growth areas.

[4]2010-2040 wholesale figures are based on total allowable amounts sold to Howard and Charles counties by WSSC. They are assumed to use half of the allowable amount until 2020, after which the full amount is assumed to be used (personal communication, Roland Steiner, 3/25/09).

Table 4-2: Increase in average annual demand by water use category from 2010 to 2040 (mgd).

Areas Served	Single Family - Scenario 1	Multi-family - Scenario 1	Employee - Scenario 1	Unmetered - Scenario 1	Difference - Scenario 1	Difference - Scenario 2
Fairfax Water - Retail Customers	1.3	6.9	7.3	1.6	17.1	41.6
Fairfax Water – Dulles	0.0	0.0	0.2	0.0	0.2	0.2
Fairfax Water - Ft. Belvoir	0.0	0.0	0.2	0.0	0.2	0.2
Fairfax Water - Herndon	0.0		0.1	0.0	0.1	0.2
Fairfax Water - Loudon Water	3.8	3.2	5.5	1.4	13.9	15.3
Fairfax Water - Prince William Co. Service Authority	2.4	7.6	5.1	1.5	16.6	18.2
Fairfax Water/Virginia American - City of Alexandria	0.0	2.0	2.4	0.6	5.0	5.5
Fairfax Water/Virginia American - Dale City	-1.5	1.5	0.4	0.0	0.4	0.7
TOTAL Fairfax Water	6.0	21.2	21.2	5.1	53.5	81.9
Aqueduct - Arlington County DES	-0.5	0.8	2.8	0.6	3.7	4.3
Aqueduct - D.C.WASA	3.5	2.7	9.9	4.1	20.2	23.1
Aqueduct - Falls Church DES	0.7	0.8	1.2	0.4	3.1	3.9
Aqueduct - Fort Meyer	0.0	0.0	0.0	0.0	0.0	0.0
Aqueduct - Vienna PWD	0.1	0.0	0.0	0.0	0.1	0.3
TOTAL Washington Aqueduct	3.8	4.3	13.9	5.1	27.1	31.6
TOTAL WSSC – Retail Customers	0.8	9.2	14.8	3.8	31.8[1]	40.6
TOTAL WMA Water Suppliers	10.7	34.7	49.9	14.0	112.5	154.0
City of Rockville DPW	-0.1	1.0	0.5	0.1	1.5	1.7
TOTAL plus Rockville	10.6	35.7	50.4	14.1	114.0	155.7

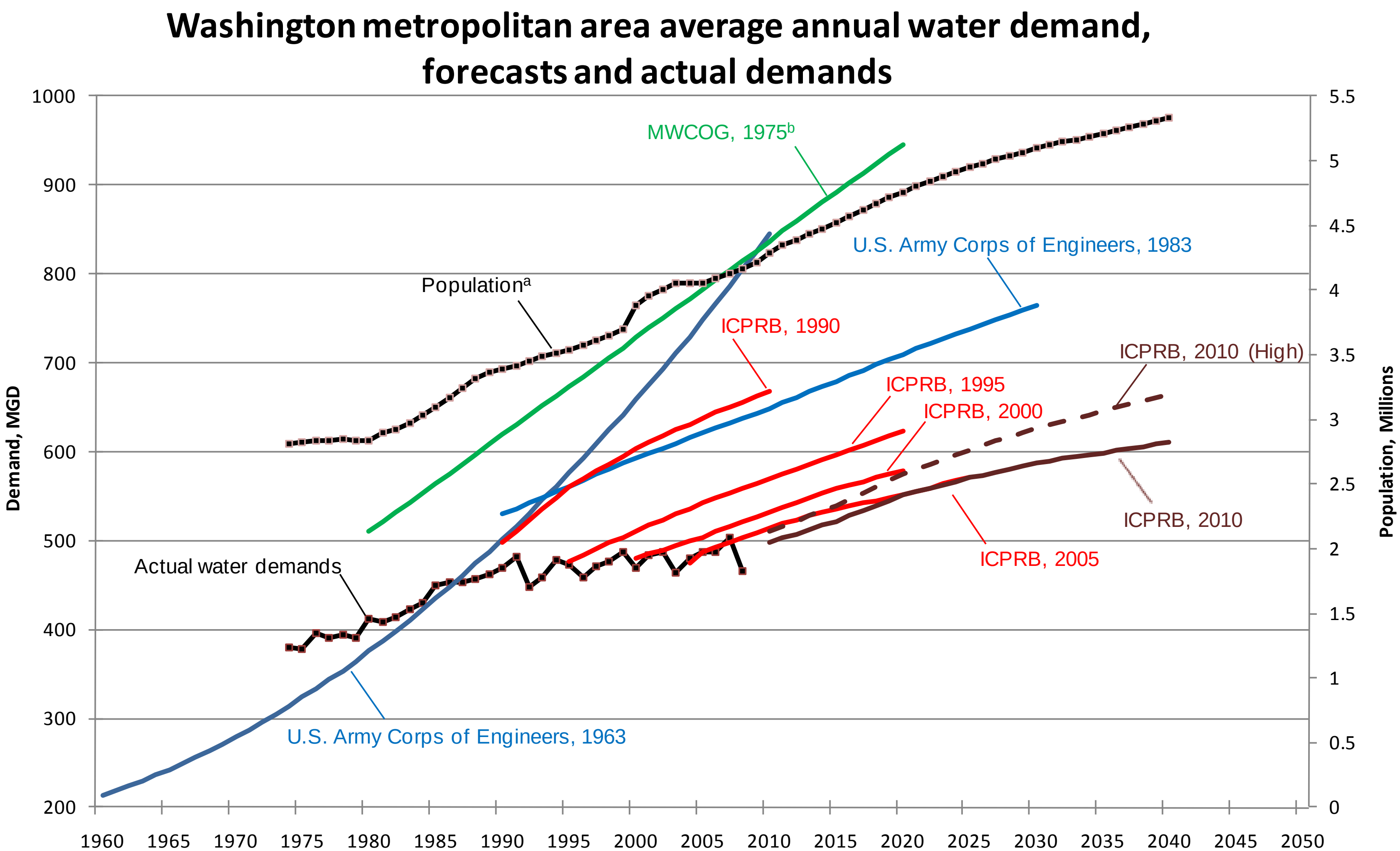
Note: Assuming a minimum unmetered water use of 10 percent, the unmetered water use is forecast as 66 mgd in 2010 and 79 mgd in 2040.
[1]This total includes the increase between 2010 and 2040 in the amount assumed to be sold to wholesale customers, Charles and Howard counties. In 2010 the amount sold is assumed to be 3.2 mgd and in 2040 it is 6.4 mgd.

4.3 Comparison of Water Demand Forecast with Previous Studies

In Figure 4-1, the forecasted WMA demands in Table 4-1, excluding Rockville, are compared with results from previous studies done by ICPRB and other organizations (Kame'enui *et al.*, 2005; Hagen and Steiner, 2000; Mullusky *et al.*, 1996; Holmes and Steiner, 1990; USACE, 1975; 1983). It is clear from this figure that demand forecasts have consistently fallen over time. Throughout most of the past four decades, population has continued to grow in the WMA, but unit use values have fallen. However, current results indicate that these decreasing trends in unit use may be leveling off. The demand forecast lines in Figure 4-1 for ICPRB’s 2005 and 2010 studies are close to one another. The similarity in these results is due to overall similarities in MWCOG demographic forecasts and the fact the unit use values have remained relatively constant throughout the past decade, with the exception of multi-family households, as discussed in Section 3.8.

The 2010 ICPRB forecast of likely annual average demand (Scenario 1) for 2025 is within 1 mgd of the level forecasted by the 2005 study (Figure 4-1). The 2010 ICPRB forecast of annual average demand for 2020 is approximately 1 mgd less than the level forecast by the 2005 study, 28 mgd less than the level forecast by the 2000 study, and 72 mgd less than the level forecast by the 1995 study. The forecasts in the 2010 and 2005 studies are similar because of similarities in the MWCOG demographic forecast (Section 3.5) and little change in use rates.

In contrast, the high 2010 ICPRB forecast of annual average demand (Scenario 2) for 2025 is approximately 23 mgd greater than the level forecasted by the 2005 study (Figure 4-1). The 2010 ICPRB forecast of annual average demand for 2020 is approximately 31 mgd greater than the level forecast by the 2005 study, approximately 4 mgd less than the level forecasted by the 2000 study, and approximately 48 mgd less than the level forecasted by the 1995 study. The forecast in the 2010 study under Scenario 2 is higher than that in the 2005 study mainly due to the potential additional 19 mgd from the Fairfax County special growth areas and a 13 mgd increase in water use due to more conservative assumptions concerning changes in water use behaviors for single family households. Also, the current study includes predicted demand from WSSC’s wholesale customers, Howard and Charles counties.



[a] Population is a sum of the populations within Montgomery, Prince George's, Prince William, Loudoun, Fairfax, and Arlington Counties, as well as the District of Columbia, according to data provided by the U.S. Census Bureau.

[b] As cited in U.S. Army Corps of Engineers, 1975

Figure 4-1: Comparison with forecasts from earlier studies for WMA water suppliers. The dramatic jump in population between 2000 and 2001 is a result of the changes prompted by the completion of the U.S. Census Bureau 2000 study.

5 Estimating Daily Demand

5.1 Introduction

Water demand in the WMA varies daily depending on the season, weather conditions, and the day of the week. Reservoir releases and other drought-related water supply operations are most likely to take place during periods of high demand, which typically occur from mid-July through late October. In order to evaluate the ability of the WMA system to meet future demands, seasonal and daily variations are added to the average annual demand forecasts detailed in Chapter 4, to simulate forecasted demands at a daily time step for use in the Potomac Reservoir and River Simulation Model (PRRISM). This chapter describes the methods used to simulate seasonal and daily demand.

Estimates of seasonal and daily variations in demand are obtained by analyzing variations in daily water production data from each of the three WMA suppliers. Production data is the amount of water treated and distributed to retail or wholesale customers. This is different from billing data which reports the amount of water consumed by end users. The difference between production and billing data is unmetered water, which is assumed to be lost in the distribution network. Production data is used to estimate seasonal and daily variations in demand instead of billing data, which is relied upon for the average annual demand forecasts discussed in chapters 3 and 4, because production data is available on a daily time step, whereas billing data is only available on a monthly, quarterly, or, in some cases, annual basis. The analyses described in this chapter closely follow the methodology developed in past studies (Steiner 1984, Hagen and Steiner, 2000; Kame'enui *et al*., 2005). WMA water supplier demand patterns are described in Sections 5.2 and 5.3. Demand can exceed river flow in the summer and fall months, which is the primary motivation for developing a detailed model of demand for the summer and fall seasons (Section 5.4). Daily variability in the WMA demand is described along with its effect on system efficiency of operations (Section 5.5). The model used to simulate daily variations in demand is described in Section 5.6. Implementation of the seasonal and daily demand model in PRRISM is described in Section 5.8. The advantages of using the detailed demand model developed in this chapter are summarized in Section 5.9.

5.2 Patterns in Recent Daily Water Production

Water production in the Washington metropolitan area is highly variable over the year. Water production is typically lowest in the winter months and climbs through the summer months due to increased outdoor water use (Figure 5-1). Figure 5-1 shows 95% confidence intervals for long-term daily averages of total water production for the three WMA water suppliers. Average production ranges from a low of about 400 mgd in mid-winter up to a high of about 600 mgd in the summer. Note that daily production can be significantly higher during dry years, as occurred during both the drought year of 2002 and the more recent dry year of 2007. The increase due to dry and hot conditions is the motivation for linking demand to historical weather variables, in order to provide the best and most conservative (highest) estimate of demand that would occur during drought years in the historical record.

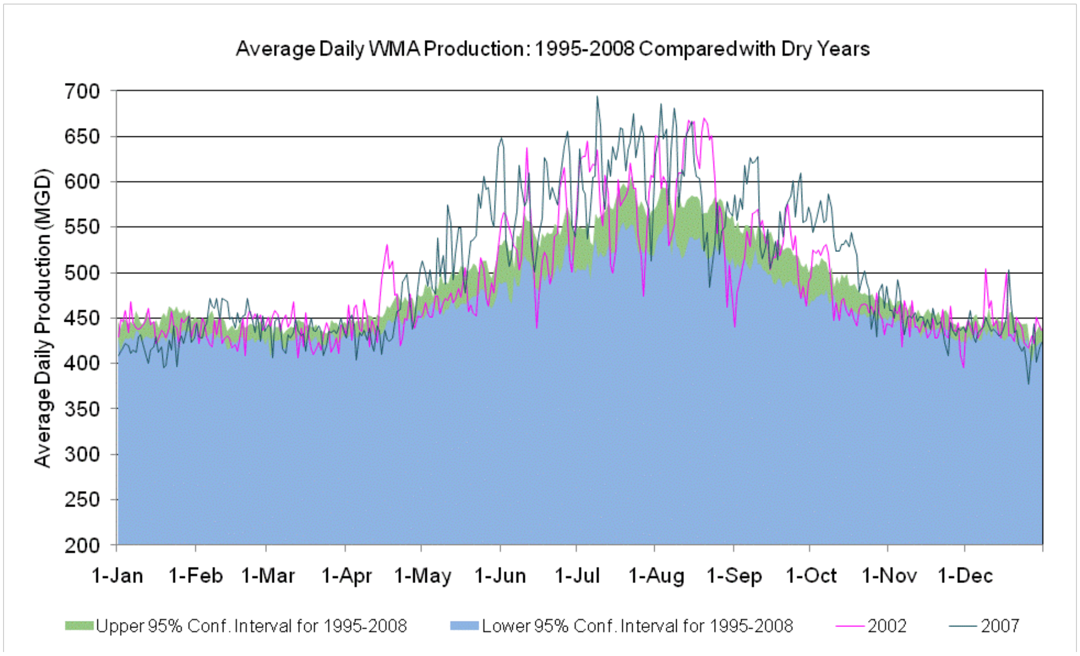


Figure 5-1: Recent daily WMA CO-OP water production.

5.3 Patterns in Recent Monthly Water Production

Monthly water production factors, that is, the ratio of average monthly to average annual production, are calculated for each water supplier, and are given in Table 5-1, Table 5-2, and Table 5-3. Long-term (1995 to 2008) averages of the monthly production factors are also computed (Table 5-4). These average monthly production factors represent typical seasonal variations in WMA production, and are used to convert the annual demand forecasts to forecasts of monthly demand.

Use of these average monthly production factors in the demand forecast implicitly assumes that monthly production factors are stationary, that is, that they will remain relatively constant throughout the forecast period. In a past WMA water supply study (Hagen and Steiner, 2000), August production factors for the CO-OP system were computed for several time periods and were found to be increasing slightly over time. To examine whether or not a significant trend has developed, the average production factors for each of the three major WMA suppliers were examined. In Figure 5-2, average production factors for 1990 through 2003, used in the 2005 WMA water supply study, and 1995 through 2008, used in the current study, are compared with average production factors for the recent years, 2005 through 2008. Little change is evident in monthly production factors for Washington Aqueduct and WSSC in Figure 5-2. However, an increase over time in August production factors is evident for Fairfax Water. To further investigate this potential trend, least squares regression was used to test for the significance of the Fairfax Water increases. During the time period from 1990 to 2008, a trend in Fairfax Water August production factors was not present at the five percent significance level. However, there are anecdotal reports from water suppliers in the Northern Virginia suburbs that outdoor summer water use is increasing in some areas. Potential trends in monthly production factors for summer months should continue to be monitored in future WMA water supply studies.

Table 5-1: Fairfax Water monthly production factor (average monthly production/average annual production).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
January	0.87	0.89	0.85	0.84	0.88	0.89	0.87	0.84	0.96	0.90	0.83	0.83	0.79	0.90
February	0.86	0.89	0.83	0.82	0.82	0.91	0.84	0.83	0.93	0.90	0.81	0.82	0.77	0.84
March	0.89	0.89	0.82	0.85	0.84	0.90	0.86	0.82	0.93	0.90	0.83	0.84	0.76	0.84
April	1.00	0.98	0.88	0.91	0.89	0.93	0.94	0.91	0.97	0.95	0.92	0.93	0.82	0.93
May	0.99	1.02	0.98	1.00	1.11	1.07	1.12	0.98	0.97	1.08	1.01	1.07	1.10	1.00
June	1.06	1.15	1.14	1.04	1.27	1.11	1.09	1.14	1.04	1.09	1.18	1.21	1.24	1.15
July	1.16	1.11	1.35	1.19	1.31	1.12	1.14	1.26	1.16	1.16	1.15	1.19	1.33	1.22
August	1.36	1.14	1.28	1.29	1.20	1.05	1.13	1.32	1.13	1.11	1.21	1.39	1.26	1.32
September	1.17	1.05	1.08	1.22	0.98	1.04	1.10	1.11	1.03	1.06	1.29	1.04	1.23	1.09
October	0.93	0.99	1.01	1.00	0.91	1.04	1.03	0.98	1.00	1.00	1.01	0.94	1.05	1.00
November	0.86	0.95	0.91	0.93	0.90	0.98	0.99	0.90	0.95	0.93	0.89	0.86	0.84	0.86
December	0.83	0.93	0.86	0.90	0.87	0.94	0.88	0.90	0.93	0.91	0.88	0.86	0.79	0.84

Table 5-2: WSSC monthly production factor (average monthly production/ average annual production).

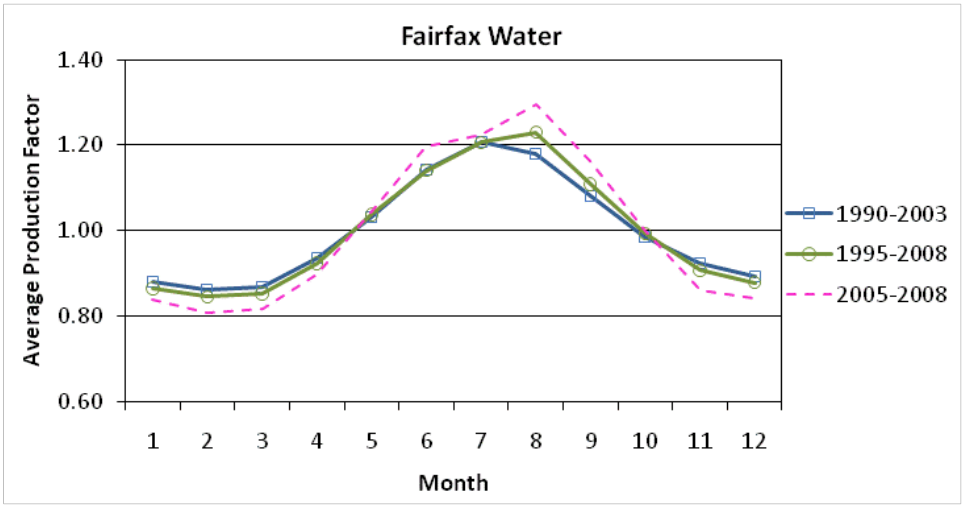
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
January	0.95	1.01	0.94	0.89	0.95	0.97	0.95	0.93	0.99	0.99	0.94	0.92	0.87	0.95
February	0.95	1.00	0.92	0.88	0.90	0.98	0.92	0.90	0.97	0.99	0.94	0.92	0.95	0.93
March	0.94	0.96	0.91	0.90	0.91	0.95	0.95	0.90	0.97	0.93	0.94	0.93	0.91	0.92
April	0.97	0.98	0.96	0.93	0.94	0.94	1.01	0.95	0.98	0.96	0.96	0.96	0.92	0.95
May	0.96	1.01	1.01	1.01	1.10	1.04	1.07	0.99	0.99	1.04	1.00	1.04	1.06	1.00
June	1.02	1.08	1.05	1.04	1.21	1.07	1.08	1.11	1.02	1.05	1.10	1.09	1.10	1.09
July	1.10	1.05	1.19	1.15	1.23	1.06	1.06	1.16	1.06	1.06	1.07	1.10	1.17	1.10
August	1.20	1.05	1.16	1.17	1.03	1.04	1.06	1.17	1.07	1.05	1.09	1.21	1.13	1.14
September	1.09	1.02	1.05	1.14	0.96	1.01	1.06	1.03	1.03	1.04	1.11	1.01	1.09	1.06
October	0.96	0.98	0.99	1.00	0.93	0.99	0.99	0.96	0.98	0.97	0.99	0.97	1.01	0.99
November	0.94	0.93	0.92	0.97	0.91	0.96	0.95	0.93	0.98	0.96	0.94	0.92	0.90	0.95
December	0.93	0.92	0.90	0.93	0.91	0.98	0.90	0.96	0.97	0.95	0.93	0.90	0.90	0.93

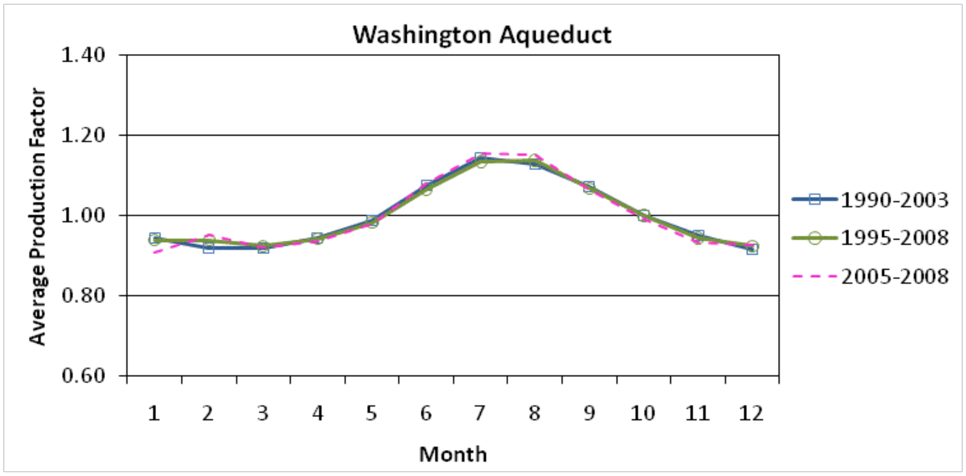
Table 5-3: Aqueduct monthly production factor (average monthly production/ average annual production).

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
January	0.91	0.99	0.97	0.89	1.00	0.94	0.91	0.94	0.97	0.97	0.95	0.90	0.83	0.95
February	0.92	0.97	0.97	0.86	0.93	0.95	0.88	0.94	0.95	0.97	0.97	0.94	0.97	0.93
March	0.90	0.96	0.93	0.89	0.93	0.93	0.89	0.94	0.93	0.94	0.91	0.95	0.91	0.92
April	0.92	0.98	0.95	0.93	0.92	0.95	0.94	0.96	0.95	0.94	0.95	0.95	0.91	0.92
May	0.94	1.00	0.96	0.95	0.99	1.00	1.07	0.95	0.95	1.00	0.94	0.99	1.03	0.97
June	1.04	1.06	1.05	1.05	1.12	1.05	1.09	1.08	1.01	1.03	1.08	1.06	1.12	1.07
July	1.12	1.08	1.18	1.10	1.21	1.09	1.10	1.16	1.10	1.11	1.14	1.15	1.16	1.17
August	1.20	1.07	1.14	1.15	1.12	1.11	1.11	1.21	1.10	1.12	1.10	1.21	1.17	1.13
September	1.11	1.02	1.06	1.17	0.99	1.06	1.07	1.08	1.05	1.09	1.10	1.00	1.08	1.07
October	1.01	0.99	0.98	1.05	0.96	1.03	1.00	0.98	1.02	1.00	0.98	0.97	1.03	0.99
November	0.95	0.94	0.93	0.99	0.92	0.95	1.00	0.88	1.01	0.91	0.94	0.95	0.92	0.92
December	0.96	0.94	0.88	0.96	0.90	0.93	0.92	0.87	0.97	0.90	0.94	0.93	0.88	0.95

Table 5-4: Average monthly production factors for the WMA system between 1995 and 2008.

	WSSC	Fairfax Water	Aqueduct	CO-OP
January	0.945	0.867	0.938	0.917
February	0.939	0.848	0.939	0.908
March	0.930	0.856	0.923	0.903
April	0.957	0.926	0.941	0.941
May	1.023	1.036	0.982	1.014
June	1.079	1.136	1.065	1.093
July	1.111	1.204	1.134	1.150
August	1.111	1.227	1.138	1.159
September	1.051	1.106	1.067	1.075
October	0.980	0.993	1.000	0.991
November	0.940	0.910	0.944	0.931
December	0.929	0.881	0.924	0.911





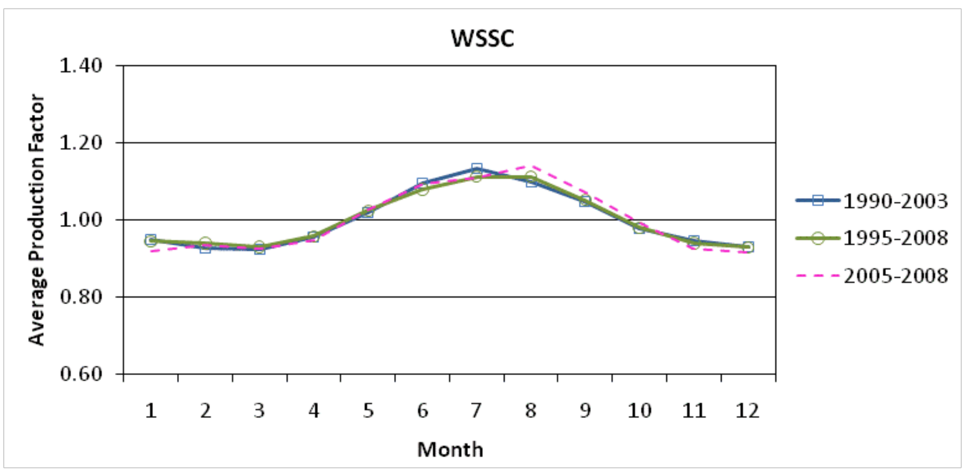


Figure 5-2: Comparisons of average monthly production factors over several time periods.

5.4 Seasonal Variation in Demand

Given the increase in demand seen from about mid-July through late October or early November, demand can potentially be higher than Potomac River flow during this four month period (Figure 5-3). This is the time period during which Potomac augmentation releases are most likely to occur in order to ensure adequate flow. Because the critical period for comparing demand to available resources is summer through fall, the focus of daily demand modeling efforts for the current study addresses two primary seasons of demand: summer (June through August) and fall (September through November).

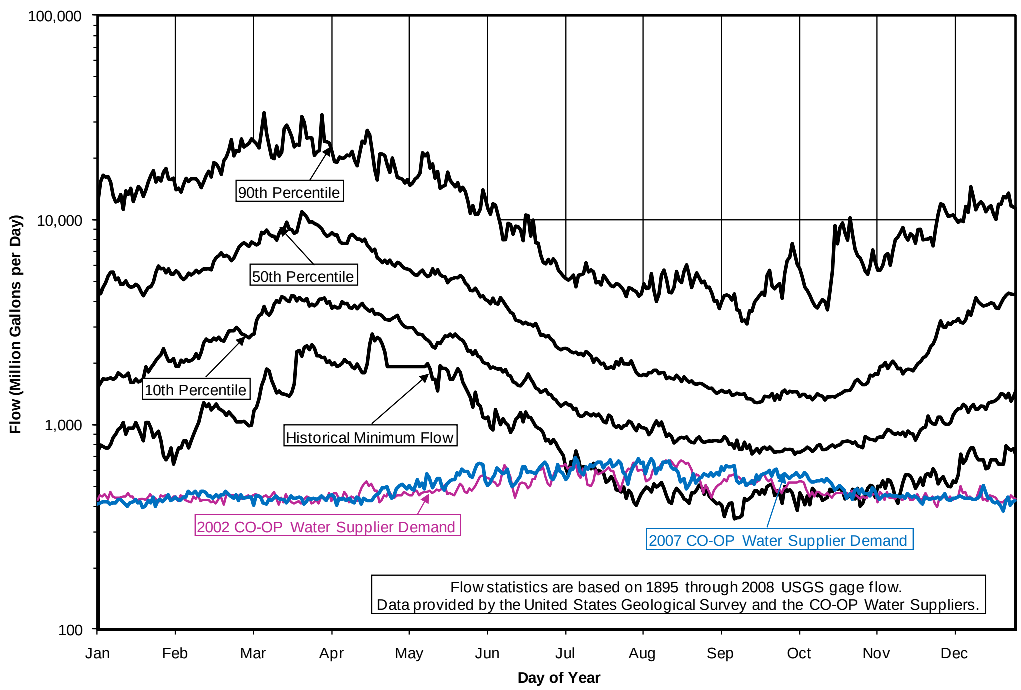


Figure 5-3: Flow of the Potomac River at Point of Rocks and water supplier demand (mgd).

5.5 The Importance of Modeling Daily Variability in the CO-OP System

In Potomac system operations, releases are made to meet demand which fluctuates on a daily basis and can be quite variable during droughts (Figure 5-1). Daily variability in demand affects the efficiency of upstream reservoir releases. Releases from Jennings Randolph Reservoir can take up to nine days to reach the WMA supplier intakes, and in a nine-day timeframe, historical system demand has dropped by as much as 242 mgd (August 15 through 24 of 1997). In both model runs and in actual operations, if water is released from Jennings Randolph Reservoir and demand is lower than predicted, then flow exceeds the minimum flow recommendation. (From the water supplier perspective, this is an inefficient operation, but it should be noted that the variation in flow echoes natural variability and can be viewed as a net benefit to the environment.) Alternatively, if water is released from Jennings Randolph Reservoir and demand is higher than predicted, then the additional demand must be met with releases from Little Seneca Reservoir, which requires a day of travel time to the most downstream water supply intake. Since the variability of daily demand is important in determining operational efficiency, simulations of daily variations must be added to predicted monthly demand (derived from the average annual demand forecast as described in Section 5.3). A multivariate linear regression model paired with an autoregressive integrated moving average (ARIMA) model is used to estimate variability in daily demand, as is discussed in more detail in the following sections.

5.6 Developing the Daily Demand Model

Temperature and rainfall have a significant impact on water demand. While many papers have been written relating water demand to independent variables such as temperature and precipitation, Maidment and Miaou (1986) provide a useful summary of various types of relationships. In 2005, ICPRB developed a model that relates daily water demand for the WMA water suppliers to independent variables, including temperature, precipitation, soil moisture, and day of week (Steiner, 1984; Kame'enui, 2005). For this study, a new model is developed for these same dependent and independent variables, using 1995 through 2008 data.

Model development involves several steps. First, seasonal water use patterns from production data (from Section 5.3) are used to convert the forecast of annual average demand, derived from the billing data, into monthly average demand. Second, the historical daily production data are detrended. Third, a regression model is employed to relate daily departures from monthly average conditions to weather and other variables. Finally, to account for the autocorrelation in the error term from the regression model, ARIMA models are developed to capture the non-random component of the error. The resulting model illustrates how the WMA water suppliers' demand varies as a function of historical and forecasted weather variables. A more detailed discussion of this process follows below.

5.6.1 Method Used in Prior Studies

Mean monthly production factors, peak 7-day, and peak 1-day production factors were used in ICPRB's prior studies (Holmes and Steiner, 1990; Mullusky *et al.*, 1996; Hagen and Steiner, 2000) to disaggregate estimates of future average annual demand to demand estimates that varied by time of year. Application of this method results in a step function of future demand, in which demand is constant for 3 weeks, then are stepped up to a higher constant value for six days, and finally peaks for a period of one day. In order to better simulate daily operations (and model the inefficiency of a Jennings Randolph release), a simple algorithm was developed for the 2000 study to disaggregate future annual demand to demand that varied on a daily basis, as based on recent years' historical demand patterns. Model inputs allowed for the specification of historical demand patterns (1991, 1997, or 1998) to be used in modeling demand. Reservoir storage was relatively insensitive to which years' demand pattern was used, but model results were presented for the year which most depleted reservoir storage.

The current study and the 2005 study (Kame'enui *et al.*, 2005) model demand as a function of weather and other variables. This allows for an examination of what today's demand would be given a repeat of the extreme weather conditions that occurred during the 1930 drought of record. The application of the 2005 statistical methods for the development of the current study model equations is discussed in the following sections.

5.6.2 Converting Average Annual Demand into Monthly Average Demand

The average monthly production factors, Table 5-4, were calculated as the ratio of monthly average production to average annual production for each water supplier for 1995 through 2008 data. To estimate demand that varies by month for each water supplier, these average monthly production factors are then multiplied by the forecast of average annual demand. Additional steps are required to explore the causes of variation in daily demand from these monthly average values.

5.6.3 Detrending the Data

The water supplier production data is detrended before a regression model is fitted. The procedure by which the data is detrended is discussed in this section, and is based on the same method employed by Steiner (1984) and used by Kame'enui *et al.* (2005).

Stationarity in the mean of the data is determined prior to derivation of the regression coefficients. This is necessary to remove the effects of changes in factors that are not explicitly accounted for in the regression analysis, such as those changes due to population growth or decline. The effects of these factors are embodied in the time trend, which is removed from the data prior to model parameterization. Long-term detrending is accomplished for each WMA water supplier per the following procedure, in which 14 years of daily data were regressed on time per Equation 1:

$$Y(t) = M_t + B + e(t) \qquad \text{Equation 1}$$

Where Y is the untransformed water use data, in units of mgd; t is the index of days (1 to 5114, for 14 years); B is the constant; M is the slope of regression line; and e is the residual error.

The resulting equations for each WMA water supplier are given in Equation 2 (Aqueduct), Equation 3 (WSSC), and Equation 4 (Fairfax Water):

$$Y(t) = -0.0057\,t + 187.91 \qquad \text{Equation 2}$$

$$Y(t) = 0.0010\,t + 163.96 \qquad \text{Equation 3}$$

$$Y(t) = 0.0085\,t + 116.49 \qquad \text{Equation 4}$$

When compared to the 2005 ICPRB study, the linear regressions of daily demand against time show the following: Aqueduct maintains negative growth in demand; however, the rate at which the negative growth is occurring has increased slightly since the 2005 study by Kame'emui *et al.* (2005 ICPRB study). WSSC has shifted from negative growth in the 2005 ICPRB study to positive growth in the current study; however, the rate at which WSSC is growing is still small. Fairfax Water maintains positive growth in demand; however, the rate at which the positive growth is occurring at has decreased slightly since the 2005 ICPRB study. Both coefficients in all three regression equations were significant, with all P-values less than 0.00001. These regressions provide the parameters with which to remove the long-term trend in water use for each of the water suppliers.

The last point on the regression line is picked as the long-term stationary mean to which all the residuals are added to form the detrended series. The result is a demand series that represents current conditions from which forecasts can be made and from which model parameters can be estimated. The point on the regression line corresponding to the most recent observation can be represented by Equation 5:

$$Y(t') = M\,t' + B \qquad \text{Equation 5}$$

Where t' is the time index of the most recent observation. The last time index in the current study is equal to 5114, which corresponds to December 31, 2008, and should be used in Equation 2 through Equation 4. Table 5-5 shows that Aqueduct's long-term stationary mean decreased since the 2005 ICPRB study; WSSC and Fairfax Water's long-term stationary mean increased.

Table 5-5: Comparison of the 2005 and 2010 ICPRB studies' long-term stationary means.

Water Supplier	2005 ICPRB Study $Y(t')$, mgd	Current Study $Y(t')$, mgd
Aqueduct	173.575	158.760
WSSC	164.889	169.074
Fairfax Water	141.643	159.959

The detrended time series $Y'(t)$ is constructed by adding the residual term from Equation 1 to the value calculated in Equation 5 for each t, as represented by Equation 6.

$$Y'(t) = Y(t') + e(t) \qquad \text{Equation 6}$$

The resulting time series eliminates the component of demand that can be attributed to long-term changes in population, water price, number of connections, and size of the distribution system (Figure 5-4 through Figure 5-6).

The average monthly demand factors can be applied to the long-term stationary mean to determine the detrended average demand expected in any given month. In other words, to determine the seasonal component of annual demand, the monthly demand factors (Table 5-4) are multiplied by the long-term stationary mean value calculated using Equation 5. The resulting detrended average monthly demand is shown in Figure 5-7 through Figure 5-9. Regression models are used to investigate the role of weather and other variables in explaining the departure of daily demand from these monthly average conditions, as described in the next section.

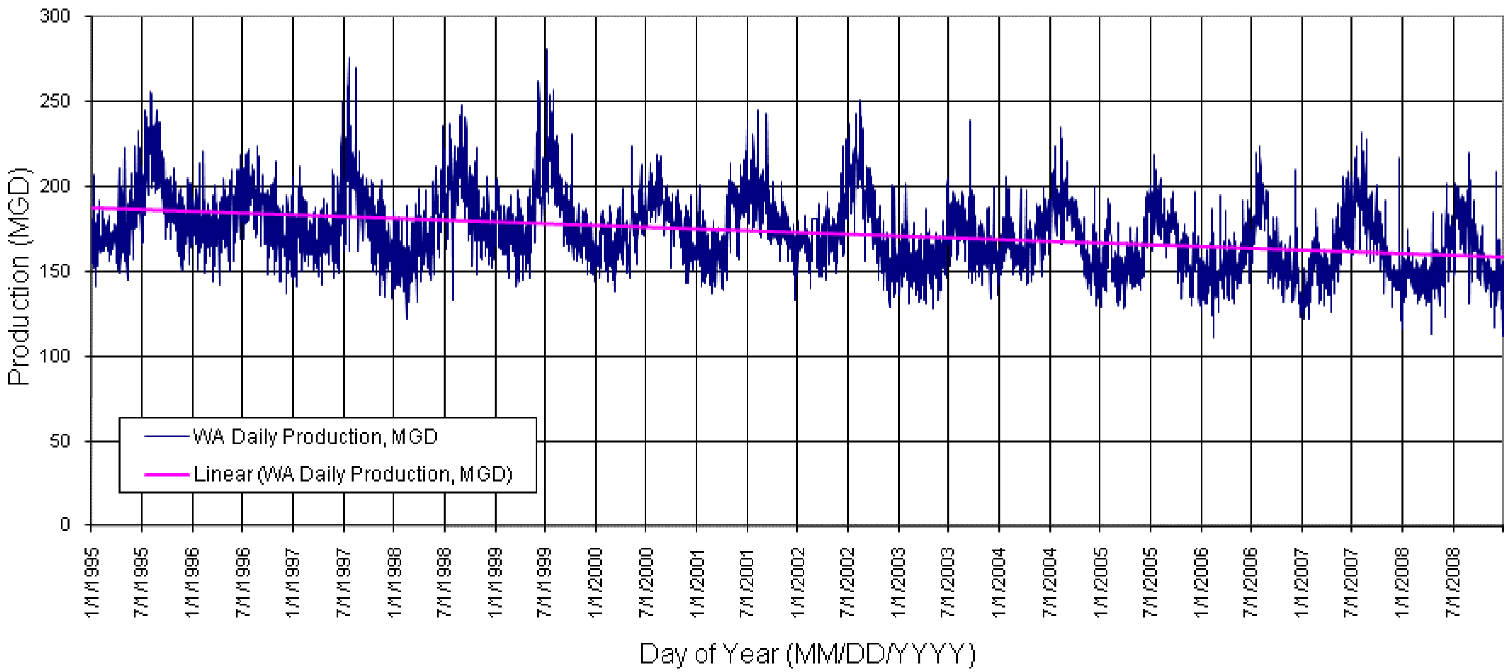


Figure 5-4: Washington Aqueduct historical daily water production data and linear regression over time (*Y* = -0.0057*X* +187.91).

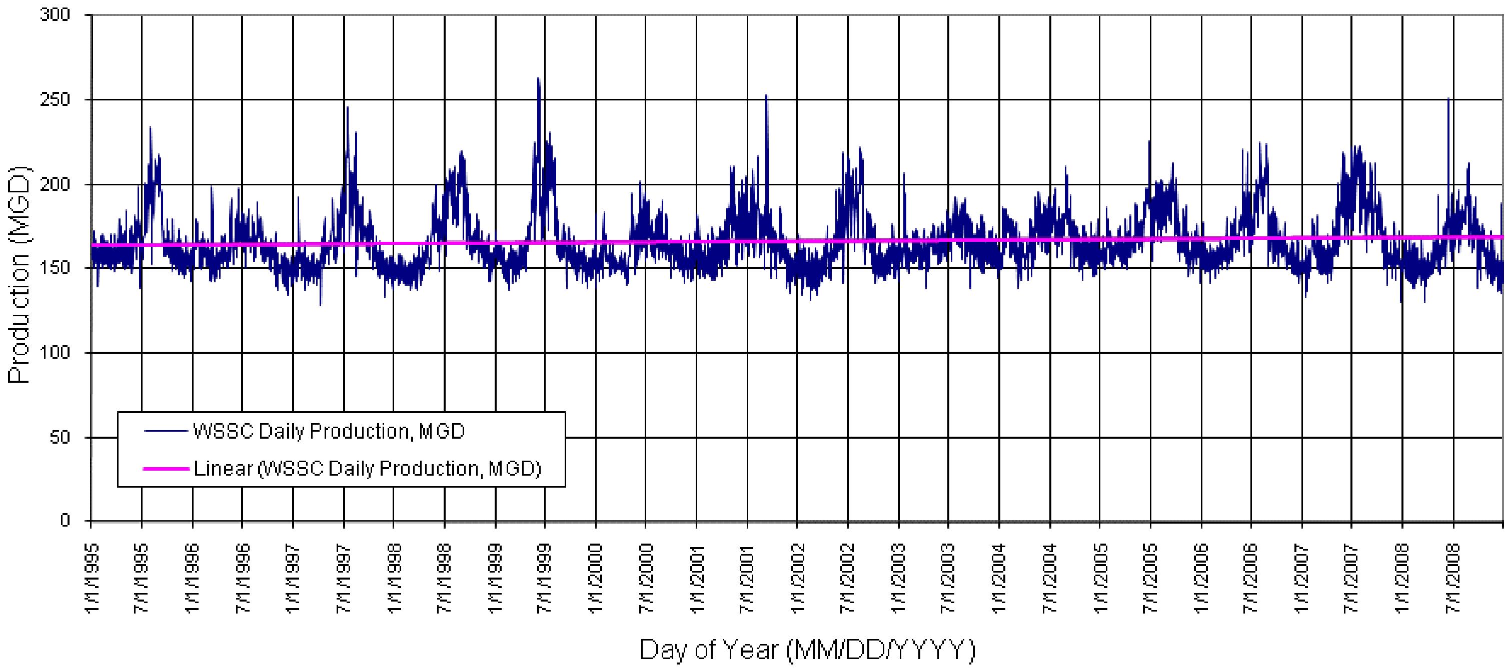


Figure 5-5: WSSC historical daily water production data and linear regression over time (Y = 0.001X + 163.96).

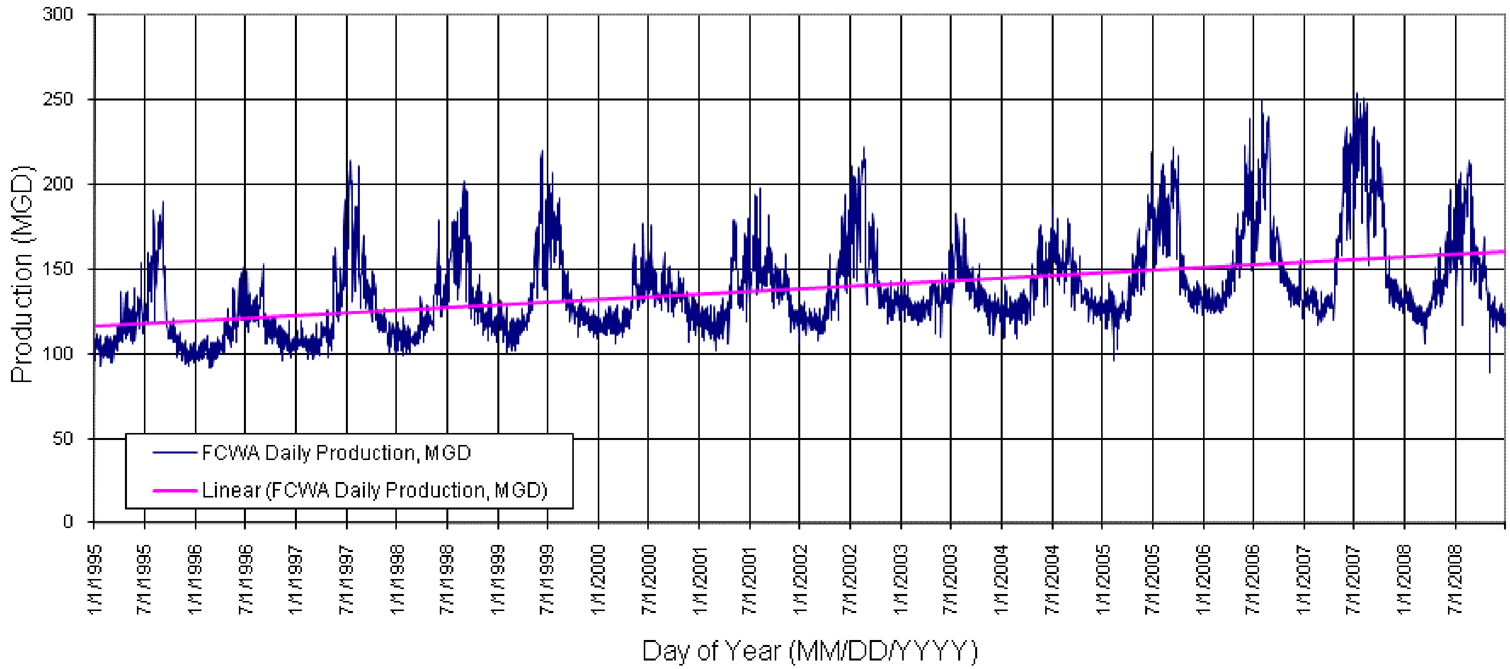


Figure 5-6: Fairfax Water historical daily water production data and linear regression over time ($Y = 0.0085X + 116.49$).

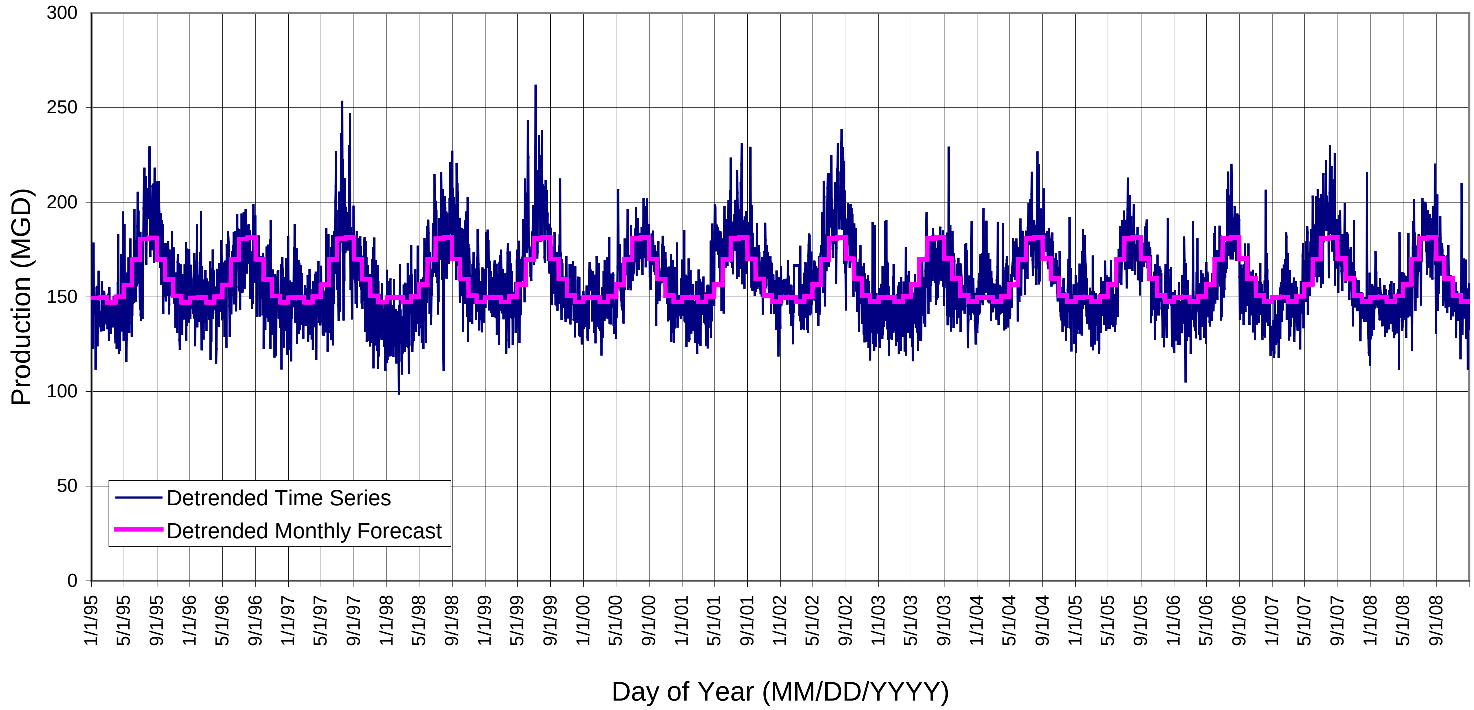


Figure 5-7: Detrended Washington Aqueduct daily and monthly water production for the three WMA water suppliers.

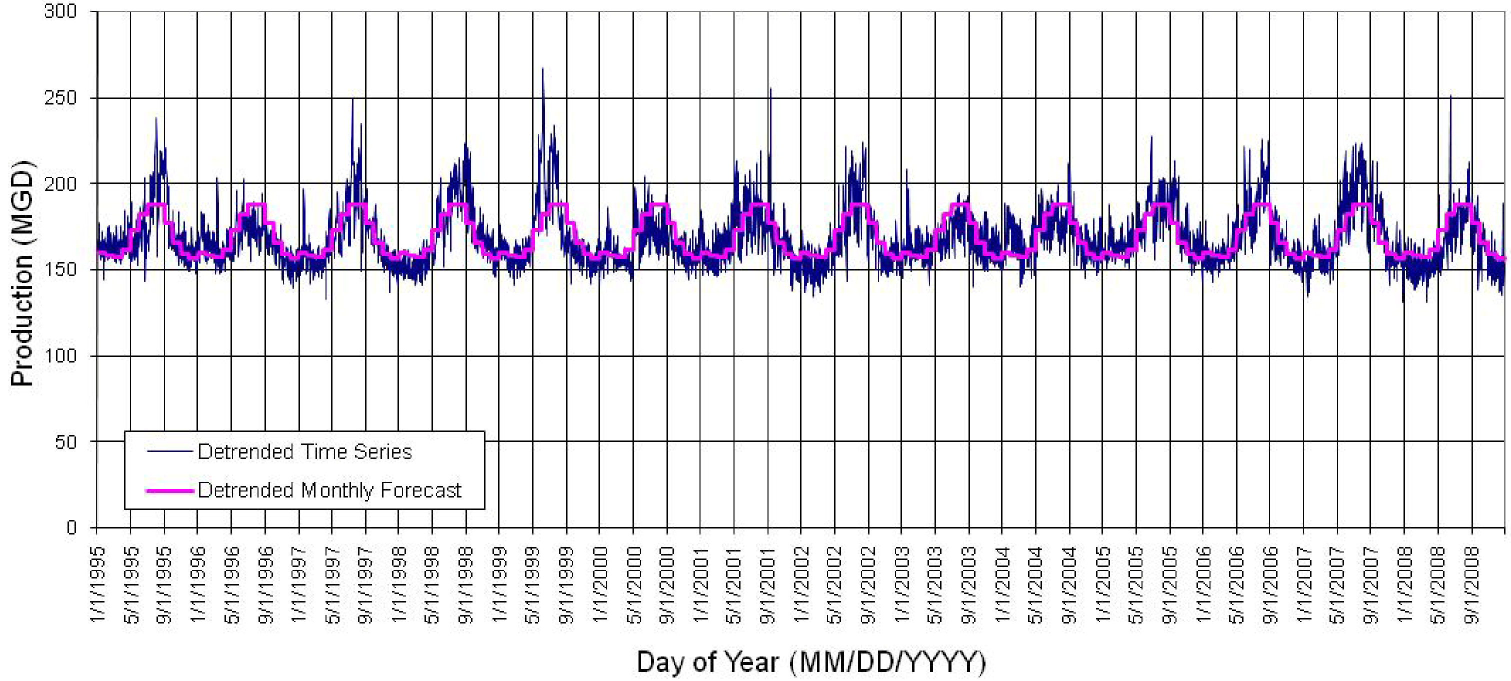


Figure 5-8: Detrended WSSC daily and monthly water production for the three WMA water suppliers.

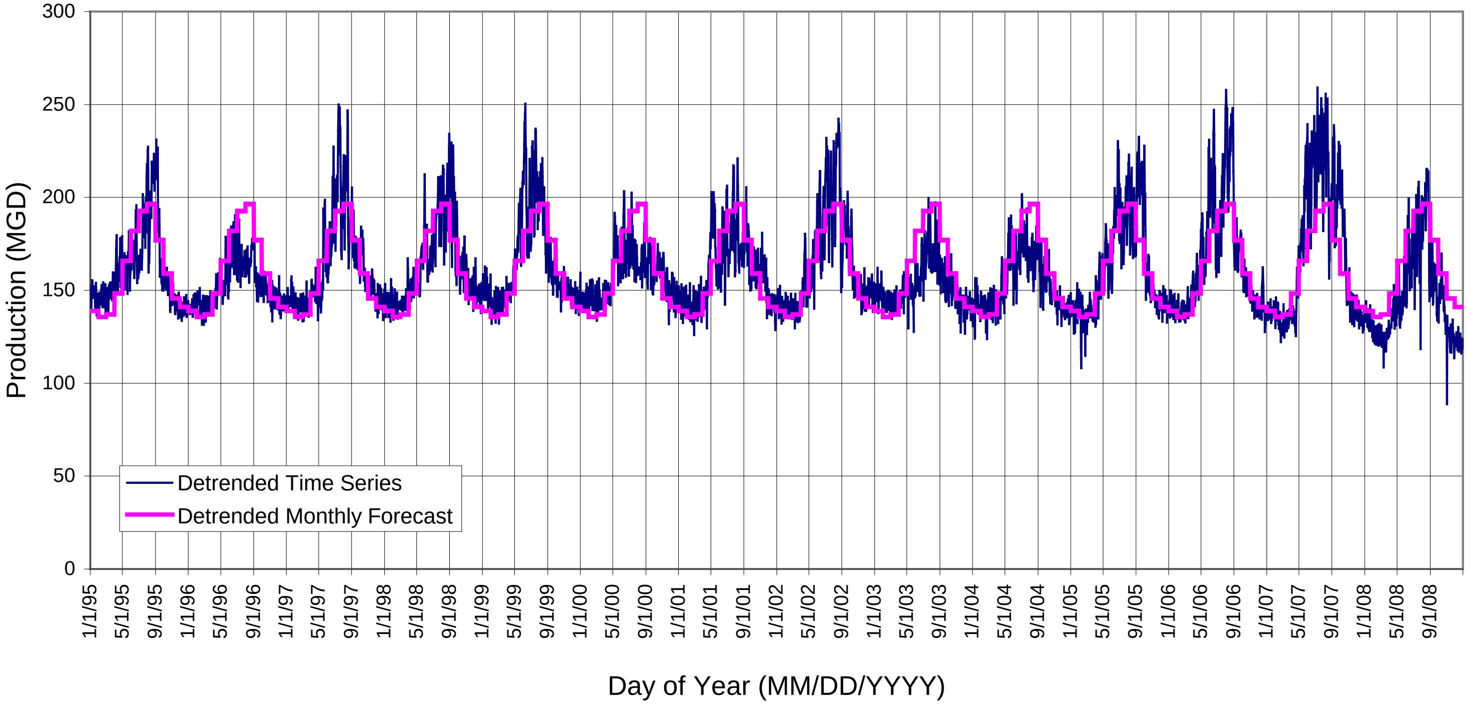


Figure 5-9: Detrended Fairfax Water daily and monthly water production for the three WMA water suppliers.

5.6.4 Regression Model Relating Daily Departures from Monthly Average Conditions to Weather and Other Variables

Regression models are used to investigate the role of weather and other variables in explaining the departure of detrended daily demand from detrended monthly average conditions.

A generic form of a regression equation is given as follows:

$$Y_t = b_0 + b_1 X_{1,t} + ... + b_k X_{k,t} + N_t \qquad \text{Equation 7}$$

where the criterion variable Y is modeled as a function of the k predictor variables $X_{1,t}, \ldots, X_{k,t}$. The residual (error) term in this equation is N_t, and the coefficients $b_0, \ldots, b_k$, describe the fixed coefficients that modify the predictor variables.

The criterion variable Y is taken as the departure of detrended daily demand (Equation 6) from detrended monthly average conditions. Quantities examined as predictor variables in the regression for the WMA water suppliers included temperature, both forecasted and lagged by one through five days, precipitation, both forecasted and lagged by one through five days, day of week (Sunday, Monday, Tuesday… *etc.*), Palmer Drought Severity Index, and the number of days in a row without significant rainfall (defined as less than 0.15 inches). These variables were selected based on weather-sensitive trends in demand as well as previous studies in demand forecasting (Maidment and Miaou, 1986; Steiner, 1984; Maidment *et al.*, 1985; Aly and Wanakule, 2004).

In order to support the linear regression analysis, the data were evaluated for non-linearity in the response of demand to the independent variables for all water suppliers. The non-linear responses of demand to the independent variables were found to be the same as those reported in the 2005 (ICPRB) study.

An examination of temperature versus demand for forecasted temperature, temperature, and temperature lagged one day demonstrated that demand has a non-linear response to temperature, with a breakpoint occurring at 90 degrees Fahrenheit. Demand rises at a slower rate from 70 through 90 degrees than it does from 90 degrees and higher. Therefore, to model this non-linear behavior, temperature was broken into piece-wise linear segments at the 90 degree breakpoint, with different regression coefficients applied to temperatures greater than and less than 90 degrees Fahrenheit. For temperatures lagged by more than one day, the response was much more linear and no piece-wise partition was needed.

Similarly, demand evaluated relative to precipitation for forecasted precipitation, current day's precipitation, precipitation lagged by one day, and precipitation lagged by two and three days illustrated that demand is a non-linear function of precipitation, with a breakpoint ranging from 0.2 inches (WSSC) to 0.3 inches (Fairfax Water, Aqueduct). WSSC demand decreased linearly as precipitation increased from 0 to 0.2 inches, and leveled off with no decrease in demand for precipitation of 0.2 inches and higher. Demand also decreased linearly as precipitation increased from 0 to 0.3 inches and leveled off with no decrease in demand for precipitation greater than 0.3 inches for Fairfax Water and Aqueduct. For the regression model, any precipitation greater than 0.2 inches is assigned a value of 0.2 inches for inputs to the regression model for WSSC, and any precipitation greater than 0.3 inches is assigned a value of 0.3 inches for Washington Aqueduct and for Fairfax Water. For precipitation lagged by approximately four or more days, a slight decrease in demand due to very high precipitation amounts of two to five inches was noted.

Additional examination of the number of days in a row without significant precipitation with demand shows a similar non-linear response for all three WMA water suppliers. Demand increases linearly for periods of one to 12 days, and does not increase for days greater than 12. This suggests after nearly two weeks without rain, water demand reaches an equilibrium point without additional increase in demand for further days without rainfall. To model this behavior, when the number of days in a row without significant precipitation is greater than 12, it is assigned a value of 12 as inputs to the regression model. The non-linearity in this model is extremely important to model accurately; otherwise the modeler risks over-predicting historic demand for those periods where many days in a row may occur without significant precipitation.

A backward stepwise linear regression procedure was used to determine which predictor variables were important factors in determining water demand. The software used for the analysis was SPLUS®2000 (Mathsoft, 2000). The predictor variables examined are shown in Table 5-6, where variables marked with an “x” were retained in the regression equation. Those variables not marked with an “x” were discarded because the backward stepwise linear regression identified those variables as not contributing to the information about variation in demands. Note that the day of the week variable does not include Wednesday: the coefficients associated with the remaining days of the week are a measure of the effect of those days of the week as compared to Wednesday.

Table 5-6: Independent variables examined for each water supplier. Those variables retained in the regression are marked with an "x" for summer months.

	Water supplier		
Predictor Variables	WSSC	Aqueduct	FW
Maximum daily temperature, one-day forecast			
Maximum daily temperature	x	x	x
Maximum daily temperature, one-day prior	x	x	x
Maximum daily temperature, two-days prior		x	
Maximum daily temperature, three-days prior			
Maximum daily temperature, four-days prior			
Maximum daily temperature, five-days prior			
Daily precipitation, one-day forecast			
Daily Precipitation			x
Daily precipitation, one-day prior	x	x	x
Daily precipitation, two-days prior	x	x	x
Daily precipitation, three-days prior			x
Daily precipitation, four-days prior			x
Daily precipitation, five-days prior			x
Day of week - Monday		x	
Day of week - Tuesday			x
Day of week - Thursday			x
Day of week - Friday			
Day of week - Saturday		x	
Day of week - Sunday	x	x	
Palmer Drought Severity Index	x	x	x
Number of days in a row without significant precipitation	x	x	x

A regression model was developed for each of the water suppliers for the summer months of June, July, and August and the fall months of September, October, and November. The regression coefficient estimates, standard errors of estimate (*SEE*), standard deviations (*SD*) of the criterion series, and coefficients of determination (R^2) for each water supplier are given in Table 5-7 and Table 5-8. The application of the coefficients given in Table 5-7 can be interpreted using Fairfax Water as an example. The formula for the Fairfax Water regression is provided below in Equation 8:

$$Y_t = -71.63 + (0.75 \text{ or } 0.68)*T_t + (0.17 \text{ or } 0.15)*T_{1,t} - 46.45*P_t - 29.16*P_{1,t} - 19.71*P_{2,t} - 16.20*P_{3,t} - -8.30*P_{4,t} - 9.66*P_{5,t} - 5.14*(\text{if Tuesday}) - 3.61*(\text{if Thursday}) - 2.83*Palmer_t + 0.55*NoDaysP_t + N_t \qquad \text{Equation 8}$$

where Y_t, the criterion variable, is the variation from monthly average demand (mgd); T_t is today's maximum temperature (degrees Fahrenheit); $T_{1,t}$ is the maximum temperature one day prior (degrees Fahrenheit); P_t is today's precipitation (inches); $P_{1,t} \ldots P_{5,t}$ is the precipitation one to five day's prior (inches); $Palmer_t$ is the Palmer Drought Severity Index; $NoDaysP_t$ is the number of days in a row without precipitation of 0.15 inches or more; and N_t is the error term. Note that the precipitation predictor variables are constrained to a maximum of 0.3 inches.

Table 5-7: Regression coefficients developed for WMA water suppliers (summer months).

	Water supplier		
Independent variable	WSSC	Aqueduct	FW
Intercept, *b*	-74.70	-81.46	-71.63
Maximum daily temperature >90	0.42	0.40	0.75
Maximum daily temperature <90	0.36	0.38	0.68
Maximum daily temperature >90, one day prior	0.47	0.45	0.17
Maximum daily temperature <90, one day prior	0.45	0.39	0.15
Maximum daily temperature, two-days prior		0.21	
Daily Precipitation			-46.45
Daily precipitation, one-day prior	-28.09	-17.36	-29.16
Daily precipitation, two-days prior	-11.23	-15.11	-19.71
Daily precipitation, three-days prior			-16.20
Daily precipitation, four-days prior			-8.30
Daily precipitation, five-days prior			-9.66
Day of week - Monday		-6.16	
Day of week - Tuesday			-5.14
Day of week - Thursday			-3.61
Day of week - Saturday		-4.70	
Day of week - Sunday	2.35	-12.10	
Palmer Drought Severity Index	-1.31	-1.10	-2.83
Number of days in a row without significant precipitation	0.98	0.40	0.55
Standard Error of Estimate (*SEE*)	11.56	13.89	16.41
Standard Deviation (*SD*) of Criterion Series	17.15	19.43	24.43
Coefficient of Determination (R^2)	0.55	0.56	0.53

Table 5-8: Regression coefficients developed for WMA water suppliers (fall months).

Independent variable	Water supplier WSSC	Aqueduct	FW
Intercept, *b*	-16.73	-16.53	-17.98
Maximum daily temperature	0.10		0.23
Maximum daily temperature, one day prior	0.10	0.27	
Daily precipitation, one-day forecast			-2.30
Daily precipitation	-1.64		-3.56
Daily precipitation, one-day prior	-2.86	-4.29	-2.53
Daily precipitation, two-day prior	-1.18	-1.68	-2.39
Daily precipitation, three-day prior	-1.97	-1.47	-1.63
Daily precipitation, four-day prior	-1.47	-1.53	-2.26
Daily precipitation, five-day prior	-1.50		
Day of week – Monday	7.17	-3.31	4.56
Day of week – Tuesday	1.42		-1.92
Day of week – Thursday			-1.77
Day of week – Friday	1.32		
Day of week – Saturday		-5.88	
Day of week – Sunday	6.98	-6.84	5.08
Palmer Drought Severity Index	-0.43	-0.48	-1.78
Number of days in a row without significant precipitation	0.32	0.35	0.49
Standard Error of Estimate (*SEE*)	9.56	12.66	13.20
Standard Deviation (*SD*) of Criterion Series	11.41	14.31	16.24
Coefficient of Determination (R^2)	0.31	0.22	0.35

The error term, shown in Equation 7 and Equation 8, is represented by N_t. One of the key assumptions is that N_t is an uncorrelated series; that is, N_t is equivalent to “white noise.” If N_t is not random, then the series likely contains information that can be used to further improve the forecast and additional effort is necessary to refine the model. Since N_t is indeed autocorrelated for each of the water suppliers, additional effort was warranted. The method adopted was to use an auto-regressive integrated moving average (ARIMA) model to handle the autocorrelations within the N_t term, with the regression models to describe the explanatory relationship. The resulting model is a regression model with ARIMA errors. Equation 7 is still valid but N_t is modeled as an ARIMA process (Box *et al.*, 1994; Madrikas *et al.*, 2001) and is discussed in more detail in the following section.

5.6.5 Two Components of the Regression Model Error Term

To account for the autocorrelation in the error term, N_t, from the regression model, ARIMA models were developed to capture the non-random component of the error term. Recall from Equation 7 that the overall form of the regression is $Y_t = b_0 + b_1X_{1,t} + ... + b_kX_{k,t} + N_t$.

The ARIMA modeling process separates the N_t term from Equation 7 into random and non-random components:

$$N_t = Arima_t + random_t \qquad \text{Equation 9}$$

where $Arima_t$ is the non-random portion of N_t calculated by ARIMA process at time t, and $random_t$ is the random component of N_t at time t.

The error terms, N_t, from each of the multivariate regression models for Fairfax Water, Washington Aqueduct, and WSSC models are autocorrelated. Each supplier error term series show significant partial autocorrelations for time steps one through four. Several ARIMA (p,d,q) models were calibrated to account for the autocorrelation in the error terms. The differencing term d was set to zero because of the previous detrending of the input data (Section 5.6.3). The auto-regressive term p was evaluated for lags of one through four. The moving-average term q was set to one. The software used for the analysis was R (R Foundation of Statistical Computing, 2009). The models were compared using several standard tests, which showed that: the (1,0,1) model performs best for Washington Aqueduct, WSSC, and for the CO-OP system as a whole; the (2,0,1) model performs best for Fairfax Water. Figure 5-10 through Figure 5-13 show actual and modeled demand for each water supplier and for the CO-OP system. Several traces of modeled demand are shown since each trace fluctuates by a unique random time series, representing the variation of likely demand that is feasible and incorporating the randomness inherent in the original data set.

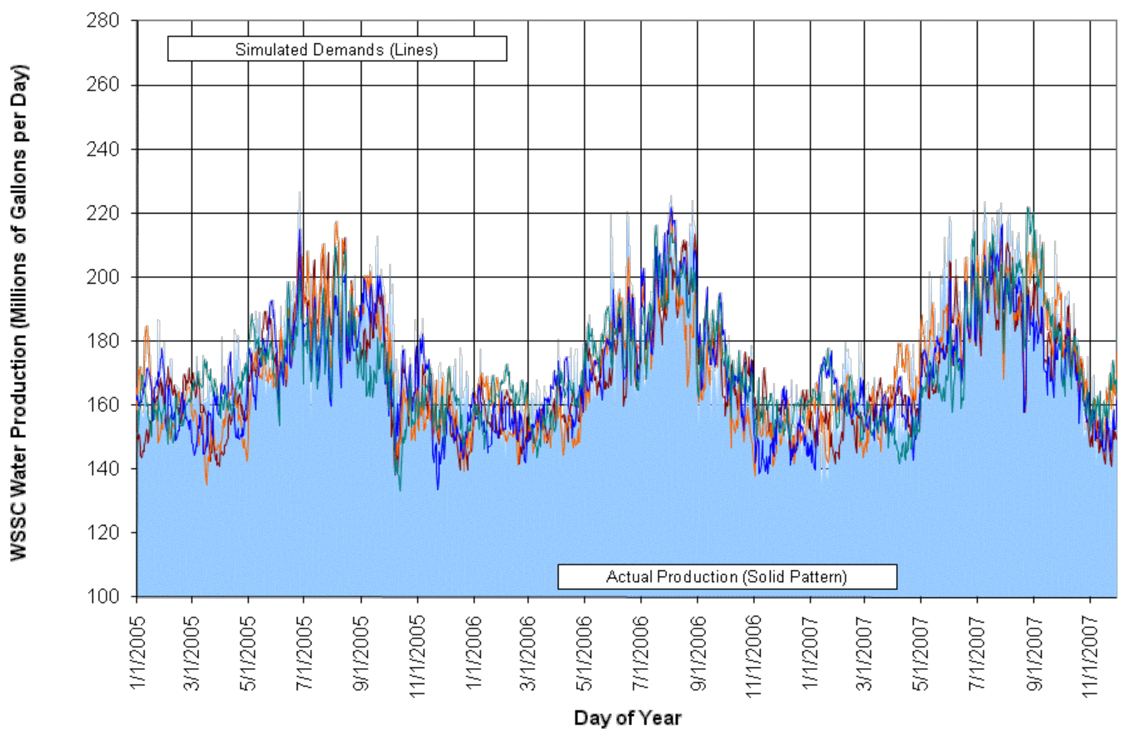


Figure 5-10: Modeled and predicted demand for WSSC from 2005 to 2007.

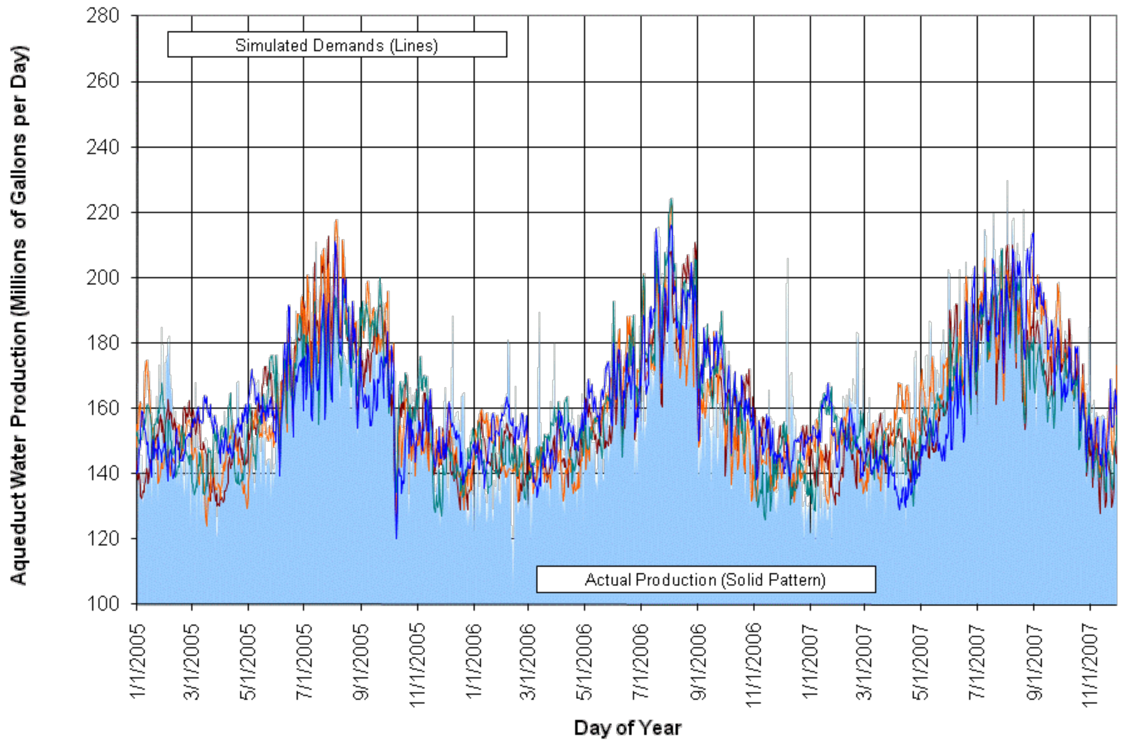


Figure 5-11: Modeled and predicted demand for Washington Aqueduct from 2005 to 2007.

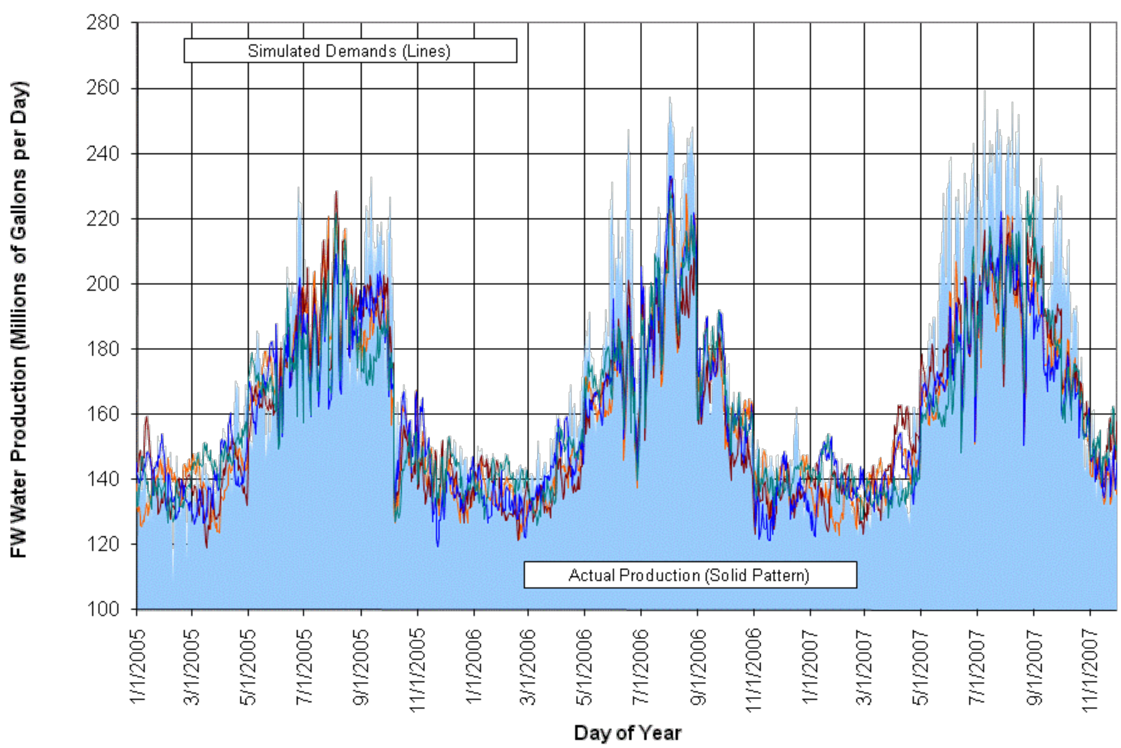


Figure 5-12: Modeled and predicted demand for Fairfax Water from 2005 to 2007.

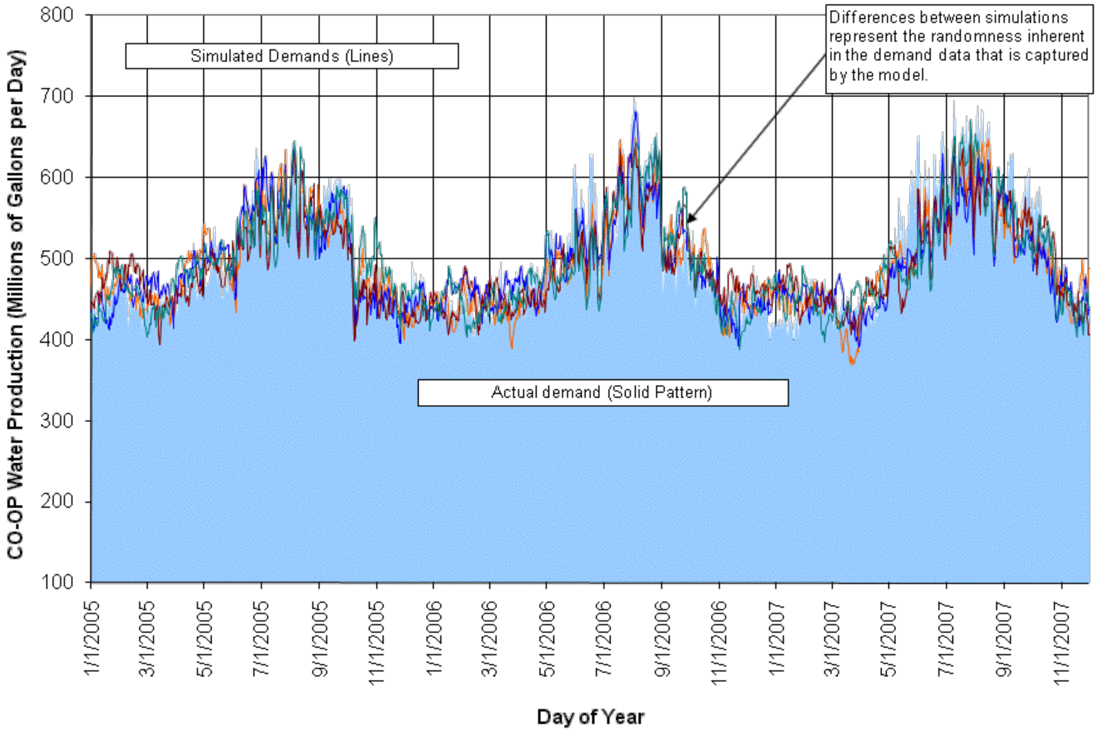


Figure 5-13: Modeled and predicted demand for the CO-OP system from 2005 to 2007.

The ARIMA coefficients are estimated by the method of maximum likelihood. The coefficient estimates and associated statistics for the selected models are given in Table 5-9. For each of the coefficients, the t-ratio is calculated as follows:

$$T - ratio = Est / SEE \qquad \text{Equation 10}$$

where *Est* is the estimated coefficient to the ARIMA model, and *SEE* is the partial standardized error of the estimated coefficient. The SEE values are estimates found from the Hessian of the log-likelihood (The R Development Core Team, 2008). The *SEE* and *T*-ratio values, therefore, can only provide a rough guide in model selection.

Table 5-9: Coefficient estimates of the ARIMA residual models.

	ARIMA	Coefficient	*Est*	*SEE*	*T-ratio*
WSSC Summer (*SEE* = 9.74)	(1,0,1)	AR1	0.914	0.023	40.604
		MA1	0.627	0.052	11.981
WA Summer (*SEE* = 12.88)	(1,0,1)	AR1	0.861	0.022	38.973
		MA1	0.663	0.076	8.710
FW Summer (*SEE* = 9.93)	(2,0,1)	AR1	1.316	0.027	48.733
		AR2	-0.341	0.053	-6.471
		MA1	0.754	0.106	7.088
CO-OP Summer (*SEE* = 22.32)	(1,0,1)	AR1	0.892	0.027	33.019
		MA1	0.460	0.046	9.860
CO-OP Fall (*SEE* = 18.88)	(1,0,1)	AR1	0.898	0.026	35.086
		MA1	0.490	0.045	10.800

When compared with the standard deviation of the ARIMA model input series, the models' contribution to the reduction of unexplained error is apparent (Table 5-10).

Table 5-10: ARIMA (1,0,1) model contribution.

	Std Dev (*SD*) Input Series	Std Error of Est. (*SEE*)	SEE^2/SD^2
WSSC Summer ARIMA (1,0,1)	11.93	9.74	0.67
WA Summer ARIMA (1,0,1)	13.82	12.88	0.87
FW Summer ARIMA (2,0,1)	16.32	9.93	0.37
CO-OP Summer ARIMA (1,0,1)	30.86	22.32	0.52
CO-OP Fall ARIMA (1,0,1)	25.62	18.88	0.54

All relative standard error ratios (SEE^2/SD^2) are less than one, indicating that the models predict better than using the average value of the initial residual error series. These values show that the effect of the ARIMA model is to reduce the remaining residual variance to 67 percent of its previous value for WSSC, to 87 percent for Aqueduct, and to 37 percent for Fairfax Water. For the case of the CO-OP system, the ARIMA model is able to reduce the residual variance by 52 percent in the summer and by 54 percent in the fall.

During the process of selecting the appropriate ARIMA model structure, coefficients are estimated for several other models for each of the water suppliers. These estimates and their associated statistics are provided in the following discussion in order to provide a measure of the adequacy of the selected model structures.

The Portemanteau lack-of-fit test was applied to several ARIMA model structures. The Portemanteau test involves calculating the *Q* statistic which is a function of the autocorrelation of the residuals (or error terms) of the model. If there is a substantial autocorrelation in the residuals of a model, then the model is deemed inadequate because there is more information that could potentially be captured by a higher order model. If there is no autocorrelation in the residuals, then the residuals represent a random, so-called white noise process containing no additional information and the model is deemed adequate. If the residuals are truly white noise, then the Q statistic can be described by a chi-squared distribution (Salas *et al.*, 1980). Therefore, this test uses the chi-squared distribution with L-p-q degrees of freedom, where L is the maximum lag considered for the residual autocorrelations, p is the autoregressive order of the model, and q is the moving average order of the model. If Q is greater than the five percent critical value from the chi-squared distribution, then there is less than a five percent chance that we would obtain the observed Q if the residuals were actually white noise. This is the standard threshold for accepting or rejecting the adequacy of the model: If there is less than a five percent chance of obtaining the observed Q from an actual white noise process, then there is too much autocorrelation left in the residuals and a higher order model should be used. If Q is less than the five percent chi-squared critical value, then the model is deemed adequate.

Table 5-11 summarizes the Portemanteau results. The ARIMA model structure (1,0,1) is found to be adequate for Washington Aqueduct, WSSC, and the CO-OP system; this model structure, however, was found to be inadequate for Fairfax Water. The higher order model structure of (2,0,1) was found to be adequate for Fairfax Water.

Table 5-11: Portemanteau test of model adequacy.

Model	Q Statistic	Chi-squared Critical Value	Pass/Fail
WSSC Summer ARIMA (1,0,1)	5.21	15.51	Pass
WA Summer ARIMA (1,0,1)	10.00	15.51	Pass
FW Summer ARIMA (1,0,1)	30.15	15.51	Fail
FW Summer ARIMA (2,0,1)	10.44	14.07	Pass
CO-OP Summer ARIMA (1,0,1)	9.63	15.51	Pass
CO-OP Fall ARIMA (1,0,1)	6.70	15.51	Pass

The T-ratios for each of the models supported the Portmanteau lack-of-fit test. All alternative ARIMA model structures of higher order model structure involved coefficients with t-ratio values of less than one. T-ratios less than one are an indicator of coefficient values not significantly different from zero. For models of ARIMA (2,0,1), only the model for Fairfax Water includes an autocorrelation term that is significantly different from zero.

When degrees of seasonal and non-seasonal differencing are increased, none of the models showed an improvement (reduced variance of the process). This observation is expected because of the previous detrending of the input data (Section 5.6.3).

The random time series component of Equation 9 was examined to ensure that it is not autocorrelated with any of the models developed for each supplier and for the CO-OP system. The random time series mean and standard deviation is provided in Table 5-12. The standard deviation of the random term is important because it is used when forecasting future demand as described in the next section.

Table 5-12: Standard deviation and average of error term (random component).

	Std Dev (*SD*) Random Component of N_t (mgd)	Average (*AV*) Random Component of N_t (mgd)
WSSC Summer	9.74	0.00
WA Summer	12.88	0.00
FW Summer	9.93	0.00
CO-OP Summer	22.32	0.00
CO-OP Fall	18.88	0.00

5.7 Comparison between 2005 and 2010 Model Calibrations

The coefficient of determination (R^2) between actual and modeled demand is given in Table 5-13 and is a measure of how well the models perform in estimating demand. Statistics are provided for the ICPRB 2005 model calibration and the current model calibration. Statistics are provided primarily for the summer model for each supplier, as that is the time period of highest demand and greatest interest. The closeness of R^2 values between the two studies suggests that model performance is not lost because of the current model calibration.

Table 5-13: Regression plus ARIMA coefficient of determination.

	2005 Coefficient of Determination (R^2)	2010 Coefficient of Determination (R^2)
FW Summer	0.81	0.89
WSSC Summer	0.71	0.72
WA Summer	0.58	0.59
CO-OP Summer	0.81	0.85
CO-OP Fall	0.63	0.87

5.8 Implementing Daily Demand Forecasts in PRRISM

In the demand model implemented in PRRISM, demand is a function of simulation year, season, month, meteorological conditions and day of the week, as characterized by the variables of Table 5-6, and a daily error term based on an ARIMA process. Demand for each of the three WMA water suppliers is simulated by first computing monthly average demand, which is the product of annual demand forecasts, given in Table 4-1, and monthly production factors, from Table 5-4. To this result is added the variation from monthly average demand, Y_t, where the regression coefficients for the three suppliers are obtained from Table 5-7 and Table 5-8. In the PRRISM calculation, the error term, N_t, is based on the ARIMA model for the CO-OP system as a whole, apportioned to the three suppliers based on relative demand. The ARIMA models for the individual suppliers were not used in the simulation because of the correlation in these error terms, which would result in a dampening of total error if they were summed. A random number generator was used to develop the random component of N_t, assuming a normal distribution, mean of zero, and the standard deviations provided in Table 5-12. (The error term for the CO-OP system is normally distributed). Seed values to initialize the N_t time series were assumed, which allows for calculation of the subsequent ARIMA terms, $Arima_t$ in Equation 9.

Time series needed to drive the regression models developed for each supplier were developed for PRRISM. Historical soil moisture and temperature data were obtained for the entire period of record, 1929 to the present. Precipitation records for each water supplier were compiled from historical data for the same period of record. It was necessary to develop composite precipitation records, since several stations have some days or months of missing data. Day-of-week was assigned to each day of the historical record. The number of days in a row without precipitation was calculated for each precipitation record.

Figure 5-14 shows a simulation of the demand that would occur today given a repeat of meteorological and soil moisture conditions from the drought of 1930. Several possible current levels of demand are shown since each trace fluctuates by a unique random time series, representing the variation of likely demand that is feasible and incorporating the randomness inherent in the original data set. For comparison, demand for the most recent drought of 2002 is also shown. The graph allows the user to compare demand that might occur during the drought of 1930 with what occurred during the drought of 2002. Overall, the demand levels for both droughts are fairly similar.

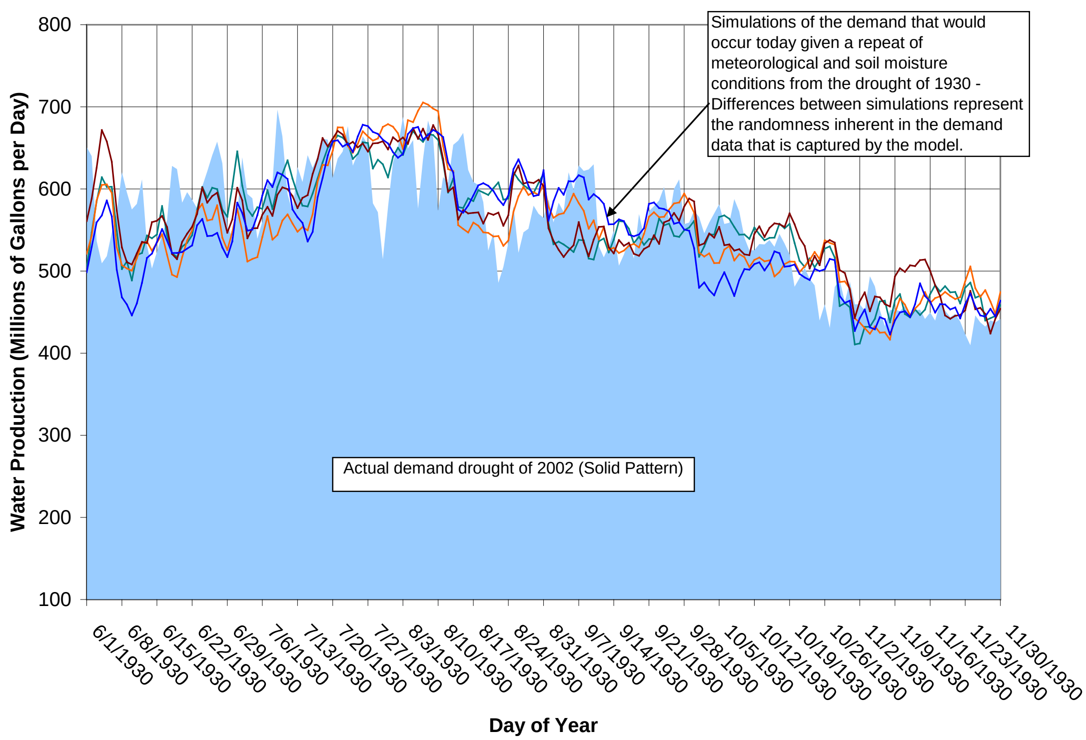


Figure 5-14: Modeled demand that would occur today given meteorology of 1930. Also shown is the demand that actually occurred in the drought year of 2002.

5.9 Advantages of Using the Detailed Demand Model

It is critical to preserve the autocorrelation and random characteristics of the original data series as system demand has a direct relationship to how reservoir releases are made and to system efficiency. Carefully determining the statistical properties of the original data set can improve operational forecasting of short-term demand, *i.e.*, the water manager can potentially use the information to forecast demand nine days into the future and improve on the efficiency of Jennings Randolph releases. This method also allows for the use of weather information to more accurately portray demand likely to occur during extreme droughts (as during the drought of record). Additionally, this method can be used to explore how changes in climate affect current and future demand.

6 Resource Analysis Method and Modeling Assumptions

6.1 Introduction

This chapter describes the system model that is used for the resource assessment portion of the study, the Potomac Reservoir and River Simulation Model (PRRISM). A history and overview of the model is provided in Section 6.2. Key system components and constraints are discussed, along with corresponding model inputs and assumptions, in the following sections. This chapter includes descriptions of the two most significant changes that have been made to the model since the last WMA resource assessment: a revision of model representation of operating rules for Jennings Randolph and Savage reservoirs' water quality releases, discussed in Sections 6.8 and 6.9, and a significant increase in the assumed sedimentation rate for Jennings Randolph Reservoir, discussed in Section 6.4. Other system components discussed in detail in this chapter are

- system reservoir water supply operations (Section 6.3),
- return flows from wastewater treatment plants upstream of the Potomac water supply intakes and Occoquan Reservoir (Section 6.5),
- Loudoun Water's proposed quarries (Section 6.6),
- the recommended environmental flow rate for the Potomac River at Little Falls (Section 6.7), and
- upstream consumptive water use (Section 6.10).

A detailed list of PRRISM inputs used in this study is provided in Appendix F.

6.2 Model Overview

PRRISM simulates future water demand and availability in the WMA system based on forecasted demands and the historical record of hydrologic and meteorological conditions. The original version of PRRISM, called the Potomac River Interactive Simulation Model, was developed at Johns Hopkins University by Richard Palmer and colleagues (Palmer *et al.*, 1979). This model was instrumental to obtaining consensus for the cooperative arrangement by the WMA water suppliers as agreed to in the Water Supply Coordination Agreement. The most recent version of PRRISM was developed for the demand and resource studies using the object-oriented programming language Extend™ (Imagine That! 2005) and is conceptually similar to the original model developed in the late 1970's; both models utilize a water balance at the reservoirs and simulate flows over the period of record. PRRISM is updated and refined on an ongoing basis to incorporate newly available data and to reflect physical and operational changes that occur in the system.

PRRISM simulates on a daily basis the processes which govern water supply and demand in the WMA system: flows in the Potomac River, storage volumes and releases from the WMA system of reservoirs, and water withdrawals by the three major WMA suppliers. Water withdrawals are based on forecasted average annual demands from billing data and simulated monthly and daily variations in demand from production data, as described in Chapters 4 and 5. Historical stream flow records have been used to develop "natural" daily Potomac River flows and reservoir inflows for input into PRRISM (Hagen and Steiner, 1998a; Hagen *et al.*, 1998b; 1998c), representing flows that would be expected in absence of withdrawals, diversions, or reservoir regulations. Estimates of reservoir evaporative losses and inflows from direct precipitation are based on historical records of temperature and precipitation. Outflows to the Potomac River from Jennings Randolph and Savage reservoirs are based on a representation of the operating rules for these reservoirs, developed in close coordination with the Baltimore District of the Army Corps of Engineers. Reservoir water supply releases from Jennings Randolph, Savage, and Little Seneca reservoirs are simulated to meet the recommended minimum stream flow at Little Falls, including a margin of safety, taking into account river flow and projected withdrawals. PRRISM can thus be used to predict how the Potomac River would respond and how the current system of reservoirs would be managed under current operating procedures in response to current or future demand.

A summary of PRRISM's modeling components, inputs, and outputs is given in Table 6-1.

Table 6-1: Primary system components, inputs and outputs for current version of PRRISM.

System components represented in PRRISM	Model Inputs	Model Outputs
Reservoir operations: • Jennings Randolph water quality storage • Jennings Randolph water supply storage • Savage Reservoir • Little Seneca Reservoir • Patuxent reservoirs • Occoquan Reservoir *Water withdrawals for:* • Washington Aqueduct • Fairfax Water • Washington Suburban Sanitary Commission • City of Rockville *Potomac River flow* *Potential water supply alternatives* *Potential Water Use Restrictions*	*Stream flows based on historic record (1929 – 2007):* • Potomac River flows • Reservoir inflows *Water demand, based on average annual demand forecasts and simulated monthly and daily variations, for:* • Washington Aqueduct • Fairfax Water • Washington Suburban Sanitary Commission • City of Rockville *Other inputs:* • Forecast year • Choice of water supply alternatives • Restriction percentages • Upstream WWTP discharges • Upstream consumptive use	*WMA system performance measures:* • Magnitude and frequency of reservoir storage shortfalls (vulnerability) • Number of days of releases • Magnitude and frequency of Potomac River low flows downstream of the water supply intakes • Magnitude and frequency of demand deficit (reliability, resiliency, and vulnerability) *Model performance checks:* • Model water balance

For this study, PRRISM was run with forecasted likely and high demands for 2030 and 2040 scenarios in a continuous mode through 78 years of historical stream flow records, from 1929 through 2007, with each year in the historical record representing potential hydrologic conditions in a corresponding forecast year. Continuous modeling allows for an examination of the effects of multi-year droughts on reservoir storage. The drought of 1930-31 is the longest drought included in the historical record, lasting from the summer of 1930 through the winter of 1931. The drought of 1966 is also noteworthy, as it includes the lowest flow [78.20 mgd (121 cfs)] ever recorded on the Potomac River at Little Falls (USGS gage station 01646500).

6.3 Reservoir Water Supply Operations

Water supply storage in Jennings Randolph and Little Seneca reservoirs is full most of the time because the reservoirs are only used during severe droughts to augment Potomac flow. Since they were brought into the CO-OP system in the early 1980s, water supply releases have only occurred in only two summer seasons; in 1999 and 2002. Water supply releases flow into the Potomac River and downstream to the water supply intakes. In low flow conditions, the Jennings Randolph releases take about nine days to reach the intakes, and the Little Seneca releases take about a day. Not all of the water released is used, due to uncertainty in weather forecasts, forecasts of demand, forecasts of stream flow, among other variables.

The Patuxent and Occoquan reservoirs are used in conjunction with the Potomac River to meet water supply demand for WSSC and Fairfax Water, respectively. The water withdrawn from these reservoirs helps supply areas more remote from the Potomac River and reduces the amount of water that must be withdrawn from the Potomac River. During periods of drought, the Patuxent and Occoquan reservoirs are operated in a coordinated fashion to maximize water supply reliability from a systems perspective. The Patuxent and Occoquan reservoirs are also operated in normal years to ensure that they are filled to 90 percent full, 95 percent of the time by June 1. This practice helps ensure that these reservoirs can be used to their maximum benefit under drought conditions to help the water supply reliability of the CO-OP system. These operations are simulated in PRRISM. More details on these reservoir operations are given below.

6.3.1 Patuxent and Occoquan Reservoirs

Withdrawals from Patuxent and Occoquan reservoirs are determined by reservoir response curves. These curves were developed for the Occoquan and Patuxent reservoir systems and allow managers to determine the maximum sustainable and safe withdrawal rate during the drought season (Hagen and Steiner, 2000). Reservoir rule curves based on the reservoir response curves are incorporated into PRRISM. The Occoquan Reservoir rule curves were updated in PRRISM based on recommendations made by Fairfax Water in early 2010. These new rule curves allow for more gradual release reductions as the Occoquan Reservoir reaches lower storages during a PRRISM simulation. The model was updated to more accurately reflect the rule curve as it is implemented in operations.

When Potomac flows are low enough to require releases from Little Seneca Reservoir, the simulated withdrawal rates from the Patuxent and Occoquan reservoirs are set higher than the rule curve withdrawal. This serves to conserve storage in Little Seneca Reservoir. When there are no Little Seneca releases, the simulated withdrawal rates are lower than the rule curve withdrawal rates to allow the use of Patuxent and Occoquan reservoirs to recover to a sustainable trajectory. These operations are also programmed into PRRISM.

During droughts, a firm target withdrawal is determined for the Potomac River intakes for WSSC and Fairfax Water. Remaining demand is taken at the Patuxent and Occoquan reservoirs. The target for Patuxent and Occoquan reservoirs is therefore variable depending on total demand. If demand is more or less than what was forecasted for the day, the adjustment is made at the Patuxent and Occoquan reservoirs, thus helping to reduce the uncertainty in how much water must be released from Little Seneca Reservoir. Reducing the uncertainty in Little Seneca Reservoir releases allows for better management of the system resources. When demand is less than forecasted, withdrawals can simply be reduced from Patuxent and Occoquan reservoirs and the water saved for future use. If the water is released from Little Seneca Reservoir and demand is less than forecasted, this water flows past the intakes and is unavailable for future use.

6.3.2 Jennings Randolph and Little Seneca Reservoirs

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

Due to fluctuations in short-term demand and in flow forecasting, not all water released from Jennings Randolph can be captured at the intakes. River flows might be greater than predicted or demand might be less, in which case water in excess of the environmental flow recommendations flows past the intakes. The Jennings Randolph release is thus less than 100 percent efficient from a water supply perspective, as discussed previously (Section 5.5). An appropriate algorithm is modeled for the Jennings Randolph release in PRRISM that simulates Jennings Randolph inefficiency. Future Potomac flow is unknown for each model timestep and must be estimated based on the algorithm used during actual operations. Flow regressions are incorporated into the model and used to estimate stream flow recessions. In turn, these recessions are used to forecast Potomac flow nine days beyond the current model timestep. In model runs, as in real life operations, the flow downstream of Little Falls can be in excess of the environmental flow recommendation. The PRRISM approximates the real-life inefficiency that might be expected of Jennings Randolph releases during periods of low flow.

The travel time of a Jennings Randolph release takes nine days when the release is large (on the order of at least 100 to 200 mgd) and travels as a “wave,” a condition called unsteady flow by hydraulic engineers. For a small release less than approximately 100 mgd, the water travels downstream as a particle, and would take approximately 20 days to arrive at the intakes. during periods of low flow. Thus, the Jennings Randolph release in both real operations and as modeled in PRRISM calls for an initial day's release of 200 mgd whenever the forecast of demand is greater than the forecast of river flow nine days hence. The large release is made to quickly get the water to the intakes as a "wave." Subsequent days' releases are at least 100 mgd whenever the forecast of nine-day demand is greater than the forecast of river flow nine days hence. Little Seneca is assumed in model runs to be 100 percent efficient, but includes a 30 mgd margin of safety in the amount released.

6.4 Effects of Sedimentation on Reservoir Storage

Reservoir storage capacities decrease with time due to the deposition of sediment. The decrease in storage in the WMA system, as a function of forecast year, is represented in PRRISM by means of an assumed sedimentation rate for each reservoir. Table 6-2 shows the approximated current and projected reservoir storage for the system reservoirs, along with sedimentation rates assumed in the current study. These rates were determined from a review of available information. A new estimate of the sedimentation rate for Jennings Randolph, 127 mg/year, is significantly higher than the rate of 44 mg/year used in previous studies. For the other system reservoirs, sedimentation rates appearing in Table 6-2 are consistent with rates used in the last resource assessment for the WMA (Kame'enui *et al.*, 2005).

Sedimentation in Little Seneca Reservoir was documented in Hagen and Steiner (1999). Sedimentation in the Occoquan Reservoir was reviewed for Fairfax Water by CDM (2002) and was found to be consistent with past results. New bathymetric survey data for the Paxtuxent reservoirs, along with a review of past survey results, are available in Ortt *et al.* (2007). An analysis of these data, discussed below, indicates that the sedimentation rate assumed in past studies, 24 mg/year, is reasonable. A new review of data for Jennings Randolph conducted for this study has resulted in a revision in the assumed sedimentation rate and current usable capacity of this reservoir, as discussed below.

Table 6-2: Effects of sedimentation on system reservoir storage volume.

Reservoir	Usable capacity in year 2010, bg	Usable capacity in year 2040, bg	Rate of sedimentation assumed, mg/yr
Occoquan Reservoir	7,804	6,604	40
Patuxent reservoirs[1]	10,068	9,348	24
Little Seneca Reservoir[2]	3,652	3,202	15
Jennings Randolph water supply [3]	12,067	10,370	127 (distributed between water supply and quality storage)
Jennings Randolph water quality [3]	15,014	12,902	
Savage Reservoir	6,151	5,611	18

[1] 2010 usable capacity consistent with assumed sedimentation rate and estimated 2004 usable capacity from Ortt, *et al*. (2007).

[2] 2010 usable capacity derived from estimated 1996 capacity and assumed sedimentation rate given in Hagen and Steiner (1999).

[3] 2010 usable capacity derived from 1997 capacities from 1998 revised stage-storage curve (Bill Haines, personal communication); assumed sedimentation rate from analysis of available data (see discussion in Section 6.4.1).

6.4.1 Revised Estimate of Jennings Randolph Reservoir Sedimentation Rate and Current Capacity

Reservoir sedimentation rates are highly variable and dependent on hydrologic conditions, with the majority of sediment deposition occurring during very large storm events. The U.S. Army Corps of Engineers, Baltimore District (Baltimore District COE) has conducted periodic hydrographic surveys to monitor sediment accumulation in Jennings Randolph Reservoir and to estimate changes in its capacity, as summarized in Table 6-3. The first such survey took place sometime before completion of the dam in May 1981. Impoundment of water in the reservoir began in July 1981, and water in the reservoir reached the conservation pool level, at 1,466 feet, in May 1982. From the pre-impoundment survey, the original capacity of the reservoir conservation pool was estimated to be 94,707 acre-feet (ac-ft) (30,860 mg), with a usable capacity (above the lowest gate sill) of 94,398 ac-ft (30,760 mg). The Baltimore District COE gave the storage capacity of the reservoir as 92,000 ac-ft (29,978 mg), after subtracting an estimated 2,707 ac-ft to account for dead storage and anticipated sediment accumulation over a 100-year period (USACE, 1986). According to the agreed upon percentage of storage in the reservoir allocated to water supply, 44.56 percent, and to water quality, 55.44 percent, the water supply and water quality storage capacities were 40,995 ac-ft (13,358 mg) and 51,005 ac-ft (16,620 mg), respectively.

Subsequent surveys of Jennings Randolph have led to updates of the long-term sedimentation rate. The original "design" sedimentation rate for the reservoir was 20.65 ac-ft/yr (6.7 mg/yr), estimated from suspended sediment concentrations measured in water samples from the North Branch Potomac River at Kitzmiller (Burns and McArthur, 1996). Based on this design rate, a total sediment accumulation of 2,065 ac-ft was originally projected over the anticipated 100-year lifetime of the reservoir. In November 1984, after the first two years of reservoir operation, the Baltimore District COE observed that significant deposition of sediment had occurred in the upper end of the lake bottom and estimated that sedimentation was occurring at a rate of approximately 135 ac-ft/yr (44 mg/yr), almost seven times the original estimate (USACE, 1986). Results of a second survey, conducted in January 1986 shortly after Tropical Storm Juan, indicated that sedimentation was occurring at a rate of 12 times the original estimate. The long-term sedimentation rate estimated from the 1986 survey was consistent with results from a June 1991 survey, indicating that accumulation of sediment was continuing at a relatively rapid pace (USACE, 1997; Burns and McArthur, 1996).

In 1997, a hydrographic survey was done of Jennings Randolph Reservoir using equipment and techniques that were more advanced than those used in earlier surveys. A detailed map of the lake bottom bathymetry was constructed using Global Positioning System equipment for horizontal control and advanced sounding equipment for depth measurements (USACE, 1997). This survey resulted in a revision of the original area capacity table for the reservoir (Area Capacity Table, Jennings Randolph Lake, revised July 1998, from Bill Haines, personal communication). In the new table, the total capacity of the reservoir conservation pool is given as 88,226 ac-ft (28,749 mg), and the usable capacity (above the lowest gate sill) is 88,176 ac-ft (28,732 mg). This results in a usable storage capacity of 39,291 ac-ft (12,803 mg) for water supply and 48,885 ac-ft (15,929 mg) for water quality. Note that the 1997 survey results show that most of the reservoir's unusable storage, that is, the storage volume below the lowest gate sill, has been lost, making the difference between total and usable storage capacity fairly insignificant given the limitations in the accuracy of the measurements. In the analysis of sedimentation described below, and in Table 6-2, the usable storage capacity for Jennings Randolph Reservoir is assumed to be equivalent to the total storage capacity, within the accuracy of available measurements.

Available survey results for total conservation pool storage capacity are summarized in Table 6-3 and plotted in Figure 6-1. The long-term sedimentation rate for Jennings Randolph Reservoir, computed by comparing the reservoir capacity in 1981 with the capacity in 1997, is approximately 132 mg/yr. The data were also analyzed using Sen's nonparametric estimate for slope, which is calculated from the median value of slopes computed from all possible pairs of data points (Gilbert, 1987). Sen's estimate is appropriate for data with outliers and gross errors, as might be present in historical estimates of reservoir volumes. Sen's estimate of the sedimentation rate is 127 mg/yr. Using this rate along with the Baltimore District COE's estimated capacity in 1997, our best estimate for Jennings Randolph conservation pool storage capacity in the year 2010 is approximately 27.1 bg, with 12.1 bg allocated to water supply and 15.0 bg allocated to water quality (Table 6-2), reflecting a loss of storage capacity of 12 percent since 1981. By 2040, the storage capacity loss is projected to be 25 percent.

Sedimentation rates can be expected to change over time as conditions change in reservoir watersheds. Figure 6-1 suggests that sedimentation rates for Jennings Randolph Reservoir may have increased in later years. To investigate this possibility, Sen's estimate was also computed using only the most recent four data points in Table 6-3, giving an estimate of a sedimentation rate in later years of 160 mg/yr. This higher rate is used in Chapter 8 in a sensitivity test for the resource analysis.

The relatively high rate of sediment accumulation in Jennings Randolph Reservoir has been attributed to coal mining activities in the watershed. Because mining activities have decreased and surface mine reclamation efforts have increased in recent years, sedimentation due to mining activities is likely to decline in the coming decades. On the other hand, future population growth and development pressures could lead to increased sediment yields in the watershed. Thus, potential changes in the watershed and their likely impacts on reservoir sedimentation rates may warrant future study.

Table 6-3: Hydrographic survey results for Jennings Randolph Reservoir.

	Estimated conservation pool total storage capacity		Estimated loss due to sedimentation	
Date	**(ac-ft)**	**(mg)**	**(ac-ft)**	**(mg)**
July 1981	94,707[1]	30,860	0	0
November 1984			270[2]	88
January 1986			900[2]	293
June 1991			2,510[2]	818
June 1997	88,226[3]	28,749	6,481	2,112

[1] USACE, 1985.

[2] Burns and McArthur, 1996.

[3] William Haines, USACE, personal communication (April 2009).

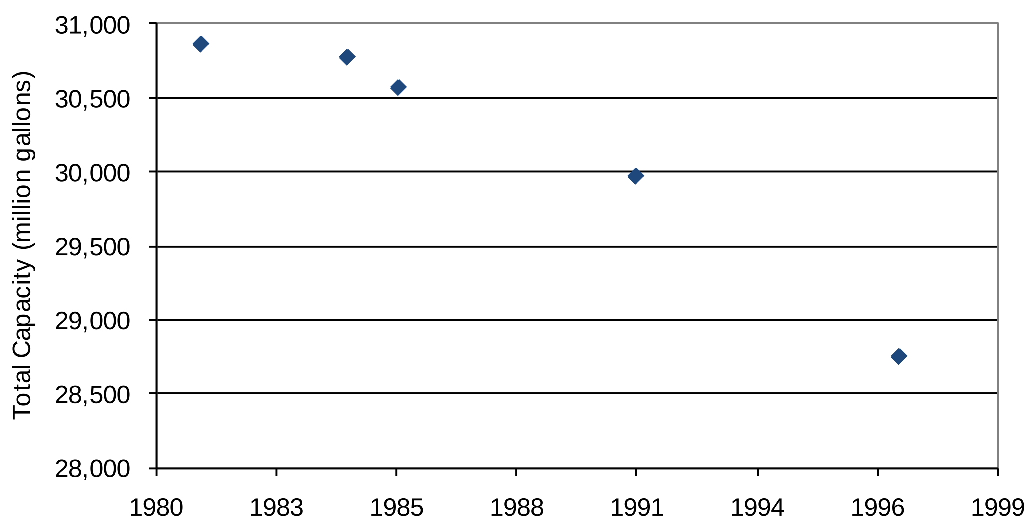


Figure 6-1: Estimated conservation pool storage capacity in Jennings Randolph Reservoir.

6.4.2 Analysis of New Bathymetric Data for the Patuxent Reservoirs

Updated information on the storage capacities of the Patuxent reservoirs, Tridelphia and Rocky Gorge, is available in a recent study by the Maryland Geological Survey (MGS) for the Maryland Department of Natural Resources (Ortt *et al.*, 2007). This report contains results from 2004 and 2005 bathymetric surveys of the reservoirs by MGS, and also summarizes results from past surveys. Past surveys include data collected by the Natural Resources Conservation Service (NRCS) at roughly ten-year intervals from 1942 through 1984, reanalyzed for WSSC by the firm, Engineering, Science, and Technology, Inc. (ES Engineering), and standard hydrographic surveys done by Ocean Surveys, Inc. (OSI) for WSSC in 1995 and 1996. The 2004 and 2005 surveys were done using differential Global Positioning System and advanced acoustic sounding equipment, and are believed to be more accurate than early surveys.

Reservoir sedimentation rates were computed from these data by ICPRB using Sen's nonparametric estimator of slope. Sen's estimates for the sedimentation rates were 9 mg/yr for Tridelphia Reservoir and 15 mg/yr for Rocky Gorge Reservoir, giving a total sedimentation rate of 24 mg/yr, consistent with the value used in ICPRB's last WMA demand and resource availability study. Sen's estimator was also used to estimate sedimentation rates for more recent years. When results from the first hydrographic surveys were eliminated from the data set (eliminating 1942 results for Tridelphia and 1954 results for Rocky Gorge) Sen's estimate was unchanged for Tridelphia but increased to 19 mg/yr for Rocky Gorge, giving a combined sedimentation rate of 28 mg/yr for the Patuxent reservoirs in more recent years. These results are consistent with anecdotal reports that development in the Rocky Gorge watershed may be leading to higher sediment loads to this reservoir. Sen's estimate for the Patuxent reservoirs sedimentation rate, 24 mg/yr, is used in this study for the resource assessment and assessment of water supply alternatives. The higher rate of 28 mg/yr computed from more recent data is used in a sensitivity test.

6.5 Effects of Increased Treated Wastewater Return Flow

The WMA is served by a number of wastewater treatment plants (WWTP). The majority of the area's wastewater is treated at D.C.WASA's Blue Plains Advanced Wastewater Treatment Plant, which discharges into the Potomac estuary south of Washington, D.C. However, several wastewater treatment plants serving the WMA discharge treated water into the Potomac River upstream of the WMA water intakes, and one plant discharges into a stream upstream of Occoquan Reservoir. Thus, this treated water is available for further use at downstream withdrawal points. These WWTP return flows are estimated for future years and are incorporated into PRRISM. The facilities considered for this analysis include WSSC's Seneca and Damascus WWTPs, Loudoun Water's Broad Run WWTP, and the Upper Occoquan Service Authority (UOSA) WWTP. The projected average annual return flows for these facilities are listed in Table 6-4.

Table 6-4: Projected return flows (mgd) from Seneca WWTP, Damascus Advanced WWTP, Broad Run WWTP, and the UOSA WWTP to the Potomac River and Occoquan Reservoir.

Year	Flow from Seneca WWTP to Potomac River[1]	Flow from Damascus Advanced WWTP to Potomac River[2]	Flow from Broad Run WWTP to Potomac River[3]	Flow from UOSA WWTP to Occoquan Reservoir[4]
2010	18.82	0.92	0	32.15
2015	20.57	0.93	3.0	36.35
2020	22.13	0.95	5.2	40.45
2025	23.49	0.96	7.8	44.45
2030	24.58	0.97	9.6	48.45
2035	26.37	0.97	11.0	52.45
2040	27.86	0.97	13.8	56.45

[1]Data provided by Kenneth Dixon of WSSC (February 2009). Projections were made using Round 7.0 demographic forecasts which went out to 2030. Projections for 2035 and 2040 were made using the Microsoft Excel forecast function (Kenneth Dixon, personal communication, 2/18/09).
[2]Data provided by Carol Mojica of WSSC (February 2009). Projections were made using Round 7.0 demographic forecasts which went out to 2030. Projected flow after 2030 is anticipated to remain constant because the wastewater treatment plant was designed to serve a specific zoned area (Carol Mojica, personal communication 2/23/09).
[3]Data reviewed by Tom Bonacquisti of Loudoun Water (June 2009).
[4]UOSA data provided by Evelyn Mahieu of UOSA (March 2009).

Changes in monthly return flow are modeled since return flow typically varies over the calendar year, with a minimum in the summer. Production factors are developed to convert average annual values to monthly values. To calculate monthly production factors, the monthly average is divided by the annual average for each month. The numbers range from 0.73 to 1.02 for these treatment plants. It is important to capture the variation in production since water supply releases from the Jennings Randolph and Little Seneca reservoirs would occur during the times that releases from the treatment plants are at their lowest. Lower estimates of wastewater return flow are a conservative assumption in the PRRISM model as lower return flows from these treatment plants cause higher releases rates from the reservoirs. Table 6-5 shows the production factors calculated for Seneca, Damascus Advanced, and UOSA WWTPs.

Table 6-5: Production factors (mgd) for treated wastewater return flows for Seneca, Damascus Advanced, Broad Run, and UOSA WWTPs.

	Monthly Factors			
Month	Seneca WWTP (minimum of 2005-2008 factors)[1]	Damascus Advanced WWTP (minimum of 2005-2008 factors)[2]	Broad Run WWTP (minimum of 2005-2008 factors)[3]	UOSA WWTP (minimum of 2005-2008 factors)[4]
January	0.92	0.95	0.92	0.99
Februar	0.91	1.02	0.89	0.73
March	0.93	0.96	0.94	0.86
April	1.00	0.92	0.97	0.92
May	0.91	0.93	0.97	0.90
June	1.00	0.93	0.99	0.91
July	0.88	0.86	0.96	0.91
August	0.90	0.85	0.95	0.86
Septemb	0.90	0.85	0.97	0.84
October	0.90	0.85	0.98	0.89
Novemb	0.91	0.88	0.93	0.92
Decemb	0.92	0.95	0.99	0.97

[1]Data provided by Kenneth Dixon of WSSC (February 2009).
[2]Data provided by Carol Mojica of WSSC (February 2009).
[3]Data provided by Thomas Lipinski of Loudoun Water (March 2009).
[4]Data provided by Evelyn Mahieu of UOSA (March 2009).

The flow from Loudoun Water's Broad Run WWTP to the Potomac River (*BR flow*) was calculated using Equation 11:

$$BR\ flow = FW\ demand * LW\ fraction * 0.87 * 0.9 - 13.8 \qquad \text{Equation 11}$$

where *FW demand* is Fairfax Water's average annual water demand by simulation year (mg); *LW fraction* is the ratio of Loudoun Water's average annual demand over Fairfax Water's average annual demand by simulation year (dimensionless); coefficient *0.87* is Fairfax Water's average production factor for winter months (dimensionless); coefficient *0.9* assumes a 10 percent winter time consumptive use (dimensionless); and the constant *13.8* is assumed to be flow diverted to the Blue Plains Advanced Wastewater Treatment Plant (Blue Plains) and is not considered because this flow is discharged to the Potomac estuary (mg). PRRISM simulations of Broad Run flow were capped at the annual average values reported in Table 6-4. Broad Run flow was treated differently compared to the other WWTPs in order to ensure that the return flows were consistent with a range of demand forecasts.

6.6 Loudoun Water

Currently, Loudoun Water can take up to 50 mgd of treated water from Fairfax Water and 7 mgd of water supply from the City of Fairfax's Goose Creek Water Treatment Plant. However, stream flow in Goose Creek has been diminished in recent dry years and Loudoun Water can only reliably expect up to 3 mgd from this source. The combined water capacity from these two sources is not sufficient to meet Loudoun Water's long-term water demand projections. Based on current water use trends, peak-day water demands are expected to exceed the current 50 mgd allocation from Fairfax Water by year 2010, and at least seven years are needed to implement new capacity.

Due to their growing demand, Loudoun Water forecasts the need for an additional 40 mgd of water supply and treatment capacity. To meet this growing demand Loudoun Water has (1) purchased additional land for an off-river water treatment plant; (2) entered into an agreement with Luck Stone Corporation for eventual raw water storage in mined rock quarries located within Loudoun County.

For purposes of reporting the results for the current system resource analysis, we conservatively assume that all of Loudoun Water's demand will be met by Fairfax Water and is thus included in the estimate of future demand in the WMA. Preliminary information on the future availability of the Loudoun Water's quarries and water treatment plant are described in Section 8.4 of the alternatives analysis.

6.7 Environmental Flow Recommendations

The current environmental flow recommendations for the WMA are used for the resource analysis. The recommendations are based on a 1981 study (MD DNR, 1981). The flow recommendations include a 300 mgd minimum daily flow downstream of Great Falls and a 100 mgd minimum daily flow downstream of Little Falls, the most downstream metropolitan area water supply intake. The flow recommendations are currently being reviewed.

In April 2003, ICPRB and the Maryland Department of Natural Resources (MD DNR) convened a workshop with a special panel of nationally recognized experts on habitat assessment methods to investigate and develop a method to evaluate the environmental flow-by requirements. At this workshop, members of the special panel collectively considered and debated the various methods applicable to the Potomac River. Five principle recommendations came from that workshop:

1. Define the desired hydrologic regime (*i.e.*, natural ranges of flow).
2. Collect background (hydrologic, biologic) data.
3. Develop a biological community-habitat conceptual model.
4. Collect data and conduct simulations to fill the gaps.
5. Evaluate and refine management targets (an adaptive management approach).

In September 2003, MD DNR's Power Plant Research Program issued "Habitat Assessment of the Potomac River From Little Falls to Seneca Pool" (MD DNR, 2003) which provided substantial background information describing the history of current low-flow requirements, a review of the studies conducted to support those requirements, and a report on the habitat assessment conducted during low flow conditions in 2002. The assessment included development of a habitat map, a field survey of habitat types, and measurements of hydraulic and water quality conditions, spanning the period July through October 2002, when flows were as low as 151 mgd at the gage at Little Falls Dam.

In November 2004, ICPRB convened a Potomac River Low-Flow Study Methods Update Workshop to carry forward the process. While the intent of the workshop was to initiate the first recommendation of the 2003 workshop by defining desired hydrological regimes, it became apparent during the course of discussion that elements of the workshop's Recommendation #2, calling for background data to be collected and discussed, especially biological information, needed to happen first. The group came to consensus that the next step is to convene a workshop with regional biologists and perhaps others from across the nation with expertise on the possibly affected species and guilds. In 2005, ICPRB conducted a scaled down version of that workshop to address interim measures and to begin collecting some of the information needs. Reports on these activities can be found at *http://esm.versar.com/pprp/potomac*.

In 2009, ICPRB, the Baltimore District COE, and The Nature Conservancy have entered a partnership and have successfully worked to secure initial funding for a watershed-wide evaluation of flow. This effort will look at a variety of flow ranges, from floods to base-flows to low-flows. The Potomac River mainstem and selected major tributaries are the focus of initial efforts which are currently underway.

Any change in the environmental flow-by recommendation could have an effect on system reliability. The modeling tools developed for this analysis are easily updated for inclusion in a broader scope study to examine the environmental flow issue.

6.8 Jennings Randolph and Savage River Water Quality Releases

The North Branch region of the Potomac River basin includes two major multi-purpose reservoirs. Savage River and Jennings Randolph reservoirs (collectively known as the North Branch reservoirs) are located above Luke, Maryland. The Savage River Reservoir is owned by the Upper Potomac River Commission (UPRC) with operational guidance provided by the Baltimore District COE. Jennings Randolph is owned and operated by the Baltimore District COE. The North Branch reservoirs are operated for four primary purposes: flood control, water quality enhancement, recreation, and water supply for the WMA. The usable conservation storage in Jennings Randolph is formally allocated to one of two purposes: water quality or water supply. These two segments of storage are operated separately: ICPRB requests releases from water supply storage on behalf of the CO-OP utilities, while the Baltimore District COE operates water quality storage. Savage is generally operated in coordination with Jennings Randolph, but it does not have official storage allocations. To the degree possible, these reservoirs are also managed to provide whitewater boating and fishing opportunities downstream, along with boating and beach access on Jennings Randolph itself.

The existing master manual of operations for flood control and water quality storage in Jennings Randolph was originally developed in the late 1970s and revised in 1985. Several factors have changed significantly since that time. Prior to the 1980s, the North Branch Potomac River had severe acid mine drainage problems, but these problems are gradually subsiding due to reclamation and treatment practices. One of the primary water quality objectives for the water quality storage in Jennings Randolph was to improve pH conditions. Now that acid mine drainage problems have subsided, pH is much less of a concern. Other water quality issues have come to the forefront, such as temperature. At the same time, recreational activities on and below the reservoirs have increased and gained in prominence, especially fishing and whitewater boating. Because of the changing conditions, ICPRB has spent a substantial amount of effort working with the reservoir operators and stakeholders to study how operations can be changed in order to better balance needs within the basin. The Baltimore District COE has gradually adjusted its operations to reflect these changes but it is possible that more can be done.

In 2005, the North Branch Potomac River Advisory Committee was formed by the agencies collectively responsible for the operations and management of Jennings Randolph and Savage River reservoirs and the lands surrounding the two reservoirs plus other groups. The committee was established to provide a forum for input regarding operations and management of the dams, the surrounding public lands, and downstream flow levels for all project purposes, especially recreation.

After considerable discussion and debate, the committee reached a consensus on a set of recommendations that they believe will enhance the management of the two reservoirs for all interested parties (NPS, 2008). The committee made great strides in developing broadly acceptable flow management objectives that can be used in making reservoir release decisions. However, the dry conditions in 2007 proved to be a significant challenge. It was unclear whether there would be enough water to make whitewater releases while still supporting the beach, fisheries objectives, and water quality needs. This showed that more work can be done to better describe how stakeholder objectives can be met under different hydrologic scenarios. Other issues remain to be resolved through the continued work of this committee.

The ICPRB has modified the way PRRISM represents North Branch water quality operations so that specific recreational needs can be met throughout the year while still attempting to meet all legally mandated purposes of the Jennings Randolph and Savage reservoirs. These modifications are improvements to the PRRISM versions used in past studies because the model better represents the Baltimore District COE's balancing of competing needs for the limited water resource. The 2000 PRRISM version conservatively assumed the minimum release from Jennings Randolph and Savage water quality storages at all times. The 2005 PRRISM version used a modified Jennings Randolph rule curve to address some recreation and elevation targets (Prelewicz *et al*., 2004); however, many of the early North Branch operational guidelines were followed. Since the 2005 study, the ICPRB continued to modify, verify, and calibrate a model of the North Branch water quality operations in close coordination with the Baltimore District COE. The version of the PRRISM used in the 2010 study includes all recreational and environmental storage elevation targets that are either mandated by the government or recommended by the North Branch Potomac River Advisory Committee. This process involved developing a new Jennings Randolph rule curve to better reflect current Baltimore District COE operations, including a stepped rule table to guide releases when downstream flow and lake elevation targets need to be abandoned during dry conditions. Savage reservoir rule curves were not modified; water quality releases, however, have been adjusted to accommodate the needs of downstream fisheries. The North Branch model development and verification is available in Appendix E, including figures of the updated rule curves. Differences between the 2005 and 2010 WMA water supply studies as a result of these operational changes are discussed in Section 7.5.

6.9 Savage Reservoir Matched Releases

The Savage River Reservoir, with an estimated storage capacity of 6.3 bg, is used for water quality improvement, to provide flow for industrial processes, incidental flood control, and, historically, to dilute relatively acidic flows in the North Branch of the Potomac. While the Baltimore District COE master manual for the North Branch system does not directly dedicate Savage storage for water supply purposes, Savage's water quality operations are simulated in PRRISM. These operations allow concurrent Savage releases during Jennings Randolph releases for water quality purposes. These concurrent Savage releases are also referred to as "matched" releases.

The original need for the Savage matched release is described in Savage Reservoir Operation and Maintenance Cost Sharing Agreement, signed in 1982 by the water suppliers, the Upper Potomac River Commission (UPRC), and Allegany County. The agreement states that the matched releases from Savage were originally necessary to dilute the acidic water released from Jennings Randolph Reservoir water supply storage; and thereby reduce the acidity of water released from Jennings Randolph during periods of extreme low flow. Now that acid mine drainage has substantially subsided in the North Branch of the Potomac, matched releases from Savage no longer serve their intended purposes. However, during the drought of 2002 Savage was used to match the Jennings Randolph water supply release even though water acidity was not a concern. The continuing implementation of this agreement is contingent on approval by the UPRC, the owners of Savage Reservoir.

The proportion of the matched release from Savage is based on the relative sizes of the two North Branch reservoirs. The conservation capacity of Savage is roughly one fifth the size of the conservation capacity of Jennings Randolph. During the drawdown season (approximately late spring through early fall) matched water supply releases are split between Jennings Randolph and Savage to maintain a five-to-one ratio. The term "20 percent match", therefore, means that Savage releases are 20 percent as large as Jennings Randolph releases. This definition requires that 84 percent of total flow augmentation needed for CO-OP comes from Jennings Randolph and 16 percent comes from Savage.

PRRISM models the match exactly: any time the simulation calculates a need for water supply releases from the North Branch, 84 percent of the need comes from Jennings Randolph water supply storage and 16 percent of the need comes from Savage. The matches are cut off if Savage drops below a guide curve from the Baltimore District COE's Master Manual (Curve C, which is meant to protect Westernport's water supply).

6.10 Upstream Consumptive Demand

Water withdrawals from the Potomac River and its tributaries by upstream users have an impact on the amount of water available to meet demand in the WMA. Water withdrawn upstream is for the most part returned to the river as wastewater treatment plant discharge. However, a portion of this water is not returned to the river due to evaporation, transpiration, incorporation into products, consumption by humans or livestock, diversion to another basin, or other processes. The portion of a water withdrawal that is removed and is not available for downstream use is termed “consumptive use”. The effects of upstream consumptive use are included in the resource assessment by incorporating forecasts of consumptive use into PRRISM, as described below.

An examination of cumulative consumptive use in the Potomac basin is provided in the Water Supply Demand and Resource Analysis in the Potomac River Basin (Basin Study; Steiner *et al*., 2000). Consumptive use upstream of the WMA intakes in the Potomac River basin reduces the amount of water that is available for downstream use by the WMA water suppliers. The Basin Study finds that consumptive water use in the Potomac Basin is significant during droughts.

The Basin Study suggests that total June through August consumptive use in the Potomac basin upstream of the metropolitan water supply intakes for 2000 was approximately 129 mgd during hot and dry years. Projected June through August consumptive use in the basin is forecast to increase by 30 mgd between 2000 to 2030 assuming hot and dry conditions—approximately one mgd each year.

The Basin Study provides the information needed to calculate consumptive use for other months (*i.e.*, September through May). Total September through May consumptive use in the Potomac basin upstream of the metropolitan water supply intakes for 2000 was estimated to be 42 mgd, increasing by four mgd to 46 mgd in 2020. (September through May consumptive use is calculated as the sum of commercial, industrial, thermoelectric, mining, and livestock consumptive uses. Irrigation and domestic consumptive water use are assumed to be zero during the September through May period.)

Stream flow resources and demand are modified in PRRISM to account for present and forecast levels of consumptive demand. The adjustment is made in two parts. First, the stream flow record is modified to represent flows prior to human consumptive use. Second, demand is modified to represent current or forecast levels of consumptive demand depending on whether the simulation is for current or for forecast years. These steps are described in more detail below.

The stream flow record is modified to represent flows prior to human consumptive use, as follows. It is assumed that actual consumptive use in 1929 was zero and that the 1929 historical stream flow record did not have to be adjusted. It is assumed that actual consumptive use in 2000 was 129 mgd and that the historical stream flow record in 2000 must be adjusted by adding 129 mgd in June, July, and August. For the years between 1929 and 2000, the historical stream flow record is adjusted by adding an amount that varies linearly from 129 mgd in 2000 to zero mgd in 1929, for June through August. A similar algorithm is followed for September through May. For the years between 1929 and 2000, the historical stream flow record is adjusted by adding an amount that varies linearly from zero mgd in 1929 to 42 mgd in 2000, for September through May.

Resources were modified to account for consumptive demand as follows. In model runs, estimates of current levels of consumptive use were subtracted from Potomac available flow before Washington area water supply withdrawals were made. For example, if a model run is made representing 2000 conditions, a consumptive use of 129 mgd is subtracted from available stream flow in all years, prior to water supply withdrawals in summer months. When projected 2025 demand is modeled, stream flow resources are decreased by an additional 25 mgd in the summer and four mgd in the other months for all years of the historical record, prior to water supply withdrawals. An adjustment of one mgd is made to account for additional consumptive use by the Mirant power plant near Dickerson, Maryland, which was outside of the scope of the Basin Study.

7 Resource Analysis

The results of the resource analysis are presented in this chapter. PRRISM simulations were used to evaluate how the current WMA water supply system would respond to forecasted demands under the range of hydrologic conditions that occurred from 1929 through 2007. Forecasts of average annual WMA demands, given in Chapter 4, along with estimates of seasonal and daily variations in demand, described in Chapter 5, are used in PRRISM to generate a time series of daily withdrawals for a specified forecast year. PRRISM simulates daily Potomac River inflows and outflows, including reservoir releases made to maintain the recommended minimum flow at Little Falls, under the assumptions discussed in Chapter 6. Unless otherwise noted, all scenarios were run using the PRRISM input parameters given in Appendix F.

7.1 Scenarios

Model results are presented for the 20-year demand forecast, out to 2030, and also for the 30-year demand forecast, out to 2040. The 30-year forecast has been included in this study to assist the Northern Virginia Regional Commission in their current water supply planning effort. Future scenarios considered in the resource assessment are described in Section 4.2 and below, and summarized in Table 7-1.

In Chapter 4, forecasted annual average demands were presented for two different sets of assumptions, reflecting uncertainties in future demographic changes and water use behavior. Demand forecasts were first computed using MWCOG Round 7.2 demographic projections, under the assumption that both single family household and multi-family household unit use would decrease throughout the forecast period due to the effects of the Energy Policy Act of 1992. These assumptions are most consistent with those used in ICPRB's most recent demand forecast (Kame'enui *et al.*, 2005). A second, higher set of demand forecasts was computed by adding estimated demand from potential future growth in several areas in Fairfax County, not included in the Round 7.2 projections but currently under evaluation. The second set of demand forecasts also includes increases resulting from the assumption that water use in single family households will be constant throughout the forecast period, rather than decreasing. This second assumption may be appropriate because there are indications that water savings from low-flow plumbing fixtures, as specified by the Energy Policy Act, may be offset by increases in summertime outdoor water use for single family households (see Section 3.8).

Simulations were also done to evaluate the sensitivity of the model results to uncertainties in reservoir sedimentation rates. Newly available data, along with historical data on reservoir capacities for Jennings Randolph and the Patuxent reservoirs were analyzed in this study (see Section 6.4), resulting in a higher estimated sedimentation rate for Jennings Randolph, 127 mg/yr, and an estimate consistent with past assumptions for the Patuxent reservoirs, 24 mg/yr. Alternative estimates of these sedimentation rates were also obtained by eliminating data from the first year of operation for each reservoir, resulting in estimates of 160 mg/yr for Jennings Randolph and 28 mg/yr for the Patuxent reservoirs. These higher estimates indicate that sedimentation may have increased in recent years due to land use or other changes in these watersheds. The impact on the WMA water supply system of higher sedimentation rates is evaluated in four model sensitivity runs.

Table 7-1: Summary of model run and assumptions for resource analysis and sensitivity tests.

Demand scenario	Reservoir sedimentation rates	Demand forecast year
Scenario 1 (likely demands): using MWCOG Round 7.2 growth forecasts and assuming future unit use reductions for both SFH and MFH	As given in Table 6-2	2030
Scenario 2 (higher demands): using MWCOG Round 7.2 growth forecasts plus additional estimated demand from Fairfax County potential growth areas, and assuming future unit use reductions only for MFH		
Scenario 1 (likely demands): using MWCOG Round 7.2 growth forecasts and assuming future unit use reductions for both SFH and MFH	As given in Table 6-2	2040
Scenario 2 (higher demands): using MWCOG Round 7.2 growth forecasts plus additional estimated demand from Fairfax County potential growth areas, and assuming future unit use reductions only for MFH		
Scenario 1 (likely demands): using MWCOG Round 7.2 growth forecasts and assuming future unit use reductions for both SFH and MFH	Assuming higher sedimentation rates for Jennings Randolph and Patuxent reservoirs, 160 mg/yr and 28 mg/yr, respectively	2030
Scenario 2 (higher demands): using MWCOG Round 7.2 growth forecasts plus additional estimated demand from Fairfax County potential growth areas, and assuming future unit use reductions only for MFH		
Scenario 1 (likely demands): using MWCOG Round 7.2 growth forecasts and assuming future unit use reductions for both SFH and MFH	Assuming higher sedimentation rates for Jennings Randolph and Patuxent reservoirs, 160 mg/yr and 28 mg/yr, respectively	2040
Scenario 2 (higher demands): using MWCOG Round 7.2 growth forecasts plus additional estimated demand from Fairfax County potential growth areas, and assuming future unit use reductions only for MFH		

Note: SFH = single family home; MFH = multi-family home

PRRISM simulations assume that the Potomac River environmental flow minimum of 100 mgd at Little Falls is met or exceeded at all times. Shortfalls in the Potomac resource are allocated to the WMA water suppliers and reported in PRRISM output as a deficit. When Jennings Randolph or Little Seneca reservoir is empty, the free flowing Potomac River will still have water available for use. If reservoir storage in Jennings Randolph or Little Seneca Reservoir is depleted, it raises the prospect of a combined reduction in demand by the three water suppliers, *i.e.*, a “flow allocation” per the allocation provisions of the LFAA, with due consideration given to the 100 mgd minimum recommended flow.

As discussed in previous chapters, the modeled water supply demand includes a randomly generated component of demand; therefore, each model run will have slightly different expression of water supply demand and results. These demands represent the variation of demand that is feasible for a given set of meteorological conditions while incorporating the randomness inherent in the original demand data set. (Sections 5.6 and 5.8 provide more detail on the random component of demand.) Since demand is slightly different in each model run, the model is run 20 times and results are presented in terms of the average result as well as the standard deviation associated with each model metric, which are described in Section 7.2.

7.2 Model Run Measures of Performance (metrics)

Model run results are expressed in terms that define the reliability, vulnerability, and resiliency of the Potomac system, where these terms are consistent with those developed in the water resources literature (Hashimoto *et al.*, 1982). Reservoir reliability is the statement of probability of meeting a given demand, expressed as a percentage of time the demand can be met. Vulnerability is a measure of the magnitude or significance of a failure, and can be defined as the largest deficit during a simulation. Resiliency gages the ability of the system to recover from system failure, and can be defined as the maximum number of consecutive periods of shortage during a simulation (Wurbs, 1996).

These concepts are addressed in various model run metrics:

- *Percentage of years with no Potomac deficits.* This metric is a measure of reliability, expressed as a percentage of years in the simulation in which all demand is met.
- *Maximum number of days in a row of Potomac deficits.* This metric is a measure of resiliency, expressed as the maximum number of consecutive days in which demand cannot be met.
- *Number of days in which Potomac deficits must be allocated*. This metric is a measure of the vulnerability of the system, expressed as the number of days a shortfall exists.
- *Maximum amount of deficit allocated in a single day, mgd*. This metric is a measure of the vulnerability of the system, expressed as the maximum shortfall on any given day over the simulation period.
- *Average amount of deficit allocated, mgd*. This metric is another measure of vulnerability, expressed as the average amount of Potomac deficit that must be allocated to the water suppliers.
- *Total amount of deficit allocated, mg.* Another measure of vulnerability, expressed as the total amount of a shortfall over the course of the simulation period.
- *Number of Patuxent water supply shortfalls.* This metric is a measure of the vulnerability of the Patuxent Reservoir, expressed as the number of days with zero storage and/or the number of days where the Patuxent release is below the emergency storage request of 20 mgd.
- *Number of Occoquan water supply shortfalls.* This metric is a measure of the vulnerability of the Occoquan Reservoir, expressed as the number of days where the Occoquan release is below the minimum demand of 45 mgd for Occoquan's area served.

- *Percentage of years with voluntary, mandatory, and emergency restrictions.* This metric is a measure of the reliability of the system, expressed as a percentage of years during the simulation in which water use restrictions are implemented.

Other model run metrics include:

- *Minimum storage in Jennings Randolph water supply account and Little Seneca, Occoquan, and Patuxent Reservoirs, expressed in billion gallons, bg.*
- *Minimum combined total storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply account, bg.*
- *Number of years in simulation.*
- *Average annual demand, drought year for 1930, mgd.* This reports the demand simulated by the model given the meteorological conditions of 1930, as reduced by simulated water use restrictions.
- *System mass balance check, mgd.* This provides a check on model consistency by reporting the root mean square mass balance error for Potomac River inflows and outflows, accumulated over all days of the model run.
- *Average of natural flow summer of 1930, mgd.* This metric is the average flow in June, July, and August of the drought of record, 1930, and is the flow that would have occurred without upstream reservoir regulation, consumptive use, return flows from wastewater treatment plants, or upstream reservoir withdrawals.
- *Average of natural flow fall of 1930, mgd.* This metric is the average flow in September, October, and November of the drought of record, 1930.
- *Average of flow downstream of intakes summer 1930, mgd.* This metric is the average of flow downstream of the water supply intakes in June, July, and August of 1930 and represents the modeled flow after all upstream augmentation, withdrawals, and consumptive use.
- *Average of flow downstream of intakes fall of 1930, mgd.* This metric is the average of flow downstream of the water supply intakes in September, October, and November of 1930.

7.3 Discussion of Results

PRRISM simulation results for 2030 and 2040 demand forecasts for both the likely demand and high demand assumptions appear in Table 7-2 and Table 7-3. Results in these tables are to a large degree determined by conditions that occurred during the drought of 1930-1931. This drought was the longest in the historical record and is the period in which modeled system reservoir storage was most often depleted given 2030 and 2040 demands.

Scenario 1 – likely demands:

For forecasted water withdrawals under the likely demand scenario, model simulation results given in Table 7-2 (2030 demands) and Table 7-3 (2040 demands) predict that during a repeat of the worst drought of record, the minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply is 9.2 bg for 2030 demands and 7.4 bg for 2040 demands. The minimum combined storage in Jennings Randolph and Little

Seneca reservoirs is 5.4 bg for 2030 demands and 3.5 bg for 2040 demands. For 2040 likely demands, Jennings Randolph Reservoir minimum water quality storage is zero. Mandatory water use restrictions occur in 0.1 percent of years for 2030 likely demands and 3.4 percent of years for 2040 likely demands. Emergency restrictions are not predicted occur. There are no years with Potomac deficits and system reliability is 100 percent over the 78-year simulation record.

Scenario 2 – high demands:

Model results indicate the current system would have difficulty meeting 2040 demands during a serious drought if the assumptions of the high demand scenario prove to be valid. From Table 7-2 and Table 7-3, the minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply during a repeat of the worst drought of record is 5.7 bg for the 2030 high demand forecast and 2.9 bg for the 2040 forecast, and the minimum combined storage in Jennings Randolph and Little Seneca reservoirs is 3.6 bg for 2030 demands and 0.8 bg for 2040 demands. Also, for this scenario mandatory restrictions are predicted for both the 2030 and 2040 forecasts. Although there are no years with Potomac deficits, emergency water use restrictions and five Occoquan water supply shortfalls are predicted to occur for 2040 high demands.

For the 2040 high demand scenario forecast, minimum storage volumes reported in Table 7-3 for Occoquan Reservoir, and Jennings Randolph Reservoir water supply and water quality storages are near zero or zero. Occoquan storage, which is depended upon to provide water to a portion of the area served by Fairfax Water, was drawn down to near zero during the portion of the simulation representing the drought of 1966. Storage in Jennings Randolph water supply was drawn down to near zero during the portion of the simulation representing the drought of 1930. Storage in Jennings Randolph water quality reached zero in several years of the simulation period. It should be noted that in actual drought operations, options might be found to shift demand away from a reservoir that was in danger of becoming completely depleted. PRRISM only incorporates approximations to system operating rules, and outcomes during actual drought operations would likely be somewhat different. In particular, during drought operations an effort is made to keep storage balanced in the system reservoirs, and PRRISM algorithms cannot completely replicate the decision-making process that would take place under these circumstances.

Also under the 2040 high demand scenario, there were years with Occoquan water supply shortfalls. Model simulations predict that the Occoquan reservoir could not meet minimum Occoquan area served demands for an average of five days, with a maximum of 16 days. An Occoquan water supply shortfall cannot be transferred to the Potomac because of system constraints.

Table 7-2: Results for 2030 demands for Scenario 1 and Scenario 2 forecasts. Results represent an average of the 20 runs over the 78 year simulation period.

	Scenario 1 – likely demands		Scenario 2 – high demands	
	Average	Std. dev.	Average	Std. dev.
Reliability, Vulnerability, Resiliency				
Percentage of years with no Potomac deficits	100.0%	0.0%	100.0%	0.0%
Maximum number of days in a row of Potomac deficits	0	0	0	0
Number of days in which Potomac deficits must be allocated	0	0	0	0
Maximum amount of deficit allocated in a single day, mgd	0	0	0	0
Average amount of deficit allocated, mgd	0.0	0.0	0.0	0.0
Total amount of deficit allocated, mg	0.0	0.0	0.0	0.0
Number of Patuxent water supply shortfalls	0	0	0	0
Number of Occoquan water supply shortfalls	0	0	0	0
Percentage of years with restrictions				
Voluntary restrictions	3.8%	0.0%	3.8%	0.0%
Mandatory restrictions	0.1%	0.4%	2.9%	0.7%
Emergency restrictions	0.0%	0.0%	0.0%	0.0%
Minimum reservoir storage, bg, (percent full of)				
Little Seneca Reservoir	2.0	0.19	1.5	0.24
Jennings Randolph water supply account	3.4	0.46	1.9	0.34
Jennings Randolph water quality account	0.5	0.00	0.5	0.03
Patuxent Reservoir	0.5	0.16	0.2	0.09
Occoquan Reservoir	2.7	0.12	1.0	0.14
Savage Reservoir	0.6	0.01	0.6	0.01
Little Seneca Reservoir and Jennings Randolph water supply account, combined	5.4	0.65	3.6	0.55
Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined	9.2	0.80	5.7	0.65
Miscellaneous				
Number of years in simulation (10/1/1929 – 9/30/2002)	78	0	78	0
Average annual demand drought year (1930, mgd)	599	4	631	4
System mass balance check (mgd)	0	0	0	0
Minimum average flow (mgd)				
Minimum average natural flow summer (1930)	1,148	0	1,148	0
Minimum average natural flow fall (1930)	607	0	607	0
Minimum average summer flow downstream of intakes (1930)	540	6	517	5
Minimum average fall flow downstream of intakes (1930)	194	6	184	4

Table 7-3: Results for year 2040 demands for Scenario 1 and Scenario 2 forecasts. Results represent an average of the 20 runs over the 78 year simulation period.

	Scenario 1 – likely demands		Scenario 2 – high demands	
	Average	Std. dev.	Average	Std. dev.
Reliability, Vulnerability, Resiliency				
Percentage of years with no Potomac deficits	100.0%	0.0%	100.0%	0.0%
Maximum number of days in a row of Potomac deficits	0	0	0	0
Number of days in which Potomac deficits must be allocated	0	0	0	0
Maximum amount of deficit allocated in a single day, mgd	0	0	0	0
Average amount of deficit allocated, mgd	0.0	0.0	0.0	0.0
Total amount of deficit allocated, mg	0.0	0.0	0.0	0.0
Number of Patuxent water supply shortfalls	0	0	0	0
Number of Occoquan water supply shortfalls	0	0	5	5
Percentage of years with restrictions				
Voluntary restrictions	3.8%	0.0%	4.5%	0.7%
Mandatory restrictions	3.4%	0.8%	3.8%	0.0%
Emergency restrictions	0.0%	0.0%	2.3%	1.0%
Minimum reservoir storage, bg, (percent full of)				
Little Seneca Reservoir	1.5	0.27	0.5	0.20
Jennings Randolph water supply account	1.9	0.36	0.1	0.16
Jennings Randolph water quality account	0.0	0.00	0.0	0.00
Patuxent Reservoir	0.4	0.10	0.3	0.15
Occoquan Reservoir	2.9	0.12	0.1	0.11
Savage Reservoir	0.6	0.02	0.5	0.06
Little Seneca Reservoir and Jennings Randolph water supply account, combined	3.5	0.53	0.8	0.26
Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined	7.4	0.61	2.9	0.41
Miscellaneous				
Number of years in simulation (10/1/1929 – 9/30/2002)	78	0	78	0
Average annual demand drought year (1930, mgd)	615	5	656	3
System mass balance check (mgd)	0	0	0	0
Minimum average flow (mgd)				
Minimum average natural flow summer (1930)	1,148	0	1,148	0
Minimum average natural flow fall (1930)	607	0	607	0
Minimum average summer flow downstream of intakes (1930)	521	9	499	8
Minimum average fall flow downstream of intakes (1930)	196	7	191	7

7.4 Sensitivity Tests for Sedimentation Rates

New analyses of storage capacities were done in this study for Jennings Randolph and the two Patuxent reservoirs; these were the only reservoirs for which new data were available. The analyses, discussed in Chapter 6, indicate that sedimentation rates for these reservoirs may have increased in recent years. Four PRRISM simulations were done to evaluate changes in system performance under the assumption that Jennings Randolph and Patuxent reservoir rates are 160 mg/yr and 28 mg/yr, respectively, instead of 127 mg/yr and 24 mg/yr, respectively. Results are given in Table 7-4 and Table 7-5.

The higher reservoir sedimentation rates result in a change in simulated total combined reservoir capacities of approximately -1.2 bg for the 2030 forecast year and -1.6 bg for 2040, relative to the modeled starting storage capacities for Jennings Randolph in 1997 and for the Patuxent reservoirs in 2004. PRRISM results show that changes in predicted minimum combined system storage are not as great, falling from 9.2 to 9.1 bg for the 2030 low demand forecast, and from 5.7 to 5.6 bg for the 2030 high demand forecast. For 2040, predicted minimum system storage drops from 7.4 to 6.8 bg for the low demand forecast, and from 2.9 to 2.7 bg for the 2040 high demand forecast.

Table 7-4: Results of sedimentation sensitivity tests for the 2030 demand forecasts.

	Scenario 1 – likely demands		Scenario 2 – high demands	
Results	**Average**	**Std. dev.**	**Average**	**Std. dev.**
Reliability, Vulnerability, Resiliency				
Percentage of years with no Potomac deficits	100.0%	0.0%	100.0%	0.0%
Maximum number of days in a row of Potomac deficits	0	0	0	0
Number of days in which Potomac deficits must be allocated	0	0	0	0
Maximum amount of deficit allocated in a single day, mgd	0	0	0	0
Average amount of deficit allocated, mgd	0.0	0.0	0.0	0.0
Total amount of deficit allocated, mg	0.0	0.0	0.0	0.0
Number of Patuxent water supply shortfalls	0	0	0	0
Number of Occoquan water supply shortfalls	0	0	0	0
Percentage of years with restrictions				
Voluntary restrictions	3.8%	0.0%	3.8%	0.0%
Mandatory restrictions	0.1%	0.4%	3.3%	0.6%
Emergency restrictions	0.0%	0.0%	0.0%	0.0%
Minimum reservoir storage, bg, (percent full of)				
Little Seneca Reservoir	1.9	0.14	1.5	0.18
Jennings Randolph water supply account	3.2	0.32	1.8	0.41
Jennings Randolph water quality account	0.0	0.00	0.0	0.00
Patuxent Reservoir	0.5	0.15	0.3	0.11
Occoquan Reservoir	2.8	0.14	1.0	0.10
Savage Reservoir	0.6	0.01	0.6	0.01
Little Seneca Reservoir and Jennings Randolph water supply account, combined	5.2	0.45	3.4	0.52
Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined	9.1	0.56	5.6	0.75
Miscellaneous				
Number of years in simulation (10/1/1929 – 9/30/2002)	78	0	78	0
Average annual demand drought year (1930, mgd)	599	5	631	4
System mass balance check (mgd)	0	0	0	0
Minimum average flow				
Minimum average natural flow summer (1930), mgd	1,148	0	1,148	0
Minimum average natural flow fall (1930), mgd	607	0	607	0
Minimum average summer flow downstream of intakes (1930), mgd	542	10	517	6
Minimum average fall flow downstream of intakes (1930), mgd	192	8	184	6

Table 7-5: Results of sedimentation sensitivity tests for the 2040 demand forecasts.

	Scenario 1 – likely demands		Scenario 2 – high demands	
Results	**Average**	**Std. dev.**	**Average**	**Std. dev.**
Reliability, Vulnerability, Resiliency				
Percentage of years with no Potomac deficits	100.0%	0.0%	100.0%	0.0%
Maximum number of days in a row of Potomac deficits	0	0	0	0
Number of days in which Potomac deficits must be allocated	0	0	0	0
Maximum amount of deficit allocated in a single day, mgd	0	0	0	0
Average amount of deficit allocated, mgd	0.0	0.0	0.0	0.0
Total amount of deficit allocated, mg	0.0	0.0	0.0	0.0
Number of Patuxent water supply shortfalls	0	0	0	0
Number of Occoquan water supply shortfalls	0	0	4	4
Percentage of years with restrictions				
Voluntary restrictions	3.8%	0.0%	5.0%	0.4%
Mandatory restrictions	3.7%	0.4%	3.8%	0.0%
Emergency restrictions	0.0%	0.0%	2.2%	1%
Minimum reservoir storage, bg, (percent full of)				
Little Seneca Reservoir	1.5	0.19	0.7	0.26
Jennings Randolph water supply account	1.4	0.35	0.1	0.08
Jennings Randolph water quality account	0.0	0.00	0.0	0.00
Patuxent Reservoir	0.4	0.15	0.3	0.11
Occoquan Reservoir	2.9	0.08	0.1	0.11
Savage Reservoir	0.6	0.04	0.5	0.04
Little Seneca Reservoir and Jennings Randolph water supply account, combined	2.9	0.50	0.8	0.24
Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined	6.8	0.72	2.7	0.49
Miscellaneous				
Number of years in simulation (10/1/1929 – 9/30/2002)	78	0	78	0
Average annual demand drought year (1930, mgd)	615	4	655	4
System mass balance check (mgd)	0	0	0	0
Minimum average flow (mgd)				
Minimum average natural flow summer (1930)	1,148	0	1,148	0
Minimum average natural flow fall (1930)	607	0	607	0
Minimum average summer flow downstream of intakes (1930)	516	9	499	7
Minimum average fall flow downstream of intakes (1930)	197	7	186	6

7.5 Comparison of Results in 2005 and 2010 Studies

PRRISM has undergone numerous updates and enhancements since the 2005WMA water supply study (Kame'enui *et al.*, 2005) was conducted, and some of these changes have had an impact on model results. The most significant changes are listed below, along with "version numbers" to identify the version of PRRISM which incorporates each successive change:

PRRISM 2005.1: Improvements in the simulation of Patuxent and Occoquan reservoir evaporation and direct precipitation, as well as an increased Fairfax Water treatment loss rate.

PRRISM 2005.2: Updates to model representation of Jennings Randolph and Savage reservoir operations to better reflect current Baltimore District COE practices, including:

- Changes resulting from recent recommendations of the North Branch Potomac River Advisory Committee.
- Improvements to model representation of Jennings Randolph Reservoir spills.

PRRISM 2005.3: Updates to the stage storage curves for Jennings Randolph and Savage reservoirs, used to convert elevations to volumes, based on new Baltimore District COE data.

PRRISM 2010: Updates to Jennings Randolph Reservoir sedimentation rate, as discussed in Chapter 6 and to operational rule curves for Occoquan Reservoir.

The effects of these changes are documented in Table 7-6, which compares simulation results for the versions of PRRISM described above with results that appear in the 2005 study. (The model used in the 2005 study is denoted PRRISM 2005.) The first five sets of model results in Table 7-6 are from simulations done with 2025 demands derived in the 2005 study from MWCOG Round 6.4a demographic projections. The last set of results is from the current version of PRRISM, denoted here as PRRISM 2010, with demand forecasts for the year 2030, based on Round 7.2 projections.

Results in Table 7-6 show the effects of the changes made to PRRISM in the past several years on model predictions of system performance. In PRRISM 2005.1, predicted minimum storage in the Patuxent and Occoquan reservoirs decreases due to more conservative assumptions concerning direct precipitation and evaporation, but minimum combined Little Seneca and Jennings Randolph water supply storage increases. Changes in North Branch reservoir operations, implemented in PRRISM 2005.2, had a mixed effect on minimum reservoir storages, with only a minor decrease in overall minimum water supply storage for the likely demand Scenario 1, but a more significant drop in storage for the high demand Scenario 2. Results from PRRISM 2005.3 reflect the decreases in estimated Jennings Randolph storage capacity discussed in Section 6.4. The last two sets of runs in Table 7-6 were done using PRRISM 2010, which incorporates the final change made to the model – the increase in the sedimentation rate for Jennings Randolph Reservoir and updated operational rule curves for Occoquan Reservoir. The final set of model runs uses PRRISM 2010 with this study's newly calculated demands, for the year 2030, and using the extended 78 year historical record. The decreases in minimum reservoir storages between these last two sets of runs are primarily due to the increase in forecasted demands. In the case of Occoquan, the new operational rule curves are able to conserve more storage over a longer forecast period compared to the 2005 runs. For example, the 2010 operational rule curves do not allow Occoquan storage to drop to 0.9 bg until forecast year 2030; whereas the 2005 operational rule curves allow Occoquan storage to drop to 0.9 bg for forecast year 2025. The 2005 study forecast total demand for the WMA water suppliers to be 572 mgd in 2025 for the likely growth scenario, and the current study forecasts total WMA demand to be 588 in 2030 for Scenario 1.

Table 7-6: Comparable simulations documenting effects of model changes (single runs using same sets of random numbers).

Measure	PRRISM 2005 2005 Report, based on Round 6.4a		PRRISM 2005.1 2025 demands based on Round 6.4a		PRRISM 2005.2 2025 demands based on Round 6.4a		PRRISM 2005.3 2025 demands based on Round 6.4a		PRRISM 2010 2025 demands based on Round 6.4a		PRRISM 2010 2030 demands based on Round 7.2	
	Scenario 1 forecast	Scenario 2 forecast	Scenario 1 forecast	Scenario 2 forecast	Scenario 1 forecast	Scenario 2 forecast	Scenario 1 forecast	Scenario 2 forecast	Scenario 1 forecast	Scenario 2 forecast	Scenario 1 forecast	Scenario 2 forecast
% years with no Potomac deficits	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Max. no. days in a row of Pot. deficits	0	0	0	0	0	0	0	0	0	0	0	0
No. days when Pot. deficits allocated	0	0	0	0	0	0	0	0	0	0	0	0
Max. deficit allocated in a 1 day, mgd	0	0	0	0	0	0	0	0	0	0	0	0
Ave. deficit allocated, mgd	0	0	0	0	0	0	0	0	0	0	0	0
Tot. deficit allocated, mg	0	0	0	0	0	0	0	0	0	0	0	0
No. Patuxent WS shortfalls	0	0	0	0	0	0	0	0	0	0	0	0
No. Occoquan WS shortfalls	0	0	0	0	0	0	0	0	0	0	0	0
% years with voluntary restrictions	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	5.5%	3.8%	3.8%
% years with mandatory restrictions	0%	0%	0%	0%	0%	1.4%	0%	1.4%	0%	4.1%	0%	1.3%
% years with emergency restrictions	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Min. reservoir storage, bg (% full): L Seneca	2.7	2.6	2.3	1.9	2.4	2.0	2.3	1.9	2.3	2.1	1.9	1.6
Min. reservoir storage, bg (% full): JR WS	4.6	3.3	5.8	4.3	6.1	3.0	5.7	2.8	3.4	1.4	3.8	2.4
Min. reservoir storage, bg (% full): JR WQ	1.5	1.3	1.1	1.1	1.6	1.7	2.2	2.2	0.9	0.9	0.5	0.5
Min. reservoir storage, bg (% full): Patuxent	2	1.8	1.5	1.2	1.1	0.9	1.1	0.9	0.6	0.4	0.4	0.2
Min. reservoir storage, bg (% full): Occoquan	1.6	1.6	1.1	1.1	1.1	0.9	1.1	0.9	2.9	2.9	2.7	0.9
Min. reservoir storage, bg (% full): Savage	0.7	0.7	0.6	0.4	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6
L Seneca & JR WS, combined	7.4	6.0	8.1	6.3	8.5	4.9	8.1	4.7	5.7	3.6	5.8	4.1
Patuxent, Occoquan, and L Seneca & JR WS, combined	12	10.3	11.5	9.2	11.1	7.0	10.7	6.7	10.0	7.2	9.6	6.1
No. years in simulation	73	73	73	73	73	73	73	73	73	73	78	78
Ave. annual demand drought year	587	623	587	626	587	624	587	624	588	622	599	634
Min. ave. natural flow summer	1141	1141	1148	1148	1148	1148	1148	1148	1148	1148	1148	1148
Min. ave. natural flow fall	606	606	607	607	607	607	607	607	607	607	607	607
Min. ave. summer flow downstr. of intakes	567	550	561	529	579	545	579	545	562	535	549	524
Min. ave. fall flow downstr. of intakes	245	220	240	209	209	196	208	195	197	189	198	185

8 Summary of Water Supply Alternatives

This chapter describes four potential alternatives for increasing water supply for the WMA. The alternatives are:

- Intake/pumping station on the Potomac estuary near head-of-tide below Little Falls, with discharge to Washington Aqueduct's Dalecarlia Reservoir
- Reverse osmosis membrane treatment plant on the Occoquan estuary
- Use of two quarries located in Fairfax County to augment Fairfax Water storage
- Use of Loudoun County quarries to augment system storage, serving as pumped storage reservoirs

Descriptions of the first three alternatives were derived from summaries provided by Fairfax Water of studies completed between March 2003 and March 2005 (CDM, 2002; 2003; 2004; 2005). The objective of these studies was to evaluate and assess the water supply benefits of new sources of supply to Fairfax Water and the WMA. These past studies included evaluations of water quality, water treatment, transmission, and permitting issues, evaluations of cost-effectiveness[1], and the results of analyses of alternatives done by ICPRB using older versions of PRRISM. The first steps necessary to implement the fourth alternative, use of Loudoun County quarries, are currently being taken by Loudoun Water, which is working to secure future use of several quarries. The description of this alternative is based on information provided by Loudoun Water.

8.1 Potomac Estuary Intake/Pumping Station Below Little Falls, with Discharge to Dalecarlia Reservoir

The consideration of the Potomac estuary as a water supply source for the WMA has a long history (Jaworski *et al.*, 1971). The free-flowing Potomac River discharges into the Potomac estuary approximately a mile and a half below the Little Falls dam. The location of the head of tide varies with tidal conditions but is located in the vicinity of Chain Bridge. Water in this portion of the Potomac estuary has been determined to be essentially fresh, even under drought conditions. Thus, the estuary is a potential source of water that can be withdrawn without reducing flows between Great Falls and Little Falls, or between Little Falls and the head-of-tide, the two portions of the river subject to environmental flow recommendations.

[1]Conceptual construction cost estimates were updated by Fairfax Water to reflect February 2009 costs and were calculated by multiplying the original conceptual cost estimate by the ratio of the Engineering News Record (ENR) Construction Cost Index (CCI) value in Feburary 2009 divided by the CCI index at the completion of the study.

A Potomac estuary water supply intake/pumping station and transmission system was constructed near Chain Bridge and the Washington Aqueduct's Dalecarlia Treatment Facility in the late 1970s. A study for Fairfax Water completed in 2005 (CDM, 2005) evaluated options for re-establishing these existing facilities, which were designed for a 100 mgd capacity and were never used for water supply purposes following construction completion. This study included an evaluation of estuary water quality using the Water Quality Analysis Simulation Program (WASP) model to simulate drought conditions and the impact of Combined Sewer Overflows (CSO) event discharges. A condition assessment of the intake and transmission system was conducted. The study presented options for reinstatement of the estuary pumping station and transmission system, permitting requirements, and evaluated the cost-effectiveness of this supply compared with other water supply options. The preferred option was identified as the construction of a new raw water pumping station adjacent to the existing Hydro Plant (an abandoned 80-year old building that has been renovated as a historic structure), rock tunneling of a new inlet and transmission pipe to the sediment forebay at Washington Aqueduct’s Dalecarlia Reservoir, and re-use of the existing intake structure.

A review of water quality data for the estuary and the Aqueduct’s existing raw water supply indicates that there is very little difference between the two sources. As a result, conventional treatment may be utilized. Simulated CSO tracer concentrations using the WASP model indicated that CSO discharges should not pose a risk to the water supply. The construction cost ($0.46 to $0.92 million per mgd) and annualized unit costs ($0.11- $0.21 per thousand gallons) for the Potomac estuary water supply are significantly less than Occoquan estuary and other options previously considered for the WMA. The CDM report concluded that a 100 mgd system is the preferred supply option because of the increased yield, ease of operations and maintenance, and facility security. The cost effectiveness of the estuary supply is increased under an alternative considered in the original evaluation of alternatives by ICPRB for the 2005 CDM study, a “variable” flow-by between Great Falls and Little Falls.

8.2 Occoquan Estuary Membrane Treatment Plant

Another estuarine water supply alternative for the WMA has been considered. In a study completed for Fairfax Water in 2004, conceptual design information was developed for facilities required for the use of the Occoquan River estuary as a water supply. The study (CDM, 2004) provided an evaluation of the costs and benefits associated with the use of this source and includes a delineation of a proposed location, sizing information for the estuary intake structure and raw water piping, determination of treatment requirements based on various withdrawal rates, estimation of the cost associated with those facilities, and a review of permitting issues associated with an estuary water supply. Finished water production capacities of 25 and 50 mgd were evaluated. During drought periods, a reverse-osmosis (RO) membrane treatment plant would be required to treat the brackish estuary water supply, which can reach 2,500 mg/L total dissolved solids (TDS) levels in Occoquan Bay. The construction cost for the estuary treatment facilities is estimated to be $69,000,000 for a 25 mgd capacity plant and $120,000,000 for a 50 mgd capacity plant, or $2.4 to $2.76 million per mgd. Unit costs for the estuary water supply are $1.18 to $1.45 per thousand gallons for the most effective regional operating rules.

8.3 Use of Lorton Quarries as Supplemental Water Supply Sources

A third alternative that has been considered is the use of two quarries located near Fairfax Water's Occoquan Reservoir as supplemental water supply sources, the Lorton Quarry and the Vulcan Quarry. The Lorton Quarry is owned by Fairfax Water and is currently used for solids disposal. The Vulcan Quarry is also located near Fairfax Water's Griffith water treatment plant. A facility needs assessments was done for Fairfax Water, along with an evaluation of benefits and costs associated with potential water supply uses of the two quarries.

Fairfax Water's study of the quarries (CDM, 2003) covers the following topics concerning Lorton Quarry: an evaluation of how the quarry can be used as supplemental or emergency supply for the future Griffith treatment facilities; an evaluation of the pumping facilities required to use the quarry as a water supply; identification of water quality issues and treatment requirements; and a comparison of the costs and benefits of using the quarry for solids disposal or for supplemental water supply uses.

The study evaluated the use of Lorton Quarry as a 10-day emergency supply, a 100-day drought supply, or as a recycling facility. The yield for these options ranges from 1.6 to 5.6 mgd, although a 10-day emergency supply could provide as much as 38 mgd. The Lorton Quarry, if it were also continued to be used for solids disposal, would have a useful life of 20 or 21 years, or through 2030-2031, before the solids level reached the water supply intake structure. The construction cost for this facility would be \$0.43 to \$2.68 million per mgd. Unit costs would be \$0.31 to \$0.64 per thousand gallons.

For the Vulcan Quarry, Fairfax Water's study evaluated the water supply benefits of its use as a pumped storage reservoir following the termination of mining activities, facility requirements for pumped storage uses of the quarry, and projected costs for water supply storage volumes ranging from 3 to 7 bg. Evaluations of the benefits of the Vulcan Quarry done using an earlier version of PRRISM determined that it would provide a safe yield of 16 mgd to 28 mgd, based on a 3 bg to 7 bg storage capacity. The construction costs would be \$1.44 to \$2.5 million per mgd, with a unit cost of \$0.29 to \$0.50 per thousand gallons.

8.4 Loudoun Water Quarries as Supplemental Water Supply Sources

A fourth alternative is the use of four mined rock quarries located within Loudoun County for water storage to supplement the upstream raw water storage volume in the Potomac Basin. It is anticipated that storage space in retired quarries will become available at several locations at times dependent on the pace of future mining activities. While the Potomac River is adjacent to property owned by Loudoun Water, Loudoun Water regards the Potomac as wholly allocated during low flow periods, and agency personnel have said that Loudoun Water does not want to be in competition with the downstream WMA water suppliers during droughts (Presentation at ICPRB Business Meeting, T. Coughlin, Loudoun Water, 9/13/2004). To this end, Loudoun Water has examined the feasibility of using the four quarries as raw water supply alternatives to meet their growth in demand, rather than using the Potomac River during low flow periods. As part of the chosen option in Loudoun Water's Central Water Supply Plan (Black & Veatch, 2008), use of these quarries would be implemented along with a new off-river water treatment plant.

The four quarries are expected to be developed and utilized over time. Quarry A, with a projected volume of 1.13 bg and a usable volume of 1.02 bg, is expected to be available for water storage starting sometime between 2017 and 2020. Quarry A will be used exclusively by Loudoun Water for supply to the proposed Loudoun Water Treatment Plant during periods of low flow in the Potomac River. Other quarries are expected to be retired and available for Loudoun Water storage and potentially available for Potomac River augmentation and potential downstream use during the second phase of Loudoun Water's plan. Quarry C may become available sometime between 2030 and 2035, with a projected volume of 4.16 bg and a usable volume of 3.75 bg. Quarry B may become available by 2050 with a usable storage volume of 5.83 bg. Quarry D is a future quarry operation.

On March 18, 2009, Loudoun Water purchased additional land for the water treatment facility. The new Loudoun Water Treatment Plant will be implemented in two phases of 20 mgd capacity to match increases in projected demands and to defer a portion of the capital cost. The production capacity of the proposed plant is 20 mgd in 2016, increasing to 40 mgd in approximately 2035. The respective construction costs for the first and second phases of the facility are $214 million and $66 million.

A detailed evaluation of the benefits to the WMA system of the Loudoun County quarry alternative, including comparisons with the other three water supply alternatives described above, will likely be addressed in a future study.

9 Conclusions

The WMA's current water supply system is approximately 30 years old. The resource analysis done for this study indicates that the system will continue to be reliable over the 20-year forecast period, to the year 2030, under a range of hydrologic conditions similar to the 78-year period of historical record, with no years experiencing Potomac deficits, and with 100 percent system reliability. However, by the year 2040, taking into consideration the uncertainty in future demand forecasts, the current system may have difficulty meeting the region's water demands during periods of drought.

This study provides forecasts for two demand scenarios in order to take into account the uncertainties in both demographic forecasts and in predictions of future water use behavior. Forecasts are computed for a likely demand scenario, Scenario 1, which is most consistent with recent studies and based on MWCOG Round 7.2 growth forecasts. Forecasts are also computed for a higher demand scenario, Scenario 2, with: 1) additional preliminary estimates of water demand due to potential development in Fairfax County not considered in Round 7.2, and 2) no unit use reductions over the forecast period for single family households, assuming that decreases in water use from indoor low-flow fixtures and appliances will be offset by increases in summertime outdoor water use.

Average annual demand in the WMA, including Rockville, is estimated to be approximately 503 mgd in year 2010 under Scenario 1, or 515 mgd for Scenario 2, and this is projected to increase to 593 mgd (18 percent) in 2030 under the assumptions of Scenario 1, or 632 mgd (26 percent) for Scenario 2. By the year 2040, WMA demand is forecast to increase to 617 mgd (23 percent) for Scenario 1, or 671 mgd (30 percent) for Scenario 2.

When forecasted demands are compared with results from past studies by ICPRB and other organizations, it is clear that demand forecasts have consistently fallen over time. Throughout most of the past four decades, population has continued to grow in the WMA, but unit use values have fallen. However, current results indicate that these decreasing trends in unit use may be leveling off. Unit use values have remained relatively constant throughout the past decade, with the exception of values for multi-family households, which continue to decrease.

PRRISM model runs indicate the current system would have difficulty supplying demands in 2040 during periods of severe drought if the assumptions of the high demand scenario prove to be valid. The minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph reservoirs during a repeat of the worst drought of record is predicted to be 2.9 bg for the 2040 high demand forecast, and the minimum combined storage in Jennings Randolph and Little Seneca reservoirs is 0.8 bg. Also, the possibility of mandatory and emergency water use restrictions and Occoquan Reservoir water supply shortfalls are predicted for the 2040 high forecasts.

A number of other issues potentially affecting the WMA system are identified in this study. Summertime outdoor water use may be increasing in some areas of the WMA, offsetting the benefits of more water efficient indoor fixtures and appliances. This was evidenced by a slight upward trend in August production factors for Fairfax Water, first identified in the 2000 WMA water supply study (Hagen and Steiner, 2000), and a slight increasing trend in WSSC unit use values for single family households. Also, increasing sedimentation in system reservoirs may be occurring. Jennings Randolph Reservoir appears to be losing storage capacity due to sedimentation occurring at a higher rate than was estimated in the past. Recent data indicates that sedimentation rates for both Jennings Randolph and the Patuxent reservoirs may be higher in more recent years.

Based on these conclusions, the following recommendations are suggested for future consideration:

1. Completion of the evaluation of water supply alternatives to determine the most beneficial and cost-effective resources to meet future demands, including an improved methodology for optimizing existing and potential water supply resources.
2. A new hydrographic survey to measure current storage capacity of Jennings Randolph Reservoir. New surveys of Savage Reservoir and Little Seneca Reservoir may also be warranted.
3. Consideration of new watershed protection efforts to reduce loss of storage in system reservoirs, potentially under the auspices of the Potomac River Basin Drinking Water Source Protection Partnership.
4. Investigation in the next WMA water supply study of changes and impacts of summertime outdoor water use.

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Appendix A Production Data

Table A-1: Production Data for Washington Aqueduct

	2005	2006	2007	2008	Average
Average annual production, mgd	164	159	165	158	161
Monthly average production, mgd					
January	155	143	137	150	146
February	159	149	160	146	154
March	148	151	150	144	148
April	156	151	150	146	151
May	153	157	170	153	158
June	176	169	184	168	174
July	187	183	191	184	186
August	179	193	192	179	186
September	181	159	178	169	172
October	161	154	170	156	160
November	155	150	152	146	151
December	154	148	145	150	149
Peak 1-day production, mgd					
January	193	167	158	175	173
February	190	187	187	161	181
March	179	195	167	159	175
April	176	170	181	185	178
May	176	188	206	184	189
June	202	192	209	202	201
July	219	220	224	202	217
August	205	224	232	220	221
September	197	182	201	204	196
October	185	182	192	177	184
November	178	171	165	159	168
December	197	210	217	209	208
Maximum 1-day production, mgd	219	224	232	220	224

Table A-2: Production Data for Fairfax Water

	2005	2006	2007	2008	Average
Average annual production, mgd	152	159	167	145	156
Monthly average production, mgd					
January	127	132	132	131	130
February	123	129	128	122	126
March	126	134	127	121	127
April	140	147	137	134	140
May	153	170	183	145	163
June	180	192	207	167	186
July	175	189	221	176	190
August	184	220	210	191	201
September	197	164	204	158	181
October	154	149	175	144	156
November	135	137	139	124	134
December	133	136	132	122	131
Peak 1-day production, mgd					
January	142	141	139	141	141
February	137	139	140	130	136
March	137	146	137	131	138
April	159	165	168	151	161
May	174	223	225	172	199
June	219	239	239	198	224
July	201	240	255	207	226
August	212	250	251	214	232
September	222	182	235	193	208
October	218	168	211	169	191
November	143	145	158	136	146
December	143	156	144	130	143
Maximum 1-day production, mgd	222	250	255	214	235

Table A-3: Production Data for Washington Suburban Sanitary Commission

	2005	2006	2007	2008	Average
Average annual production, mgd	172	169	172	163	169
Monthly average production, mgd					
January	161	156	150	154	155
February	162	156	163	152	158
March	161	157	156	151	156
April	165	163	158	154	160
May	173	175	183	162	173
June	188	185	189	177	185
July	184	187	202	178	187
August	187	205	194	185	193
September	192	171	188	173	181
October	170	165	174	161	168
November	161	156	155	154	157
December	160	153	156	151	155
Peak 1-day production, mgd					
January	187	178	163	169	174
February	173	165	181	165	171
March	176	170	168	168	170
April	182	181	178	167	177
May	188	221	212	193	204
June	226	219	222	251	230
July	202	219	223	197	210
August	203	225	219	213	215
September	213	186	213	193	201
October	204	181	195	177	189
November	188	166	169	172	174
December	177	167	178	189	178
Maximum 1-day production, mgd	226	225	223	251	231

Table A-4: Total Production Data for the CO-OP Water Suppliers

	2005	2006	2007	2008	Average
Average annual production, mgd	488	487	504	465	486
Monthly average production, mgd					
January	443	431	419	435	432
February	444	434	451	420	437
March	435	442	433	416	432
April	461	461	445	434	450
May	479	502	536	460	494
June	544	545	580	512	545
July	546	558	614	539	564
August	550	618	596	554	580
September	569	494	570	500	533
October	485	468	518	461	483
November	450	443	446	424	441
December	447	436	433	423	435
Peak 1-day production, mgd					
January	488	449	452	464	463
February	485	465	472	442	466
March	463	494	450	444	463
April	513	497	503	488	500
May	534	612	638	519	576
June	630	624	656	591	625
July	600	661	695	603	640
August	611	696	686	620	653
September	595	535	628	580	584
October	587	531	586	508	553
November	485	474	492	458	477
December	491	489	503	480	491
Maximum 1-day production, mgd	630	696	695	620	660

Appendix B Calculation of Unit Use Factors for Each Supplier

B1 Introduction

This section provides detailed documentation of the calculation of the unit use factors. Unit use factors were determined for single family and multi-family households and for employees, which contains commercial, municipal, and any other use of water, for each of the region's water suppliers. This section also includes information on data sources and summaries of billing records, as well as the method used for calculating unmetered water use. Other relevant notes are included as needed in regard to data availability and calculations.

Due to limited data availability, some unit use figures are assumed for specific utility customer classes using professional judgment. These instances are noted for each occurrence below. These estimates are a result of limited disaggregation of water use data by service providers and therefore could not be avoided.

B2 Data Sources

The study authors thank all those who helped to provide data for this report. Many of those who provided data are mentioned below. We thank these individuals as well as those who we may have neglected to mention. Without the support of many, this report would not have been possible.

B2.1 Water Data

The following employees of the water providers were invaluable to the data collection process by which the unit use factors were calculated:

Arlington Department of Environmental Services: Dave Hundelt, Barbara Forbes, Elizabeth Craig

DCWASA: Charles Kiely, Syed Khalil

Fairfax Water: Greg Prelewicz

Falls Church: Mary Ann Burke, Rodney Collins

Loudoun Water: Thomas Lipinski, Thomas Bonacquisti

Prince William County Service Authority: Beau Caire

City of Rockville DPW: Susan Strauss, Ilene Lish

City of Rockville Finance Department: Jason Zimmerman

Town of Herndon: Salah Jaro

Vienna: Marion Serfass

Virginia American: Jim Downs, Michael Youshock

WSSC: Tim Hirrel, Roland Steiner

B2.2 Demographic and Service Area Mapping Data

The following persons were invaluable to the data collection process by which the service areas were compiled:

Arlington County, Department of Community Planning, Housing & Development: Angie de la Barrera, Elizabeth Rodgers

City of Alexandria, Department of Planning and Zoning: Ralph Rosenbaum

City of Rockville, Community Planning and Development Services: Mayra Bayonet, Manisha Tewari

District of Columbia: Kimberly Driggins, Joy Phillips, Art Rodgers

Fairfax County: Fatima Khaja (Dept.of Planning & Zoning), Sterling Wheeler

Fairfax Water: Greg Prelewicz, Traci Kammer Goldberg

Falls Church Planning Division: Rodney Collins

Town of Herndon, Department of Community Development: Dana Heiberg

Loudoun County, Department of Management and Financial Services: Jill Allmon

Loudoun Water: Thomas Lipinski, Craig Lees

Maryland National Capital Park and Planning Commission: Wayne Koempel (Montgomery County, Research & Technology Center), Patrick Callahan (Prince George's County), Jacquelin Philson (Prince George's County), Joseph Valenza (Prince George's County)

Metropolitan Washington Council of Governments: Paul DesJardin, Greg Goodwin

Prince William County: Frank Hunt (Planning Office), David McGettigan

Prince William County Service Authority: Beau Caire

Town of Herndon: Salah Jaro

Town of Vienna, Planning and Zoning Department: Julie Morris

WSSC: Pedro Flores, Roland Steiner

B3 Fairfax Water

B3.1 Service Area

The current areas served map provided by Fairfax Water is the extent of the water main under current conditions. According to Fairfax Water, the general boundaries of the area served may grow only modestly at the margin and are not anticipated to change in a way that would materially impact the twenty-year water demand forecast for the WMA. In particular, Fairfax Water does not anticipate significant demand growth in areas that are not currently served by public water systems (Traci Goldberg, personal communication, February 10, 2009). This assumption was verified by Fairfax County, which indicated the areas served in the county were not likely to expand because they plan to remain low density and are not on a sewer system (Sterling Wheeler, personal communication, May 26, 2009).

B3.2 Billing Records

Fairfax Water provided billing records for both its retail and wholesale customers by year for 2005 through 2008 (Table B-1). Retail billing categories are disaggregated into single family households, townhouses, apartments, commercial, municipal, and hydrants. For this study's purposes, the single family households and townhouses were combined for the single family use category and commercial and municipal categories were combined for the employee use category. The water in the hydrant category was not combined into another use category, but was accounted for in the unmetered use calculation. In addition to its retail customers, Fairfax Water supplies water to a number of wholesale customers, including Prince William County Service Authority, Virginia American (serving the City of Alexandria and Dale City), Loudoun Water, Town of Herndon, Fort Belvoir, and MWAA Dulles International Airport. An analysis of their water use follows this section.

Table B-1: Consumption (millions of gallons per day) by customer category for Fairfax Water – retail customers.

	Single Family	Multi-Family	Employee	Total
2005	46	13	17	76
2006	47	13	18	78
2007	51	13	19	83
2008	45	13	18	76

B3.3 Unmetered Water Use

According to Fairfax Water billing records it billed approximately 76 mgd to retail customers in 2008. The amount of water sold to all wholesale customers was on average 62 mgd in 2008, for a total of 138 mgd sold to retail and wholesale customers. Fairfax Water also sells and purchases a small amount of water from other suppliers in the area to satisfy interchange agreements. In 2008, Fairfax Water produced on average 145 mgd at the Occoquan and Corbalis water treatment plants. The difference between water produced and billed water consumption is calculated as unmetered water use. In 2008, this difference was 7 mgd or 5 percent of the water produced (Table B-2).

Table B-2: Summary of water purchased and billed (millions of gallons per day) for Fairfax Water – retail and wholesale customers.

	Produced	Purchased	Billed – Retail, Wholesale, Other	Unmetered	Percent Unmetered
2005	152.372	0.216	144.850	8	6%
2006	158.508	0.062	147.339	12	7%
2007	166.524	0.150	155.214	11	7%
2008	144.685	0.279	139.514	7	5%

B3.4 Determination of Single and Multi-family Unit Use Factors

In 2008, Fairfax Water billed approximately 45 mgd to the single family household water use category (this includes the townhouse category) and 13 mgd to the multi-family household category. The number of 2008 households in the Fairfax Water's retail area served was 303,604 as based on the ICPRB analysis using a GIS overlay of Fairfax Water's retail area served with household data by traffic analysis zone, extracting the 2005 and 2010 household data and interpolating for 2008. Applying the 2008 dwelling unit ratio in Fairfax Water's service area of 2.89 (number of single family residences divided by number of multi-family residences) to the total number of households in the areas served by Fairfax Water yields 225,563 single family households and 78,041 multi-family households. Therefore, the unit use factor for single family households was 199.9 gallons per day (45 mgd divided by 303,604 single family households) and 165.6 gallons per day for multi-family households (13 mgd divided by 78,041 multi-family households in 2008) (Table B-3).

B3.5 Determination of Employee Unit Use Factors

Fairfax Water reports that approximately 18 mgd of water was consumed by employee category (commercial and municipal) in 2008. The number of 2008 employees in the Fairfax Water area served is 439,043 as based on the ICPRB analysis using a GIS overlay of Fairfax Water's area served with employment information by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. The per employee daily water use is thus calculated as 40.0 gallons per day (Table B-3).

Table B-3: Dwelling unit ratio and unit use (gallons per day) by customer category for Fairfax Water - retail.

	2005	2006	2007	2008
Households	298,126	299,952	301,778	303,604
Dwelling unit ratio	2.93	2.92	2.90	2.89
Single family	222,349	223,434	224,399	225,563
Multi-family	75,777	76,518	77,379	78,041
Employment	412,577	421,399	430,221	439,043
Unit use (gpd)				
Single family	206.4	211.2	227.6	199.9
Multi-family	170.0	167.5	167.8	165.6
Employee	41.8	42.3	44.4	40.0

B4 Fairfax Water - Prince William County Service Authority (PWCSA)

B4.1 Service Area

According to PWCSA, growth in Prince William County will occur mainly in the Haymarket, Gainesville-Wellington, Lake Ridge, Hoadly, and Oak Ridge areas (Beau Caire, personal communication, April 2, 2009). Redevelopment of Woodbridge and Dumfries-Triangle is also expected. Prince William County is promoting mixed use areas to concentrate development in specified areas.

B4.2 Billing Records

PWCSA provided information on water pumped or conveyed through metering stations from January 2002 through August 2008 (Table B-4). This information was used as a proxy for customer billing information which was not available. A categorical breakdown of water use by customer category was, likewise, not available. Figures for 2007 are reported here and were used in the analysis, as they constitute the last complete year of data. While these numbers are a good approximation of consumption, they also include water used for system flushing and fire use (Beau Caire, personal communication, February 19, 2009).

B4.3 Unmetered Water Use

PWCSA relies on water from Fairfax Water and the City of Manassas, in addition to some water drawn from wells to meet its demands (Beau Caire, personal communication, February 19, 2009). Purchasing records available from Fairfax Water indicate that on average in 2007, PWSCA purchased 23.64 mgd. Typically, PWSCA purchases between 2 and 5 mgd from the City of Manassas each year as well (Beau Caire, personal communication, February 19, 2009). In 2007, 2.99 mgd were purchased on average. PWCSA has 5 mgd capacity rights with the City of Manassas, but usage depends on water quality during the summer months (Beau Caire, personal communication, February 19, 2009). In 2007, the last complete year of data, PWCSA reported that 28.03 mgd was conveyed to customers and that a total of 26.63 mgd was purchased from Fairfax Water and the City of Manassas. These numbers indicate that more water is being sent to customers than is purchased or is pumped from wells. This discrepancy could be due to inaccuracies at pumping station and purchasing meters (Beau Caire, personal communication, April 2, 2009).

Table B-4: Summary of water purchased and billed (millions of gallons per day) for PWCSA.

	Purchased	Pumped	Unmetered	Percent Unmetered
2004	20.27	20.29	-0.02	-0.10%
2005	23.72	24.09	-0.37	-1.56%
2006	23.77	25.91	-2.14	-9.00%
2007	26.63	28.03	-1.4	-5.26%

B4.4 Determination of Single and Multi-family Unit Use Factors

The number of 2007 households in the area served by PWCSA is 86,649, as based on the ICPRB analysis using a GIS overlay of PWCSA's area served with household data by traffic analysis zone, extracting the 2005 and 2010 household data and interpolating for 2007. Applying the dwelling unit ratio of 3.97 in the area served (number of single family residences divided by number of multi-family residences) to the number of 2007 households yields 69,215 single family households and 17,434 multi-family households.

The unit use factor for PWCSA's multi-family households was assumed to be equal to that of Loudoun Water's, 203.0 gallons per day. Applying Loudoun Water's multi-family unit use factor to the number of multi-family households yields a total water use of 3.539 mgd. The single family unit use factor was calculated by subtracting the total amount used by multi-family households and employees from the total pumped in 2007, divided by the number of employees. This yields a single family unit use factor of 290.0 gallons per day (Table B-5).

B4.5 Determination of Employee Unit Use Factors

Loudoun Water's employee unit use factor (54.5 gpd) was assumed for PWCSA. The number of 2007 employees in the PWSCA service area was 81,100 as based on the ICPRB analysis using a GIS overlay of PWCSA's service area with employment data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2007. Assuming per employee daily water use is 54.5 gallons, the daily demand for PWCSA employees in 2007 was 3.54 mgd.

Table B-5: Dwelling unit ratio and unit use (gallons per day) by customer category for PWCSA.

	2005	2006	2007
Households	81,006	83,828	86,649
Dwelling unit ratio	4.03	4.00	3.97
Single family	64,901	67,062	69,215
Multi-family	16,105	16,766	17,434
Employment	78,005	79,553	81,100
Unit use (gpd)			
Single family	270.8	277.3	290.0
Multi-family	173.8	188.9	203.0
Employee	47.6	52.1	54.5

B5 Fairfax Water - Virginia American – City of Alexandria

B5.1 Service Area

Virginia American does not have a map of the area they serve in the City of Alexandria; it is assumed that the entire city receives water from them.

B5.2 Billing Records

Billing data were available by calendar year from 2005 to 2007 (Table B-6). Values for 2007 are reported here. Virginia American uses residential, commercial, industrial, fire/special, and other for its water use billing categories. Virginia American's residential water use category includes single family homes and duplexes with one meter per occupant (Jim Downs, personal communication, February 13, 2009). This category was used for this study's single family use category. The commercial category includes apartment buildings, businesses, and other commercial water uses. This category usually covers units with two meters per structure (Jim Downs, personal communication, February 13, 2009). The industrial category encompasses high-volume production facilities with multiple water feeds. Virginia American's "other" category includes water sold to municipal government facilities. Given the structure of the billing categories, separate multi-family household and employee figures could not be parsed out.

Table B-6: Consumption (millions of gallons per day) by customer category for City of Alexandria.

	Single Family	Multi-family/Employee	Total
2005	3.49	11.99	15.48
2006	3.75	11.33	15.08
2007	3.93	11.45	15.38

B5.3 Unmetered Water Use

In 2007, Virginia American purchased on average 16.71 mgd from Fairfax Water. In the same year, Virginia American billed 15.38 mgd to customers in the City of Alexandria. The resultant unmetered water in 2007 was 1.33 mgd or approximately 7.95 percent (Table B-7).

Table B-7: Summary of water purchased and billed (millions of gallons per day) for City of Alexandria.

	Purchased	Billed	Unmetered	Percent Unmetered
2005	18.15	15.48	2.66	14.68%
2006	18.21	15.08	3.13	17.19%
2007	16.71	15.38	1.33	7.95%

B5.4 Determination of Single Family Unit Use Factor

During 2007, 3.93 mgd were billed to single family households. The number of 2007 households in the area served by Virginia American in Alexandria is 67,976 as based on the ICPRB analysis using a GIS overlay of the area they serve with household data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2007. Applying the dwelling unit ratio in the city of 0.46 (number of single family residences divided by number of multi-family residences) to the number of 2007 households in the Virginia American service area yields 21,417 single family households and 46,559 multi-family households. The single-family water use factor was thus 183.4 gpd (Table B-8).

B5.5 Determination of Multi-family and Employee Unit Use Factor

Given Virginia American's billing categories, the amount of water billed to multi-family households and to employees could not be broken out in the same way as done for other utilities. A total of 11.45 mgd was billed to the commercial, industrial, and "other" categories in 2007. In order to calculate an approximate daily use amount for both multi-family and employee use, Fairfax Water's unit use factor for employee demand was assumed. The Fairfax Water's 2007 employee unit use factor was 44.4 GPD. The number of 2007 employees in the Alexandria service area was 107,136 as based on the ICPRB analysis using a GIS overlay of Alexandria's service area with employment data by traffic analysis zone. Applying the Fairfax Water employee unit use factor to the number of employees yields a total water use of 4.760 mgd. Subtracting this approximation of employee water use from Alexandria's total annual commercial, industrial, and "other" use, yields 6.694 mgd assumed for the multi-family category. Given 46,559 multi-family households in the area served by Virginia American as calculated above, a multi-family unit use factor of 143.8 gallons per household per day was derived (Table B-8).

Table B-8: Dwelling unit ratio and unit use (gallons per day) by customer category for City of Alexandria.

	2005	2006	2007
Households	66,337	67,156	67,976
Dwelling unit ratio	0.47	0.46	0.46
Single family	21,210	21,159	21,417
Multi-family	45,127	45,997	46,559
Employment	105,821	106,479	107,136
Unit use (gpd)			
Single family	164.7	177.0	183.4
Multi-family	167.8	148.4	143.8
Employee	41.8	42.3	44.4

B6 Fairfax Water - Virginia American – Dale City

B6.1 Service Area

Virginia American does not have a map of the area they serve; it is assumed that the entire city receives water from them.

B6.2 Billing Records

Virginia American uses the same billing categories in Dale City as are used in the City of Alexandria (see previous section for a description). Water is provided to Dale City by Virginia American, via Fairfax Water as well. Data were provided by average daily consumption by calendar year for 2005-2007 (Table B-9).

Table B-9: Consumption (millions of gallons per day) by customer category for Virginia American - Dale City.

	Single Family	Multi-family/Employee	Total
2005	3.834	1.245	5.079
2006	4.321	1.819	6.140
2007	4.025	1.684	5.709

B6.3 Unmetered Water Use

In 2007, Virginia American billed an average of 5.694 mgd to customers in the Dale City service area. Virginia American reported purchasing 6.384 mgd from Fairfax Water. Therefore unbilled water in 2007 amounted to 0.690 mgd or 10.8 percent (Table B-10).

Table B-10: Summary of water purchased and billed (millions of gallons per day) for Virginia American - Dale City.

	Purchased	Billed	Unmetered	Percent Unmetered
2005	6.308	5.079	1.229	19.5%
2006	6.512	6.141	0.371	5.7%
2007	6.384	5.694	0.690	10.8%

B6.4 Determination of Single Family Unit Use Factor

During 2007, an average of 4.025 mgd was billed to the residential water use category (single family households for this study). The number of 2007 households in the area served by Virginia American in Dale City is 21,132 as based on the ICPRB analysis using a GIS overlay of this area with household data by traffic analysis zone. Applying the dwelling unit ratio of 2.91 to the number of 2007 households in Dale City yields 15,727 single family households and 5,405 multi-family households. The single family water use factor was 255.9 gallons per household per day (4.025 mgd billed to 15,727 single family households) (Table B-11).

B6.5 Determination of Multi-family and Employee Unit Use Factor

In 2007, the average water use in the combined categories of commercial, industrial, and “other” was 1.684 mgd, divided between 0.635 mgd in commercial and 1.049 mgd in “other” (municipal). There is no industrial water use in Dale City. As in the analysis for the City of Alexandria, given that Virginia American’s commercial category includes apartment buildings, businesses, and other commercial water uses, Fairfax Water’s unit use factor (44.4 gallons per day per employee) was assumed for the employee unit use factor. The number of 2007 employees in the Virginia American service area was 9,508. Applying the employee unit use factor yields a total water use of nearly 0.422 mgd. Subtracting this assumed employee water use from Dale City’s commercial and “other” categories yields 1.262 mgd for the multi-family household category. The multi-family household unit use factor is calculated to be 233.4 gallons per multi-family household per day (Table B-11).

Table B-11: Dwelling unit ratio and unit use (gallons per day) by customer category for Virginia American - Dale City.

	2005	2006	2007
Households	20,618	20,875	21,132
Dwelling unit ratio	3.14	3.02	2.91
Single family	15,633	15,682	15,727
Multi-family	4,985	5,193	5,405
Employment	9,212	9,360	9,508
Unit use (gpd)			
Single family	245.2	275.5	255.9
Multi-family	172.6	274.0	233.4
Employee	41.8	42.3	44.4

B7 Fairfax Water - Loudoun Water

B7.1 Service Area

Loudoun Water provided a map of the area currently served. No changes to the area served are expected in the near future. While there are tentative plans to expand Dulles Airport further into Loudoun County, Fairfax Water will continue to serve the airport for the foreseeable future. The 2008 boundary is used for the 2040 area served prediction (Thom Lipinski and Craig Lees, Loudoun Water).

B7.2 Billing Records

Loudoun Water uses several water use categories including: single family residential, multi-family residential, commercial, construction, and fire hydrant meters. The construction category accounts for the water used in the construction of water mains by contractors not on contract with Loudoun Water (Thom Lipinski, personal communication, March 13, 2009). Fire hydrant meters account for the water used by construction and swimming pool contractors and landscaping companies. Billing information was provided for 2005 to 2008 by calendar year (Table B-12).

Table B-12: Consumption (millions of gallons per day) by customer category for Loudoun Water.

	Single Family	Multi-Family	Employee	Total
2005	10.33	1.59	4.42	16.33
2006	11.68	1.80	5.07	18.54
2007	13.04	2.01	5.54	20.59
2008	11.72	1.80	4.82	18.34

B7.3 Unmetered Water Use

Loudoun Water purchases water from both Fairfax Water and from the City of Fairfax. In 2008, a combined total of 21.2 mgd were purchased from both suppliers. Fairfax Water reported selling 18.2 mgd to Loudoun Water in the same year. According to Loudoun Water, a total of 18.34 mgd was billed to customers in 2008. The difference between water purchased and water sold is 2.9 mgd or 13.5 percent (Table B-13). This relatively high unmetered water use figure may be accounted for by the fact that Loudoun Water does not meter water used for system maintenance or water used in construction activities done under direct contract with Loudoun Water (Thom Lipinski, personal communication, March 13, 2009). Additionally, it could be due to extra system flushing conducted as a result of the 2007 drought that limited the amount of flushing that could be done in that year (Thom Lipinski, personal communication, March 13, 2009).

Table B-13: Summary of water purchased and billed (millions of gallons per day) for Loudoun Water.

	Purchased - Fairfax Water	Purchased - City of Fairfax	Total Purchased	Billed	Unmetered	Percent Unmetered
2005	13.2	5.1	18.3	16.33	1.9	10.6%
2006	14.4	4.9	19.3	18.54	0.7	3.8%
2007	17.9	4.2	22.1	20.59	1.5	6.7%
2008	18.2	3.0	21.2	18.34	2.9	13.5%

B7.4 Determination of Single and Multi-family Unit Use Factors

The number of 2008 households in the Loudoun Water area served is 63,356, as based on the ICPRB analysis using a GIS overlay of the area served by Loudoun Water with household data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. Applying the dwelling unit ratio in the area served of 5.19 to the number of 2008 households in the Loudoun Water area yields 53,121 single family households and 10,235 multi-family households.

During 2008, 11.72 mgd were billed to the single family residential water category. Dividing this by the number of single family households, yields a per single family household use of 220.6 gallons per day. Loudoun Water reports billing 1.80 mgd to multi-family households in 2008. This results in a use of 176.2 gallons per day per multi-family household (Table B-14).

B7.5 Determination of Employee Unit Use Factors

The number of 2008 employees in the Loudoun Water service area was 106,265 as based on the ICPRB analysis using a GIS overlay of Loudoun Water's service area with employment data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. The amount billed to the employee category in 2008 was 4.82 mgd. Therefore the unit use factor for 2008 is 45.3 gallons per day per employee (Table B-14).

Table B-14: Dwelling unit ratio and unit use (gallons per day) by customer category for Loudoun Water.

	2005	2006	2007	2008
Households	56,766	58,963	61,160	63,356
Dwelling unit ratio	5.21	5.20	5.19	5.19
Single family	47,622	49,453	51,280	53,121
Multi-family	9,144	9,510	9,880	10,235
Employment	92,702	97,223	101,745	106,265
Unit use (gpd)				
Single family	216.9	236.2	254.3	220.6
Multi-family	173.8	188.9	203.0	176.2
Employee	47.6	52.1	54.5	45.3

B8 Fairfax Water – Town of Herndon

B8.1 Service Area

The area served is bounded by the limits of the Town of Herndon. There currently are no undeveloped areas in the town and, therefore, all growth should be accounted for in the MWCOG numbers.

B8.2 Billing Records

Billing data was provided by calendar year for 2004 to 2007 and broken down into the following categories: residential, commercial, and government (including buildings, grounds, streets, community center, golf course, cemetery, and neighborhood center) (Table B-15). The residential category includes single family households, as well as apartments and condos (Salah Jaro, personal communication, March 11, 2009). The commercial and government categories were combined for this study’s employee use category. The Town of Herndon purchases water from Fairfax Water.

Table B-15: Consumption (millions of gallons per day) by customer category for Fairfax Water-Town of Herndon.

	Single and Multi-Family	Employee	Total
2004	1.15	0.94	2.09
2005	1.16	0.96	2.12
2006	1.17	0.96	2.13
2007	1.17	0.97	2.15

B8.3 Unmetered Water Use

In 2007, the Town of Herndon purchased 2.58 mgd from Fairfax Water. In the same year, Herndon reported billing 2.15 mgd to all customer categories. This translates to 0.44 mgd of unmetered water or 17 percent of the total purchased (Table B-16).

Table B-16: Summary of water purchased and billed (millions of gallons per day) for Fairfax Water-Town of Herndon.

	Purchased	Billed	Unmetered	Percent Unmetered
2004	2.35	2.09	0.26	11%
2005	2.43	2.12	0.31	13%
2006	2.45	2.13	0.32	13%
2007	2.58	2.15	0.44	17%

B8.4 Determination of Single Family and Multi-family Unit Use Factors

Due to data limitations, only one household unit use figure for both single family and multi-family households could be calculated. Given a total of 7,452 households in Herndon in 2007, 157.0 gallons per day per household were used (Table B-17).

B8.5 Determination of Employee Unit Use Factor

In 2007, there were 23,075 employees in Herndon and the employee water use factor was thus calculated to be 42.0 gallons per employee per day (Table B-17).

Table B-17: Dwelling unit ratio and unit use (gallons per day) by customer category for Fairfax Water-Town of Herndon.

	2005	2006	2007
Households	7,367	7,410	7,452
Dwelling unit ratio	2.10	2.08	2.07
Single family	4,991	5,004	5,025
Multi-family	2,376	2,406	2,427
Employment	21,969	22,522	23,075
Unit use (gpd)			
Household	157.5	157.9	157.0
Employee	43.7	42.6	42.0

B9 Fairfax Water – Fort Belvoir

B9.1 Service Area

Fort Belvoir's boundaries were extracted from areas served map provided by Fairfax Water, as Fort Belvoir is surrounded by Fairfax Water's retail area served.

B9.2 Billing Records and Unmetered Water Use

Fort Belvoir purchases water from Fairfax Water. The amount of water bought from Fairfax Water in 2008 was on average 1.721 mgd. No billing records were obtained for Fort Belvoir, therefore unmetered water use could not be directly calculated.

B9.3 Determination of Single Family, Multi-Family and Employee Unit Use Factors

Fort Belvoir's single and multi-family unit use factors are assumed to be the same as Fairfax Water's retail area served in 2008 (199.9 gallons per single family household per day and 165.6 gallons per multi-family household per day) (Table B-18). Calculating the total amount of household water use and assuming 10 percent unmetered water use, leaves 1.310 mgd available for employee use. Given an estimate of 17,886 employees, as based on the ICPRB analysis using a GIS overlay of Fort Belvoir's area served with employment data by traffic analysis zone and extracting the 2005 and 2010 data and interpolating for 2008, yields a unit use of 73.3 gallons per day.

Table B-18: Dwelling unit ratio and unit use (gallons per day) by customer category for Fairfax Water – Fort Belvoir.

	2005	2006	2007	2008
Households	464	472	480	488
Dwelling unit ratio	2.22	2.21	2.20	2.01
Single family	320	325	330	326
Multi-family	144	147	150	162
Employment	17,876	17,879	17,886	17,886
Unit use (gpd)				
Single family	206.4	211.2	227.6	199.9
Multi-family	170.0	167.5	167.8	165.6
Employee	85.1	108.4	99.9	73.3

B10 Fairfax Water – MWAA Dulles International Airport

B10.1 Service Area

The Dulles International Airport's area served is bound by the boundaries of the airport and surrounded by Fairfax County and Loudoun County.

B10.2 Billing Records and Unmetered Water Use

Fairfax Water reported selling 0.767 mgd to Dulles Airport in 2008. No billing records were obtained from Dulles, so unmetered water use could not be directly calculated. Instead, the percentage unmetered was assumed to be 10 percent.

B10.3 Determination of Single Family, Multi-Family and Employee Unit Use Factors

Dulles Airport's single and multi-family household unit use rates are assumed to be the same as Fairfax Water's retail area served in 2008 (199.9 gallons per single family household per day and 165.6 gallons per multi-family household per day) (Table B-19). In 2008, Fairfax Water reported selling 0.767 mgd to Dulles International Airport. Assuming 10 percent unmetered water use, 0.686 mgd remains available for employee use. The number of 2008 households in the Dulles area served was approximately 23: 17 single family households and 6 multi-family households using Fairfax Water's area served dwelling unit ratio (2.89). The number of employees is 15,652 as based on the ICPRB analysis using a GIS overlay of the Dulles area served with employment data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. After subtracting the water use of single and multi-family households (0.003 mgd and 0.001 mgd respectively), the remaining 0.686 mgd is attributed to the employee category. Thus the per employee water use rate was calculated as 43.8 gallons per day.

Table B-19: Dwelling unit ratio and unit use (gallons per day) by customer category for Fairfax Water – MWAA Dulles International Airport.

	2005	2006	2007	2008
Households	23	23	23	23
Dwelling unit ratio	2.93	2.92	2.90	2.89
Single family	17	17	17	17
Multi-family	6	6	6	6
Employment	14,727	15,035	15,343	15,652
Unit use (gpd)				
Single family	206.4	211.2	227.6	199.9
Multi-family	170.0	167.5	167.8	165.6
Employee	61.5	55.7	49.5	43.8

B11 Aqueduct - DC Water and Sewer Authority (DC WASA)

B11.1 Service Area

The DC WASA purchases water from Washington Aqueduct and provides water service within the boundaries of Washington, D.C.

B11.2 Billing Records

DC WASA provided annual billing data by fiscal year for 2004 to 2008 (Table B-20). Their billing records are disaggregated into residential, multi-family, municipal, commercial, D.C. Housing Authority, and federal categories. The types of uses encompassed by each category are described below (Syed Khalil, personal communication, February 6, 2009):

Residential: primarily single family dwellings, horizontal condos, and townhouses

Multi-family: dwellings with four or more units, typically large apartment buildings in the urban center

Commercial: office buildings, retail, hotel, hospitals cooperatives, vertical condos and industrial water uses, in addition Reagan National Airport and selected facilities at Soldier's Home and Howard University are included in this category.

Municipal: all District of Columbia government agencies

Federal: all Federal agencies, including the Pentagon and Arlington Cemetery

D.C. Housing Authority

For this study's purposes, the residential class was used for the single family category; multi-family and D.C. Housing Authority uses were combined for the multi-family households category; and commercial, municipal, and federal uses were combined for the employment category. It is reasonably assumed that the majority, if not all, D.C. Housing Authority clients are in multi-family dwellings. Given that the commercial category includes a portion of the water consumed by households, the unit use factors for the multi-family households and the employee category are skewed.

DC WASA also sends water to Washington Aqueduct. In 2008, this amounted to 1.09 mgd.

Table B-20: Consumption (millions of gallons per day) by customer category for Aqueduct - DC Water and Sewer Authority (DC WASA).

	Single Family	Multi-Family	Employee	Other	Washington Aqueduct	Total
2004	18.82	23.65	43.32	12.85	0.98	99.62
2005	18.28	22.20	43.98		0.97	85.42
2006	18.31	21.11	46.58		0.90	86.90
2007	18.12	20.70	46.11		1.60	86.52
2008	17.56	19.41	45.54	1.95	1.09	85.56

B11.3 Unmetered Water Use

DC WASA relies on water purchased from Washington Aqueduct. During fiscal year (FY) 2008, DC WASA purchased on average 111.35 mgd from the Aqueduct. The water billed in FY 2008 was 85.56 mgd. The difference between the amount purchased and the amount sold to all customers is 25.80 mgd, or 23.17 percent (Table B-21). This does not account for water used for hydrant flushing, cleaning and lining, street operations, etc. Water consumption for these purposes is estimated at 1.95 mgd (Syed Kahlil, personal communication, March 24, 2009).

Table B-21: Summary of water purchased and billed (millions of gallons per day) for Aqueduct - DC Water and Sewer Authority (DC WASA).

	Purchased	Billed	Unmetered	Percent Unmetered
2004	128	99.62	28.04	21.97%
2005	123	85.42	38.02	30.80%
2006	114	86.90	26.91	23.65%
2007	114	86.52	27.69	24.24%
2008	111	85.56	25.80	23.17%

B11.4 Determination of Single and Multi-family Unit Use Factors

The number of 2008 households in DC WASA's area served is 266,929, based on the ICPRB analysis using a GIS overlay of DC WASA's area served with household data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. Using a dwelling unit ratio of 0.68, there are 108,482 single family households and 158,447 multi-family households in D.C. During 2008, 17.56 mgd were consumed by single family households and 19.41 mgd by multi-family households. Given the aforementioned number of households, this results in unit use rates of 161.9 gallons per day per single family household and 122.5 gallons per day per multi-family household (Table B-22).

B11.5 Determination of Employee Unit Use Factor

To determine DC WASA's employee unit use factor, the municipal and federal billing categories were combined. In 2008, 45.54 mgd was billed to this combination of categories. The number of 2008 employees in the DC WASA area served was 773,001, as based on the ICPRB analysis using a GIS overlay of DC WASA's service area with employment data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. The employee unit use was derived as 58.9 gallons per employee per day (Table B-22).

Table B-22: Dwelling unit ratio and unit use (gallons per day) by customer category for Aqueduct - DC Water and Sewer Authority (DC WASA).

	2005	2006	2007	2008
Households	253,379	257,896	262,413	266,929
Dwelling unit ratio	0.68	0.68	0.68	0.68
Single family	102,975	104,811	106,646	108,482
Multi-family	150,404	153,085	155,767	158,447
Employment	750,260	757,840	765,421	773,001
Unit use (gpd)				
Single family	177.5	174.7	169.9	161.9
Multi-family	140.4	137.9	132.9	122.5
Employee	58.6	61.5	60.2	58.9

B12 Aqueduct – City of Falls Church

B12.1 Service Area

The City of Falls Church provided a map of current pressure areas and expects no change in this extent in the future (Rodney Collins, personal communication, April 7, 2009).

B12.2 Billing Records

The City of Falls Church Department of Environmental Services-Public Utilities Division (Falls Church DES) provided annual billing data by calendar year for 2004 through 2008 (Table B-23). Due to staffing issues in 2006 and 2007, water use data were not reported on the normal schedule. To approximate the amount consumed in these two years, the consumption data for 2006 and 2007 were averaged over the two years (Mary Ann Burke, personal communication, February 13, 2009). The city's billing categories are single family, town house, apartment, commercial, and municipal. The single family and town house categories were combined for the single family household category used in this study. The apartment designation is used for the multi-family household category, and commercial and municipal were combined for the employee category.

Table B-23: Consumption (millions of gallons per day) by customer category for Aqueduct – City of Falls Church.

	Single Family	Multi-Family	Employee	Wholesale	Total
2005	4.40	2.01	2.37	1.532	10.31
2006	7.23	2.75	4.53	1.539	16.05
2007	7.23	2.75	4.53	1.729	16.24
2008	6.69	2.85	4.11	2.113	15.07

Note: Due to a billing problem, 2006 and 2007 data were averaged to approximate values for each year.

B12.3 Unmetered Water Use

Falls Church DES purchases water predominantly from Washington Aqueduct. Through February 2007, it was receiving some water from Fairfax Water as well. In turn, Falls Church DES sells a small amount of this water to Vienna DPW. In 2008, Falls Church DES purchased, on average, 17.22 mgd from the Aqueduct and reported that no water was purchased from Fairfax Water (Mary Ann Burke, personal communication, March 5, 2009). The amount of unmetered water for Falls Church DES is equal to 1.44 mgd or 8.38 percent of the annual total (Table B-24).

Table B-24: Summary of water purchased and billed (millions of gallons per day) for Aqueduct – City of Falls Church.

	Purchased					
	from Washington Aqueduct	from Fairfax Water[1]	Total Purchased	Billed	Unmetered	Percent Unmetered
2005	10.90	4.51	15.42	10.31	5.11	33.15%
2006	10.99	4.87	15.86	16.05	-0.19	-1.19%
2007	16.86	0.68	17.54	16.24	1.30	7.39%
2008	17.22	0.00	17.22	15.78	1.44	8.38%

[1]Fairfax Water reports selling slightly different amounts to Falls Church – 2005: 4.545, 2006: 4.921, 2007: 0.724, 2008: 0.027.

B12.4 Determination of Single and Multi-family Unit Use Factors

According to the ICPRB analysis using the GIS overlay of the Falls Church area served with household data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008, there were 50,930 households in the area. Using a dwelling unit ratio of 1.92, there were 33,474 single family households and 17,456 multi-family households in 2008. Falls Church single family households have a unit use factor of 199.9 gallons per household per day and multi-family households a unit use factor of 163.3 gallons per day per household (Table B-25).

B12.5 Determination of Employee Unit Use Factor

The number of 2008 employees in the Falls Church service area is 135,011, as based on the ICPRB analysis using a GIS overlay of the area served by Falls Church with employment data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. Given this number of employees in the area served, the unit use factor is 30.4 gallons per day per employee (Table B-25).

Table B-25: Dwelling unit ratio and unit use (gallons per day) by customer category for Aqueduct – City of Falls Church.

	2005	2006	2007	2008
Households	49,251	49,811	50,371	50,930
Dwelling unit ratio	1.90	1.89	1.88	1.92
Single family	32,243	32,595	32,861	33,474
Multi-family	17,008	17,216	17,510	17,456
Employment	126,825	129,554	132,283	135,011
Unit use (gpd)				
Single family	136.6	221.8	220.0	199.9
Multi-family	118.0	159.8	157.1	163.3
Employee	18.6	35.0	34.3	30.4

B13 Aqueduct – Town of Vienna

B13.1 Service Area

A map of the current area served by the Town of Vienna was provided and no changes are expected in the future because the area is bound by other providers. The area served by the Town of Vienna extends beyond the town's boundaries, therefore, the demographic figures for the service area and the town are not necessarily the same.

B13.2 Billing Records

Both billing and purchasing data were provided for 2005 through 2008 (Table B-26). The Town of Vienna's Finance Department billed 2.22 mgd in 2008. Their billing categories are single family households, multi-family households, commercial, industrial/other, schools, and churches. The commercial, industrial/other, schools, and churches were combined into one "employee" category. Customers are billed quarterly based on their metered usage (Marion Serfass, personal communication, March 25, 2009).

Table B-26: Consumption (millions of gallons per day) by customer category for Aqueduct – Town of Vienna.

	Single Family	Multi-Family	Employee	Total
2005	1.85	0.11	0.40	2.36
2006	1.76	0.10	0.38	2.24
2007	1.82	0.10	0.37	2.29
2008	1.75	0.10	0.36	2.22

B13.3 Unmetered Water Use

According to Vienna's records, the town purchased 2.25 mgd of water from Falls Church and Fairfax Water in 2008 (2.12 mgd and 0.13 mgd, respectively). The difference between the amount purchased and the amount billed in 2008 was 0.03 mgd or 1.37 percent (Table B-27).

Table B-27: Summary of water purchased and billed (millions of gallons per day) for Aqueduct – Town of Vienna.

	Purchased	Billed	Unmetered	Percent Unmetered
2005	2.30	2.36	(0.06)[1]	-2.62%
2006	2.32	2.24	0.08	3.63%
2007	2.34	2.29	0.05	2.00%
2008	2.25	2.22	0.03	1.37%

[1]The Town of Vienna has two water towers which may account for more water being billed to customers than the amount purchased in 2005 (Marion Serfass, personal communication, March 25, 2009).

B13.4 Determination of Single and Multi-family Unit Use Factors

In 2008, 1.75 mgd was billed to the single family household category. The number of 2008 single family households in the Town of Vienna's area served was 8,892. Therefore, the single family household unit use factor was 196.8 gallons per day. Similarly, multi-family households were billed a total of 0.10 mgd, over 764 households. The multi-family household unit use factor for 2008 was 130.9 gallons per day (Table B-28).

B13.5 Determination of Employee Unit Use Factor

The employee category consists of commercial, industrial/other, school, and church accounts. 0.36 mgd was billed to these categories in 2008. There were 13,850 employees in the Town of Vienna, yielding a unit use factor of 26.0 gallons per day per employee (Table B-28).

Table B-28: Dwelling unit ratio and unit use (gallons per day) by customer category for Aqueduct – Town of Vienna.

	2005	2006	2007	2008
Households	9,647	9,650	9,653	9,656
Dwelling unit ratio	12.03	11.90	11.77	11.64
Single family	8,907	8,902	8,897	8,892
Multi-family	740	748	756	764
Employment	13,467	13,595	13,722	13,850
Unit use (gpd)				
Single family	207.7	197.7	204.6	196.8
Multi-family	148.6	133.7	132.3	130.9
Employee	29.7	28.0	27.0	26.0

B14 Aqueduct - Arlington County DES

B14.1 Service Area

Arlington County DES' area served remains the same as it was in 2005 and no changes are anticipated in the future (Dave Hundelt, personal communication, January 21, 2009).

B14.2 Billing Records

Arlington County DES uses the following water use categories: residential, commercial, apartment, and county agencies (Barbara Forbes, personal communication, June 19, 2009). The residential category represents single family households, and the apartment category includes multi-family duplexes and large apartment buildings. The commercial category contains commercial buildings, county agencies, and some large apartment buildings. For this study, the multi-family household use category will correlate with the apartment category, and the employee category will be assumed to be approximately equivalent to the commercial category. Due to these assumptions, the unit use factors for the multi-family household and employee categories will be skewed. Arlington County DES also distributes water to Ft. Myer. Data for 2005 through 2008 were provided by month for each fiscal year (June-July) and redistributed by calendar year (Table B-29).

Table B-29: Consumption (millions of gallons per day) by customer category for Aqueduct - Arlington County DES.

	Single Family	Multi-Family	Employee	Ft. Myer	Total
2005	6.06	5.69	8.18	0.33	20.27
2006	6.13	5.72	8.13	0.36	20.34
2007	6.19	5.67	8.42	0.40	20.68
2008	5.75	5.63	8.11	0.35	19.83

B14.3 Unmetered Water Use

In 2008, the agency reported purchasing 23.09 mgd from Washington Aqueduct. The total water billed to retail customers in Arlington County DES and to Fort Meyer was 19.83 mgd. Thus, the amount of unaccounted for water in 2008 was 3.26 mgd or 14.10 percent of the total purchased (Table B-30).

Table B-30: Summary of water purchased and billed (millions of gallons per day) for Aqueduct - Arlington County DES.

	Purchased	Billed	Unmetered	Percent Unmetered
2005	26.70	20.27	6.43	24.08%
2006	25.50	20.34	5.16	20.25%
2007	24.81	20.68	4.13	16.64%
2008	23.09	19.83	3.26	14.10%

B14.4 Determination of Single and Multi-family Unit Use Factors

The number of 2008 households in Arlington County DES's area served was 96,512 as based on the ICPRB analysis using a GIS overlay of Arlington County DES's area served with household data by traffic analysis zone, extracting the 2005 and 2010 household data and interpolating for

2008. Applying the dwelling unit ratio (0.60) to the number of 2008 households in the Arlington service area yields 36,185 single family households and 60,327 multi-family households. The Arlington County DES unit use for single-family households was 158.8 gallons per day per household (Table B-31). The unit use for multi-family households was 93.3 gallons per household per day.

B14.5 Determination of Employee Unit Use Factor

The employee water use in the Arlington County DES service area was 8.11 mgd in 2008. The number of 2008 employees in the area served by Arlington County DES is 204,530 as based on the ICPRB analysis using a GIS overlay of the Arlington County DES service area with employment data by traffic analysis zone, extracting the 2005 and 2010 data and interpolating for 2008. The employee unit use is calculated to be 39.7 gallons per day per employee (Table B-31).

Table B-31: Dwelling unit ratio and unit use (gallons per day) by customer category for Aqueduct - Arlington County DES.

	2005	2006	2007	2008
Households	91,909	93,443	94,978	96,512
Dwelling unit ratio	0.67	0.64	0.62	0.60
Single family	36,775	36,466	36,350	36,185
Multi-family	55,134	56,977	58,628	60,327
Employment	192,754	196,679	200,604	204,530
Unit use (gpd)				
Single family	164.7	168.0	170.4	158.8
Multi-family	103.3	100.4	96.6	93.3
Employee	42.5	41.3	42.0	39.7

B15 Aqueduct – Arlington DES – Fort Myer

B15.1 Unmetered Water Use and Billing Records

Fort Myer also relies on water purchased from Washington Aqueduct via Arlington DES. Unmetered water could not be calculated from the available data. Arlington DES's unmetered water use (14.10 percent) was assumed for Fort Myer.

B15.2 Determination of Single Family, Multi-family, and Employee Unit Use Factors

According to the ICPRB analysis using a GIS overlay of the Fort Myer area served with traffic analysis zones, extracting the 2005 and 2010 housing and employment data and interpolating for 2008, there are 305 houses and 2,121 employees in the area. Fort Myer single and multi-family households were assumed to have the same unit use as Fairfax Water's area served at 199.9 and 165.6 gallons per day, respectively. Subtracting the total household use (0.023 mgd for single family households and 0.032 mgd for multi-family households) and the unmetered water (0.042

mgd) from the total billed (0.34 mgd) to Fort Myer leaves 0.244 mgd for the employee water use category. Over 2,121 employees, the unit use factor is calculated as 115.2 gallons per employee per day in 2008.

B16 Washington Suburban Sanitary Commission (WSSC)

B16.1 Service Area

The map of WSSC's current area served was developed by buffering the distribution network by 500 feet and then excluding areas that are not served (Pedro Flores, personal communication, February 10, 2009). The future area served map is the boundaries of the pressure zone, which includes areas that will not become part of the area served. To approximate the area served in 2040, this outer boundary was overlaid with the population and employment data from the Washington Metropolitan Council of Governments Round 7.2 demographic data and clipped to exclude the areas of known no service.

B16.2 Billing Records

WSSC provided billing records by month for 2005 through 2008 (Table B-32). The billing categories are single family, multi-family, employee, and wholesale. Accounts in the employee and wholesale categories are billed monthly, whereas households, both single and multi-family, are billed quarterly. WSSC bills customers based on a calculated consumption rate, Daily Average Consumption (DAC). DAC for each account is equal to the volume used during the meter reading period (either monthly or quarterly) divided by the number of days in this period plus the past DAC, all divided by two. To calculate daily use, an average of the DAC over twelve months was taken (Tim Hirrell, personal communication, January 14, 2009). WSSC has agreements with both Howard County and Charles County, Maryland, to sell them 5 mgd and 1.4 mgd, respectively. WSSC also has agreements with DC WASA and the City of Rockville to provide water in emergency situations. The wholesale category accounts for the consumption by all four of these users.

Table B-32: Consumption (millions of gallons per day) by customer category for WSSC.

	Single Family	Multi-Family	Employee	Wholesale	Total
2005	73	33	37	2	144
2006	75	31	33	3	143
2007	76	32	32	3	143
2008	77	30	31	1	139

B16.3 Unmetered Water Use

During 2008, WSSC produced an average of 162.75 mgd for its customers in Montgomery and Prince George's counties. For the same period during 2008, 139 mgd was billed to all retail customers. The difference was 23 mgd or 14 percent (Table B-33).

Table B-33: Summary of water purchased and billed (millions of gallons per day) for WSSC.

	Produced	Billed	Unmetered	Percent Unmetered
2005	171.94	144	28	16%
2006	169.18	143	26	15%
2007	172.44	143	29	17%
2008	162.75	139	23	14%

B16.4 Determination of Single and Multi-family Unit Use Factors

WSSC billed 77 mgd to the single family household water use category and 30 mgd to multi-family households in 2008. The number of 2008 households in the combined area served in Montgomery and Prince George's counties is 618,986 as based on the ICPRB analysis using a GIS overlay of WSSC's area served with household data by traffic analysis zone in both Montgomery and Prince George's counties. Data from 2005 and 2010 were extracted and interpolated for 2008. The combined area served had a dwelling unit ratio of 1.91 in 2008. Therefore WSSC's area served contains 405,916 single family households and 213,070 multi-family households (Table B-34). The single family household unit use was 189.3 gallons per day per household and the multi-family household unit use was 142.0 gallons per day per household.

B16.5 Determination of Employee Unit Use Factor

In 2008, 31 mgd was billed to the employee category. The number of 2008 employees in the area served by WSSC was 767,501, as based on the ICPRB analysis using a GIS overlay of WSSC's area served with employment data by traffic analysis zone extracting data for 2005 and 2010 and interpolating for 2008. Thus, the employee unit use in the WSSC area served was 40.8 gallons per day per employee (Table B-34).

Table B-34: Dwelling unit ratio and unit use (gallons per day) by customer category for WSSC.

	2005	2006	2007	2008
Households	604,616	609,406	614,196	618,986
Dwelling unit ratio	2.02	1.99	1.95	1.91
Single family	404,670	405,263	405,844	405,916
Multi-family	199,946	204,143	208,352	213,070
Employment	754,707	758,971	763,236	767,501
Unit use (gpd)				
Single family	179.6	185.7	186.9	189.3
Multi-family	162.6	154.2	152.2	142.0
Employee	49.0	44.0	42.5	40.8

B17 City of Rockville DPW

B17.1 Service Area

The City of Rockville serves areas within the city limits that are not served by WSSC (Susan Strauss, personal communication, January 16, 2009).

B17.2 Billing Records

Rockville's Finance Department provided billing information for 2005 through 2008 (Table B-35). Their customer categories are residential (single family households), commercial (including apartments and condominiums), and tax exempt (churches, schools, and government buildings). The commercial and tax-exempt categories were combined into the employee category for this study. The data were provided as actual consumption by month for each meter. The sum of the consumption for all meters in a given category was taken for the year to derive consumption rates.

Table B-35: Consumption (millions of gallons per day) by customer category for City of Rockville DPW.

	Single Family	Multi-Family and Employee	Total
2005	1.71	1.86	3.57
2006	2.03	2.41	4.44
2007	2.06	2.60	4.66
2008	1.77	2.48	4.25

B17.3 Unmetered Water Use

Rockville's Department of Public Works (DPW) relies on water withdrawn from the Potomac River. Potomac diversions to the Rockville Water Treatment Plant for calendar year 2007 were obtained from Rockville DPW. Occasionally, Rockville purchases water from WSSC when Rockville's water treatment plant is out of service due to a power outage, rehabilitation work, or equipment failure. Rockville follows guidelines established by the Maryland Department of the Environment to determine the annual water lost, using the Water Audit Worksheet of Treated Water. The total amount of water produced at the Rockville Water Treatment plant and purchased from WSSC for 2007 was 5.17 mgd. The total amount of water billed in 2007 was 4.73 mgd. After deducting the amount of water that was used for city facilities, as well as other unbilled/unmetered authorized consumption and real water losses, the net unmetered water totaled 0.2 mgd or 3.9 percent.

B17.4 Determination of Single Unit Use Factor

The number of households in the Rockville DPW's area served in 2008 is 17,484 as based on the ICPRB analysis using a GIS overlay of Rockville DPW's area served with household data by traffic analysis zone, extracting 2005 and 2010 data and interpolating for 2008. Applying the dwelling unit of 1.69 to the number of 2008 households in the area served yields 10,988 single family households and 6,496 multi-family households. Using 1.77 mgd for single family household consumption and dividing by the 10,988 single family households, unit use in 2008 was 161 gallons per day per household (Table B-36).

B17.5 Determination of Multi-family and Employee Unit Use Factors

The number of 2008 employees in the Rockville DPW's area served is 64,149 as based on the ICPRB analysis using a GIS overlay of Rockville DPW's area served with employee data by traffic analysis zone, extracting 2005 and 2010 data and interpolating for 2008. The water use for the employee category was 2.48 mgd in 2008, which includes consumption by apartments and condominiums. To determine multi-family unit use, City of Rockville staff recommended estimating consumption by taking the value for single family household consumption (161 gallons per day) and reducing it by 10 percent to account for lower usage in apartments and condominiums (Ilene Lish, personal communication, June 25, 2009). This calculation yields an approximate multi-family unit use of 145 gallons per day. This value was then multiplied by the number of multi-family households (6,496) to get the total use for the year. This figure and the total single family use are subtracted from the total use in 2008, yielding a total employee use of 1.53 mgd. Thus, the employee unit use was 24 gallons per day per employee per day in 2008 (Table B-36).

Table B-36: Dwelling unit ratio and unit use (gallons per day) by customer category for City of Rockville DPW.

	2005	**2006**	**2007**	**2008**
Households	16,891	17,089	17,287	17,484
Dwelling unit ratio	1.90	1.83	1.76	1.69
Single family	11,063	11,050	11,024	10,988
Multi-family	5,828	6,039	6,263	6,496
Employment	63,034	63,406	63,778	64,149
Unit use (gpd)				
Single family	154.6	183.7	186.9	161.1
Multi-family	139.1	165.3	168.2	145.0
Employee	16.6	22.3	24.2	23.8

Appendix C Effects of the Energy Policy Act of 1992 on WMA Water Use

As with previous ICPRB demand studies, the effects of the Energy Policy Act of 1992 were considered in the analysis of future demand. This legislation has affected water use by requiring that all showerheads and toilets manufactured in the United States after January 1, 1994, meet specified flow standards. In order to remain consistent with the methodology used previously and to provide a conservative estimate of demand, the same assumptions are used here as were used in the 2005 study (Hagen *et al*., 2000). The sources used in the 2000 study continue to be used in end use and water savings literature. The key papers are the Water Research Foundation's *Residential End Uses of Water* (Mayer *et al*., 1999), *Water Use and Conservation* by Vickers (2001), *Existing Efficiencies in Residential Indoor Water Use* by Dziegielewski *et al*. (1999), and the USGAO's *Report to Congressional Requesters: Water Infrastructure, Water-Efficient Plumbing Fixtures and Reduce Water Consumption and Wastewater Flows* (2000). A detailed description of the assumptions and the literature on residential end uses of water can be found in the 2005 report. Presented here are the assumptions used to calculate the savings derived from the Energy Policy Act of 1992 and a brief update on the literature.

C1 Water Savings Calculations

Assumptions for determining the effects of low flow toilets

1. Newer, post-1994 housing stock and housing stock with remodeled bathrooms in the WMA are assumed to have a water use of 1.63 gallon per flush (Dziegielewski *et al*. 1999).
2. Older, pre-1994 housing stock in the WMA is assumed to have a water use of 3.97 gallons per flush (this is slightly higher than the 3.78 gallons per flush used in the 2005 report) (Dziegielewski *et al*. 1999).
3. All houses built after 1994 have ULF toilets.
4. Two percent of the original 1994 housing stock in the CO-OP service area is remodeled each year with ULF toilets.
5. The additional households in the 5 year forecast increments are assumed to be new homes with ULF toilets.
6. On average there are 11.75 flushes per household per day (adapted to WMA from Dziegielewski *et al*. 1999).

Assumptions for determining the effects of low flow showerheads

1. An average shower lasts 8.2 minutes (Dziegielewski *et al*. 1999).
2. A household averages 1.98 showers per day (Dziegielewski *et al*. 1999).
3. Showerhead rate through 2024: ≤0.5 – 5.25 gallons per minute (Dziegielewski *et al*. 1999).
4. Showerhead rate from 2025 on: ≤0.5 – 2.5 gallons per minute (Dziegielewski *et al*. 1999).
5. All non-compliant showerheads with 2.5 gpm showerheads by the year 2025. A 100 percent rate of retrofit and remodeling is assumed for non-compliant, older showerheads.

It is important to note that not all potential savings are account for in this analysis. For example, savings from more efficient bathroom and kitchen faucets are not considered, nor are those from washing machines. Additionally, even more efficient products are being encouraged by the EPA's WaterSense program, such as 1.28 gallons per flush toilets (McNeil *et al.*, 2008) that are not considered here.

Table C-1: Total toilet water use per household in gallons per day.

	Total Households	Households Remodeled since 1994 with LF toilets	New Households with LF toilets	Households with Conventional Toilets	LF Toilets	Conventional Toilet Water Use (gpd)	LF Toilet Water Use (gpd)	Total Toilet Water Use (gpd)	Total Toilet Water Use per Household (gpd)
1994	1,342,210	26,844	20,353	1,295,013	47,197	60,409,110	903,944	61,313,054	46
1995	1,362,562	26,844	20,352	1,268,169	94,393	59,156,895	1,807,868	60,964,762	45
2000	1,464,324	134,221	101,762	1,133,948	330,376	52,895,821	6,327,530	59,223,351	40
2005	1,556,705	134,221	92,381	999,727	556,978	46,634,747	10,667,529	57,302,275	37
2010	1,664,169	134,221	107,464	865,506	798,663	40,373,672	15,296,401	55,670,073	33
2015	1,774,836	134,221	110,667	731,285	1,043,551	34,112,598	19,986,618	54,099,217	30
2020	1,882,736	134,221	107,900	597,064	1,285,672	27,851,524	24,623,841	52,475,365	28
2025	1,967,226	134,221	84,490	462,843	1,504,383	21,590,450	28,812,703	50,403,153	26
2030	2,037,334	134,221	70,108	328,622	1,708,712	15,329,376	32,726,114	48,055,490	24
2035	2,091,657	134,221	54,323	194,401	1,897,256	9,068,302	36,337,203	45,405,505	22
2040	2,142,586	134,221	50,929	60,180	2,082,406	2,807,228	39,883,289	42,690,516	20

Table C-2: Total showerhead water use before 2025 and 2025 and beyond per household in gallons per day.

Through 2024					2025-2040			
Modal shower flow (gallons per minute)	**Shower flow used for calculation purposes (gallons per minute)**	**Percent of all showering events (Dziegielewski *et al.*, 1999)**	**Gallons/ day/ household**	**Gallons/ day/ household, as percent of all shower events**	**Shower flow used for calculation purposes (gallons per minute)**	**Percent of all showering events (Dziegielewski *et al.*, 1999)**	**Gallons/ day/ household**	**Gallons/day/ household, as percent of all shower events**
0.5 or less	0.5	0.9	8.118	0.1	0.5	0.9	7.155	0.1
0.5 to 1	0.75	4.8	12.177	0.6	0.75	4.8	10.7325	0.6
1 to 1.5	1.25	16.2	20.295	3.3	1.25	16.2	17.8875	3.3
1.5 to 2	1.75	28.7	28.413	8.2	1.75	28.7	25.0425	8.2
2 to 2.5	2.25	22	36.531	8.0	2.25	22	32.1975	8.0
2.5 to 3	2.75	11.2	44.649	5.0	2.5	27.4	35.775	11.1
3 to 3.5	3.25	6.4	52.767	3.4	0	0	0	0
3.5 to 4	3.75	4.3	60.885	2.6	0	0	0	0
4 to 4.5	4.25	2.4	69.003	1.7	0	0	0	0
4.5 to 5	4.75	1.5	77.121	1.2	0	0	0	0
More than 5.0	5.25	1.6	85.239	1.4	0	0	0	0
Average gallons/day/household				**35.3**				**31.3**

Table C-3: Per Household per day toilet and shower water use and savings. "Savings from 2010" figures used in calculating future multi-family household unit use factors.

	Toilets	Shower	Total	Savings from 2010
2010	33	34	67	-
2015	30	33	63	4
2020	28	32	60	7
2025	26	31	57	10
2030	24	31	55	12
2035	22	31	53	14
2040	20	31	51	16

Appendix D Household and Employee Water Use for Each Supplier

A detailed description of the methods used to calculate these demands can be found in Chapters 3 and 4 and in Calculation of Unit Use Factors for Each Supplier. Appendix B provides information on the assumptions used when all the data required for calculating unit use was not available. For example, when the Dulles unit use values were being calculated, the single family and multi-family household figures were assumed because billing date by customer category was not available. Also, Appendix B indicates when an unmetered water use rate of 10 percent was assumed if a supplier's rate was below that amount or unknown. The information in the tables that follow show the numbers that were used as inputs for analysis, but does not indicate the assumptions used to derived them.

Table D-1: Summary of Water Use (mgd) for both Low and High Predictions

Service Area	2005	2010	2015	2020	2025	2030	2035	2040
Total Fairfax Water (Low prediction)	157.2	175.2	186.9	199.4	210.2	218.2	223.8	228.9
Potential demand from "special growth areas"	-	12	13	15	19	23	28	32
Additional demand if SFH unit use assumed constant	-	-	1.9	3.4	5.0	6.1	7.2	8.2
TOTAL Fairfax Water (High prediction)	157.2	187.2	201.7	217.8	234.2	247.3	259.0	269.1
TOTAL Washington Aqueduct (Low prediction)	148.4	150.9	157.7	164.8	168.7	172.2	174.2	177.8
Additional demand if SFH unit use assumed constant	-	-	1.0	1.8	2.6	3.3	3.9	4.6
TOTAL Washington Aqueduct (High Prediction)	148.4	150.9	158.6	166.6	171.4	175.5	178.1	182.4
WSSC (Low prediction)	168.0	171.9	177.5	186.7	191.6	197.1	201.1	203.8
Additional demand if SFH unit use assumed constant	-	-	2.0	3.7	5.3	6.4	7.6	8.7
WSSC (High prediction)	168.0	171.9	179.6	190.4	196.9	203.5	208.6	212.5
Subtotal (Low prediction)	473.5	497.9	522.1	551.0	570.6	587.5	599.1	610.5
Additional demand if SFH unit use assumed constant	0.0	0.0	4.9	8.8	12.9	15.8	18.7	21.5
Subtotal (High prediction)	473.5	509.9	540.0	574.8	602.5	626.3	645.7	664.0
City of Rockville DPW (Low prediction)	3.9	4.8	5.0	5.3	5.6	5.8	6.1	6.3
Additional demand if SFH unit use assumed constant	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2
City of Rockville DPW (High prediction)	3.9	4.8	5.0	5.4	5.7	6.0	6.3	6.5
TOTAL plus Rockville (Low prediction)	**477.5**	**502.7**	**527.1**	**556.3**	**576.2**	**593.3**	**605.1**	**616.8**
Additional demand if SFH unit use assumed constant	0.0	0.0	4.9	8.9	13.0	16.0	18.9	21.7
TOTAL plus Rockville (High prediction)	**477.5**	**514.7**	**545.0**	**580.2**	**608.2**	**632.3**	**652.0**	**670.5**

Table D-2: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for Fairfax Water – Retail

	2005	2010	2015	2020	2025	2030	2035	2040
Households	298,126	307,256	322,900	339,687	355,139	368,121	377,773	386,624
Dwelling unit ratio	2.93	2.83	2.62	2.42	2.26	2.15	2.08	1.88
Single family households	222,349	226,944	233,781	240,343	246,270	251,232	254,985	252,278
Multi-family households	75,777	80,312	89,119	99,344	108,869	116,889	122,788	134,346
Employment	412,577	456,687	495,283	526,212	554,958	577,729	599,542	620,677
% Unmetered (% of billed)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Unit use (gpd)								
Single family households	206.4	211.3	207.3	204.3	201.3	199.3	197.3	195.3
Multi-family households	170.0	167.7	163.7	156.7	157.7	155.7	153.7	151.7
Employee	41.8	44.6	44.6	44.6	44.6	44.6	44.6	44.6
Water use (mgd)								
Single family households	45.891	47.946	48.455	49.095	49.566	50.063	50.301	49.262
Multi-family households	12.883	13.469	14.590	15.569	17.170	18.201	18.874	20.382
Employee	17.237	20.368	22.090	23.469	24.751	25.767	26.740	27.682
Unmetered	7.601	8.178	8.514	8.813	9.149	9.403	9.591	9.733
Total water use	83.61	89.96	93.65	96.95	100.64	103.43	105.51	107.06
Anticipated additional use	-	12	13	15	19	23	28	32
Total plus anticipated	83.61	101.96	106.65	111.95	119.64	126.43	133.51	139.06
Population	813,321	834,922	872,569	912,956	949,914	980,872	1,004,043	1,037,719

Table D-3: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for Fairfax Water – Dulles

	2005	2010	2015	2020	2025	2030	2035	2040
Households	23	23	23	23	23	23	23	23
Dwelling unit ratio	2.93	2.83	2.62	2.42	2.26	2.15	2.08	1.88
Single family households	17	17	17	16	16	16	16	15
Multi-family households	6	6	6	7	7	7	7	8
Employment	14,727	16,268	17,101	18,296	19,431	19,955	20,412	20,844
% Unmetered (% of billed)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Unit use (gpd)								
Single family households	206.4	211.3	207.3	204.3	201.3	199.3	197.3	195.3
Multi-family households	170.0	167.7	163.7	156.7	157.7	155.7	153.7	151.7
Employee	61.5	43.8	43.8	43.8	43.8	43.8	43.8	43.8
Water use (mgd)								
Single family households	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.003
Multi-family households	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Employee	0.906	0.713	0.749	0.802	0.851	0.874	0.894	0.913
Unmetered	0.091	0.072	0.075	0.081	0.086	0.088	0.090	0.092
Total water use	1.00	0.79	0.83	0.89	0.94	0.97	0.99	1.01
Population	57	57	57	57	57	57	57	57

Table D-4: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for Fairfax Water – Fort Belvoir

	2005	2010	2015	2020	2025	2030	2035	2040
Households	464	504	538	573	604	633	655	665
Dwelling unit ratio	2.22	2.27	2.26	2.13	2.03	1.96	1.92	1.89
Single family households	320	350	373	390	405	419	430	435
Multi-family households	144	154	165	183	199	214	225	230
Employment	17,876	17,892	21,278	21,275	21,278	21,279	21,279	21,279
% Unmetered (% of billed)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Unit use (gpd)								
Single family households	206.4	211.3	207.3	204.3	201.3	199.3	197.3	195.3
Multi-family households	170.0	167.7	163.7	156.7	157.7	155.7	153.7	151.7
Employee	85.1	73.3	73.3	73.3	73.3	73.3	73.3	73.3
Water use (mgd)								
Single family households	0.066	0.074	0.077	0.080	0.081	0.083	0.085	0.085
Multi-family households	0.024	0.026	0.027	0.029	0.031	0.033	0.035	0.035
Employee	1.520	1.312	1.560	1.560	1.560	1.560	1.560	1.560
Unmetered	0.161	0.141	0.166	0.167	0.167	0.168	0.168	0.168
Total water use	1.77	1.55	1.83	1.83	1.84	1.84	1.85	1.85
Population	1,192	1,309	1,410	1,515	1,607	1,689	1,751	1,804

Table D-5: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for FW – Loudoun

	2005	2010	2015	2020	2025	2030	2035	2040
Households	56,766	67,750	77,165	91,581	101,138	104,846	107,257	109,621
Dwelling unit ratio	5.21	5.17	4.40	3.55	3.18	2.91	2.73	2.55
Single family households	47,622	56,778	62,880	71,445	76,934	78,039	78,515	78,780
Multi-family households	9,144	10,972	14,285	20,136	24,204	26,807	28,742	30,841
Employment	92,702	115,309	139,486	167,772	188,652	203,012	214,926	225,145
% Unmetered (% of billed)	10.6%	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%	11.0%
Unit use (gpd)								
Single family households	216.9	232.0	228.0	225.0	222.0	220.0	218.0	216.0
Multi-family households	173.8	185.5	181.5	178.5	175.5	173.5	171.5	169.5
Employee	47.6	49.9	49.9	49.9	49.9	49.9	49.9	49.9
Water use (mgd)								
Single family households	10.329	13.172	14.336	16.074	17.078	17.167	17.115	17.015
Multi-family households	1.589	2.035	2.592	3.594	4.247	4.651	4.929	5.228
Employee	4.416	5.753	6.960	8.371	9.413	10.129	10.724	11.234
Unmetered	1.731	2.311	2.634	3.091	3.389	3.522	3.613	3.691
Total water use	18.07	23.27	26.52	31.13	34.13	35.47	36.38	37.17
Population	160,867	192,356	216,962	253,747	277,924	286,275	291,367	296,052

Table D-6: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for Fairfax Water – Herndon

	2005	2010	2015	2020	2025	2030	2035	2040
Households	7,367	7,580	7,785	7,910	8,036	8,141	8,217	8,400
Dwelling unit ratio	2.10	2.06	1.90	1.72	1.71	1.67	1.60	1.53
Single family households	4,991	5,105	5,099	5,000	5,074	5,092	5,052	5,081
Multi-family households	2,376	2,475	2,686	2,910	2,962	3,049	3,165	3,319
Employment	21,969	24,733	25,892	26,539	26,955	27,312	27,323	27,334
% Unmetered (% of billed)	13.0%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%	15.7%
Unit use (gpd)								
Residential households	157.5	157.5	153.5	150.5	147.5	145.5	143.5	143.5
Employee	43.7	42.8	42.8	42.8	42.8	42.8	42.8	42.8
Water use (mgd)								
Residential households	1.160	1.194	1.195	1.190	1.185	1.184	1.179	1.205
Employee	0.960	1.058	1.107	1.135	1.153	1.168	1.169	1.169
Unmetered	0.276	0.353	0.361	0.364	0.366	0.369	0.368	0.372
Total water use	2.40	2.60	2.66	2.69	2.70	2.72	2.72	2.75
Population	22,331	22,972	23,519	23,846	24,172	24,449	24,644	25,405

Table D-7: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for Fairfax Water – PWCSA

	2005	2010	2015	2020	2025	2030	2035	2040
Households	81,006	95,114	107,658	120,304	131,453	140,872	148,552	154,651
Dwelling unit ratio	4.03	3.82	2.68	2.07	1.73	1.54	1.42	1.36
Single family households	64,901	75,381	78,403	81,117	83,302	85,411	87,167	89,121
Multi-family households	16,105	19,733	29,255	39,187	48,151	55,461	61,385	65,530
Employment	78,005	85,743	101,902	119,100	136,596	154,014	166,697	185,262
% Unmetered (% of billed)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Unit use (gpd)								
Single family households	270.8	279.4	275.4	272.4	269.4	267.4	265.4	263.4
Multi-family households	173.8	188.6	184.6	181.6	178.6	176.6	174.6	172.6
Employee	47.6	51.4	51.4	51.4	51.4	51.4	51.4	51.4
Water use (mgd)								
Single family households	17.575	21.059	21.589	22.093	22.438	22.836	23.131	23.471
Multi-family households	2.799	3.721	5.400	7.115	8.598	9.793	10.716	11.309
Employee	3.716	4.408	5.239	6.124	7.023	7.919	8.571	9.525
Unmetered	2.409	2.919	3.223	3.533	3.806	4.055	4.242	4.431
Total water use	26.50	32.11	35.45	38.87	41.87	44.60	46.66	48.74
Population	235,999	276,820	306,859	336,725	362,927	385,155	403,423	418,105

Table D-8: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for Fairfax Water – Virginia American (City of Alexandria)

	2005	2010	2015	2020	2025	2030	2035	2040
Households	66,337	70,434	73,127	77,234	81,801	86,110	89,811	93,006
Dwelling unit ratio	0.47	0.45	0.43	0.41	0.39	0.37	0.36	0.35
Single family households	21,210	21,859	21,989	22,458	22,951	23,256	23,774	24,113
Multi-family households	45,127	48,575	51,138	54,776	58,850	62,854	66,038	68,893
Employment	105,821	109,109	123,820	136,032	147,312	156,831	159,768	164,844
% Unmetered (% of billed)	14.7%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%	14.0%
Unit use (gpd)								
Single family households	164.7	175.0	171.0	168.0	165.0	163.0	161.0	159.0
Multi-family households	167.8	153.3	149.3	146.3	143.3	141.3	139.3	137.3
Employee	41.8	42.9	42.9	42.9	42.9	42.9	42.9	42.9
Water use (mgd)								
Single family households	3.492	3.826	3.761	3.773	3.787	3.791	3.828	3.834
Multi-family households	7.571	7.448	7.636	8.015	8.434	8.883	9.200	9.461
Employee	4.421	4.675	5.306	5.829	6.312	6.720	6.846	7.064
Unmetered	2.273	2.226	2.331	2.459	2.587	2.707	2.774	2.841
Total water use	17.76	18.17	19.03	20.08	21.12	22.10	22.65	23.20
Population	135,854	142,420	147,212	154,114	161,675	166,652	172,787	178,128

Table D-9: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for Fairfax Water – Virginia American (Dale City)

	2005	2010	2015	2020	2025	2030	2035	2040
Households	20,618	21,903	23,111	23,340	23,518	23,653	23,771	23,871
Dwelling unit ratio	3.14	2.60	1.67	1.29	1.13	0.98	0.89	0.84
Single family households	15,633	15,824	14,467	13,142	12,451	11,688	11,186	10,864
Multi-family households	4,985	6,079	8,644	10,198	11,067	11,965	12,585	13,007
Employment	9,212	9,950	11,279	12,725	14,207	15,714	16,846	18,484
% Unmetered (% of billed)	19.5%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%	13.4%
Unit use (gpd)								
Single family households	245.2	258.9	254.9	251.9	248.9	246.9	244.9	242.9
Multi-family households	172.6	226.7	222.7	226.4	223.4	221.4	219.4	217.4
Employee	41.8	42.9	42.9	42.9	42.9	42.9	42.9	42.9
Water use (mgd)								
Single family households	3.834	4.097	3.688	3.310	3.099	2.886	2.739	2.639
Multi-family households	0.860	1.378	1.925	2.309	2.473	2.649	2.762	2.828
Employee	0.385	0.426	0.483	0.545	0.609	0.673	0.722	0.792
Unmetered	0.990	0.793	0.819	0.828	0.830	0.834	0.836	0.841
Total water use	6.07	6.69	6.91	6.99	7.01	7.04	7.06	7.10
Population	62,372	66,166	69,013	69,591	70,008	70,333	70,700	71,008

Table D-10: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for WAD – Arlington County DES

	2005	2010	2015	2020	2025	2030	2035	2040
Households	91,909	99,581	108,635	115,754	118,740	120,558	120,846	122,107
Dwelling unit ratio	0.67	0.59	0.52	0.47	0.46	0.44	0.44	0.44
Single family households	36,775	36,778	37,202	37,214	37,186	37,105	37,100	37,070
Multi-family households	55,134	62,803	71,433	78,540	81,554	83,453	83,746	85,037
Employment	192,754	212,380	235,852	257,818	265,273	269,933	276,493	278,972
% Unmetered (% of billed)	24.1%	18.8%	18.8%	18.8%	18.8%	18.8%	18.8%	18.8%
Unit use (gpd)								
Single family households	164.7	165.5	161.5	158.5	155.5	153.5	151.5	149.5
Multi-family households	103.3	98.4	94.4	91.4	88.4	86.4	84.4	82.4
Employee	42.5	41.4	41.4	41.4	41.4	41.4	41.4	41.4
Water use (mgd)								
Single family households	6.057	6.086	6.007	5.897	5.781	5.695	5.620	5.541
Multi-family households	5.694	6.179	6.743	7.178	7.209	7.210	7.068	7.006
Employee	8.185	8.785	9.755	10.664	10.972	11.165	11.436	11.539
Unmetered	4.801	3.951	4.224	4.455	4.497	4.517	4.527	4.520
Total water use	24.74	25.00	26.73	28.19	28.46	28.59	28.65	28.61
Population	196,628	208,808	224,239	235,418	239,818	242,663	243,130	245,048

Table D-11: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for WAD – D.C. WASA

	2005	2010	2015	2020	2025	2030	2035	2040
Households	253,379	275,963	295,189	312,611	323,556	334,682	345,702	359,378
Dwelling unit ratio	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Single family households	102,975	112,153	119,967	127,047	131,495	136,017	140,496	146,054
Multi-family households	150,404	163,810	175,222	185,564	192,061	198,665	205,206	213,324
Employment	750,260	788,162	815,160	859,160	893,468	920,576	929,763	957,162
% Unmetered (% of billed)	30.8%	25.5%	25.5%	25.5%	25.5%	25.5%	25.5%	25.5%
Unit use (gpd)								
Single family households	177.5	172.4	168.4	165.4	162.4	160.4	158.4	156.4
Multi-family households	140.4	122.5	118.5	115.5	112.5	110.5	108.5	106.5
Employee	58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6
Water use (mgd)								
Single family households	18.277	19.335	20.202	21.014	21.355	21.817	22.255	22.843
Multi-family households	21.111	20.067	20.764	21.433	21.607	21.952	22.265	22.719
Employee	43.977	46.186	47.768	50.347	52.357	53.946	54.484	56.090
Unmetered	25.677	21.795	22.596	23.630	24.273	24.883	25.211	25.886
Total water use	109.04	107.38	111.33	116.42	119.59	122.60	124.21	127.54
Population	582,164	610,732	640,294	677,967	714,786	734,895	759,305	789,456

Table D-12: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for WAD – Falls Church

	2005	2010	2015	2020	2025	2030	2035	2040
Households	49,251	52,050	57,673	60,182	62,258	64,163	65,639	67,203
Dwelling unit ratio	1.90	1.88	1.70	1.69	1.67	1.65	1.64	1.56
Single family households	32,243	33,953	36,327	37,787	38,905	39,959	40,789	40,981
Multi-family households	17,008	18,097	21,346	22,395	23,353	24,204	24,850	26,222
Employment	126,825	140,469	150,159	158,732	166,510	171,521	176,103	180,417
% Unmetered (% of billed)	33.2%	15.8%	15.8%	15.8%	15.8%	15.8%	15.8%	15.8%
Unit use (gpd)								
Single family households	136.6	194.5	190.5	187.5	184.5	182.5	180.5	178.5
Multi-family households	118.0	149.6	145.6	142.6	139.6	137.6	135.6	133.6
Employee	18.6	29.6	29.6	29.6	29.6	29.6	29.6	29.6
Water use (mgd)								
Single family households	4.403	6.605	6.922	7.087	7.179	7.294	7.364	7.317
Multi-family households	2.007	2.706	3.107	3.192	3.259	3.329	3.368	3.502
Employee	2.365	4.156	4.443	4.697	4.927	5.075	5.211	5.338
Unmetered	2.909	2.126	2.285	2.364	2.426	2.478	2.517	2.551
Total water use	11.68	15.59	16.76	17.34	17.79	18.18	18.46	18.71
Population	123,825	129,794	141,750	147,297	151,865	155,950	159,113	164,728

Table D-13: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for WAD – Fort Meyer

	2005	2010	2015	2020	2025	2030	2035	2040
Households	305	305	305	305	305	305	305	305
Dwelling unit ratio	0.67	0.59	0.52	0.47	0.46	0.44	0.44	0.44
Single family households	122	113	104	98	96	94	94	93
Multi-family households	183	192	201	207	209	211	211	212
Employment	2,121	2,121	1,782	1,782	1,782	1,782	1,782	1,782
% Unmetered (% of billed)	24.1%	18.8%	18.8%	18.8%	18.8%	18.8%	18.8%	18.8%
Unit use (gpd)								
Single family households	206.4	211.3	207.3	204.3	201.3	199.3	197.3	195.3
Multi-family households	170.0	167.7	163.7	156.7	157.7	155.7	153.7	151.7
Employee	92.1	114.9	114.9	114.9	114.9	114.9	114.9	114.9
Water use (mgd)								
Single family households	0.025	0.024	0.022	0.020	0.019	0.019	0.018	0.018
Multi-family households	0.031	0.032	0.033	0.032	0.033	0.033	0.032	0.032
Employee	0.195	0.244	0.205	0.205	0.205	0.205	0.205	0.205
Unmetered	0.061	0.056	0.049	0.048	0.048	0.048	0.048	0.048
Total water use	0.31	0.36	0.31	0.31	0.31	0.30	0.30	0.30
Population	2,594	2,594	2,594	2,594	2,594	2,594	2,594	2,594

Table D-14: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for WAD – Vienna

	2005	2010	2015	2020	2025	2030	2035	2040
Households	9,647	9,662	9,915	10,168	10,357	10,511	10,649	11,306
Dwelling unit ratio	12.03	11.65	11.31	10.63	10.00	9.56	9.28	8.78
Single family households	8,907	8,898	9,109	9,294	9,416	9,515	9,613	10,150
Multi-family households	740	764	806	874	941	996	1,036	1,156
Employment	13,467	14,105	14,440	14,727	14,928	15,028	15,054	15,079
% Unmetered (% of billed)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Unit use (gpd)								
Single family households	207.7	201.7	197.7	194.7	191.7	189.7	187.7	185.7
Multi-family households	148.6	136.4	132.4	129.4	126.4	124.4	122.4	120.4
Employee	29.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7
Water use (mgd)								
Single family households	1.850	1.795	1.801	1.809	1.805	1.805	1.804	1.885
Multi-family households	0.110	0.104	0.107	0.113	0.119	0.124	0.127	0.139
Employee	0.400	0.390	0.399	0.407	0.413	0.416	0.416	0.417
Unmetered	0.236	0.229	0.231	0.233	0.234	0.234	0.235	0.244
Total water use	2.60	2.52	2.54	2.56	2.57	2.58	2.58	2.69
Population	26,788	26,832	27,547	28,237	28,740	29,154	29,521	31,408

Table D-15: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for City of Rockville

	2005	2010	2015	2020	2025	2030	2035	2040
Households	16,891	17,880	19,289	20,484	21,868	23,270	24,775	26,282
Dwelling unit ratio	1.90	1.59	1.23	1.09	1.03	1.02	0.87	0.80
Single family households	11,063	10,987	10,657	10,703	11,088	11,739	11,492	11,677
Multi-family households	5,828	6,893	8,632	9,781	10,780	11,531	13,283	14,605
Employment	63,034	64,893	69,266	74,835	80,304	82,054	84,629	87,180
% Unmetered (% of billed)	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
Unit use (gpd)								
Single family households	154.6	171.6	167.6	164.6	161.6	159.6	157.6	155.6
Multi-family households	139.1	154.4	150.4	147.4	144.4	142.4	140.4	138.4
Employee	16.6	21.7	21.7	21.7	21.7	21.7	21.7	21.7
Water use (mgd)								
Single family households	1.710	1.885	1.786	1.761	1.791	1.873	1.811	1.816
Multi-family households	0.811	1.064	1.298	1.442	1.557	1.642	1.865	2.021
Employee	1.049	1.411	1.506	1.627	1.746	1.784	1.840	1.896
Unmetered	0.357	0.436	0.459	0.483	0.509	0.530	0.552	0.573
Total water use	3.93	4.80	5.05	5.31	5.60	5.83	6.07	6.31
Population	40,811	46,014	49,337	51,994	54,770	57,301	60,271	63,045

Table D-16: Demographic data, unit use (gpd), and total water use (mgd) information used in low prediction calculations, for WSSC

	2005	2010	2015	2020	2025	2030	2035	2040
Households	604,616	638,164	671,523	702,580	728,430	751,446	767,682	779,144
Dwelling unit ratio	2.02	2.03	1.91	1.80	1.71	1.62	1.57	1.54
Single family households	404,670	427,558	440,648	452,009	459,471	464,859	469,027	472,132
Multi-family households	199,946	210,606	230,875	250,571	268,959	286,587	298,655	307,012
Employment	754,707	791,144	838,718	892,620	949,158	1,013,802	1,072,578	1,123,295
% Unmetered (% of billed)	16.0%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%	15.5%
Unit use (gpd)								
Single family households	179.6	187.0	183.0	180.0	177.0	175.0	173.0	171.0
Multi-family households	162.6	146.1	142.1	139.1	136.1	134.1	132.1	130.1
Employee	49.0	44.7	44.7	44.7	44.7	44.7	44.7	44.7
Water use (mgd)								
Single family households	72.678	79.953	80.639	81.362	81.326	81.350	81.142	80.734
Multi-family households	32.502	30.770	32.807	34.854	36.605	38.431	39.452	39.942
Employee	36.987	35.364	37.491	39.900	42.427	45.317	47.944	50.211
Unmetered	22.747	22.643	23.395	24.198	24.856	25.590	26.123	26.488
Wholesale Customers (mdg)								
Howard County	3.07	2.5	2.5	5.0	5.0	5.0	5.0	5.0
Charles County	0.001	0.7	0.7	1.4	1.4	1.4	1.4	1.4
Total water use	167.99	171.93	177.53	186.71	191.61	197.09	201.06	203.78
Population	1,643,710	1,722,867	1,798,891	1,863,331	1,915,281	1,957,915	1,988,990	2,009,184

Appendix E Recent Changes to the PRRISM Model

E1 Modeling Water Quality Operations in the North Branch Potomac

Jennings Randolph Reservoir on the North Branch Potomac River and Savage Reservoir on the Savage River are both operated by the U.S. Army Corps of Engineers, Baltimore District (Baltimore District COE) to improve water quality in the North Branch Potomac River. Together, these two reservoirs regulate flow in the North Branch downstream of Luke, MD, below the confluence of the North Branch and the Savage River for water supply and water quality purposes.

In the 1970s, before the North Branch reservoirs were built, the Baltimore District COE documented the basic guidelines that they expected to follow in managing water quality storage in Jennings Randolph and Savage reservoirs in the report, *Master Manual for Reservoir Regulation North Branch Potomac River Basin*, which contains *Appendix A, Jennings Randolph Lake* (USACE, 1997), and *Appendix B, Savage River Dam* (USACE, 1999). These guidelines recommend that the North Branch reservoirs are operated to use as much of the available water quality storage as needed every year to produce the greatest possible improvement in water quality downstream in the North Branch Potomac while also meeting target elevations at each reservoir. Joint regulation of the two reservoirs is used to meet water quality and other goals. The release rules for water quality at both reservoirs are based on the expected inflow rate and the volume of remaining storage in the lake. These guidelines, however, were developed before the Water Resources Development Act of 1988 and, therefore, do not consider recreational benefits at Jennings Randolph from the beach, the MD and VA boat launches, and the recent improvements in overall water quality in the North Branch Potomac River (Personal conversation with Bill Haines, Baltimore District COE, January 7, 2009).

Because of changed North Branch conditions, the Baltimore District COE has progressively modified their water quality operational guidelines to address current reservoir elevation and downstream flow requirements. Modifications to reservoir releases are determined by professional judgment, and ICPRB is indebted to Bill Haines, Barry Flickinger, and Julie Fritz of the Baltimore District COE for their help in understanding how the Baltimore District COE makes release decisions. Earlier efforts in understanding Baltimore District COE operational modifications for the 2005 demand study were guided by Stan Brua of the Baltimore District COE.

Recommendations considered by the Baltimore District COE during this process came from the North Branch Potomac River Advisory Committee, established in 2005 through the National Park Service, Northeast Region, Trails and Conservation Assistance Program. The committee was formed in order to provide a forum for public input regarding operations and management of the dams, surrounding public lands and downstream flow levels for all project purposes, especially recreation. In 2008, the Interstate Commission on the Potomac River Basin (ICPRB) took leadership over this project.

Apart from modifications to elevation and release targets, the fundamental difference between the *Master Manual* guidelines and the modified guidelines, presented below, is the application of a stepped rule table that was developed by the Baltimore District COE in coordination with the North Branch Potomac River Advisory Committee. The stepped rule table guides when Jennings Randolph reservoir downstream flow and lake elevation targets should be abandoned during dry conditions. The goal of the stepped rule table is to accommodate all activities during the recreation season while trying to meet all legally mandated uses of the Jennings Randolph Reservoir. Savage Reservoir rule curves were not modified from the *Master Manual;* the application of these rule curves, however, was modified so that water quality releases support the needs of downstream fisheries. These modifications are a work-in-progress that may need further refinement and are best reflected in the past four years of Baltimore District COE operations (Personal conversation with Bill Haines, Baltimore District COE, April 16, 2009).

It is important to note that the Baltimore District COE finds this particular representation of the North Branch reservoir operational guidelines appropriate for ICPRB analyses but may not do so for other applications. Therefore, the Baltimore District COE prefers to be contacted prior to people trying to implement these operational guidelines into new analyses.

E2 Estimating Current Reservoir Inflows

The Baltimore District COE estimates current inflow at each reservoir. Recent inflows are examined to develop an estimate of the current inflow. If a recent storm has come through, higher inflows are disregarded. If inflows are decreasing, the lowest inflows are given more weight in determining a current inflow. An algorithm was developed to approximate this process for both Jennings Randolph Reservoir and Savage Reservoir.

Inputs to the algorithm include a time-series of inflow data for eight consecutive days. The algorithm sorts the inflows, averages the five smallest values, compares this average inflow with the most recent inflow value, and takes the smaller of either the computed average or most recent inflow value. Figure E-1 illustrates the inputs and outputs of this algorithm, as implemented using the object-oriented program Extend™. Flow inputs are in blue, and the inflow output is in red. Similarly to how the Baltimore District COE determines current inflow, the algorithm tends to disregard peak inflows, and if inflows are decreasing the algorithm gives more weight to the recent low inflows. Note that the output of this algorithm is a rough approximation of the baseflow for the inflow regime. These methods remain consistent between the 2005 ICPRB demand study and the current study.

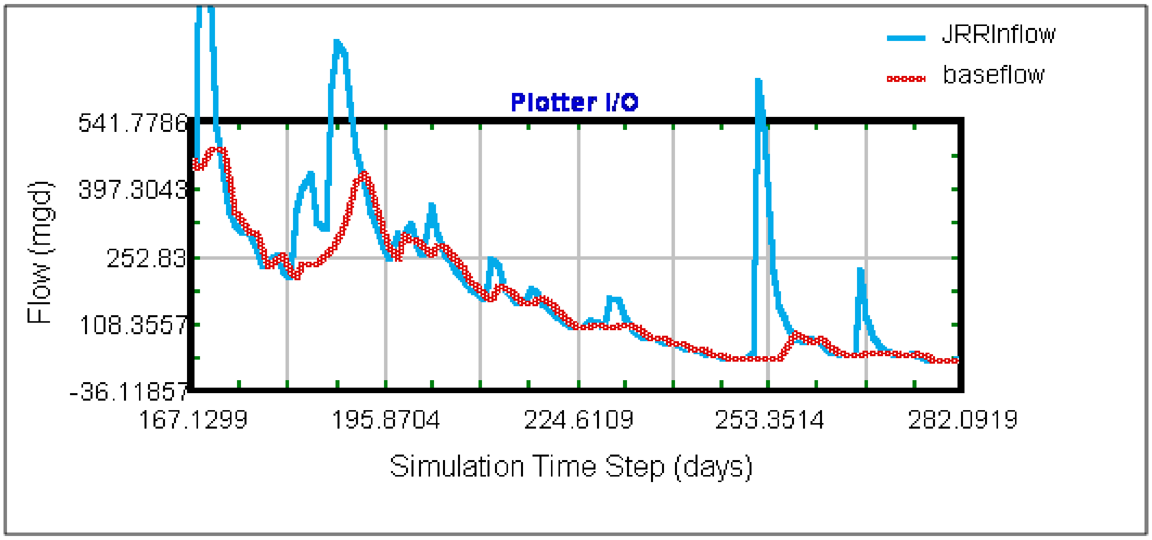

Figure E-1: Example input flow series (blue) and output (red from model subroutine in Extend).

E3 Determining Expected Inflow

Expected inflow is a prediction of inflow in the future and is used to ensure that lake elevations and outflows are adequate to support lake and downstream activities between specific date intervals. The calculation of expected inflow assumes that the inflow in upcoming months will follow the pattern (percentile) of recent inflows. The Baltimore District COE previously used the current inflow trend to look up expected inflow using graphical tools ("consecutive monthly inflow frequency curves") given in the *Master Manual*. These consecutive monthly inflow frequency curves are based on gage inflows at Kitzmiller, MD. The consecutive monthly inflow frequency curves were prepared over two- to five-month periods, depending on the desired time horizon over which the Baltimore District COE wished to make a forecast of inflow volume.

The graphical tools used by the Baltimore District COE were approximated in a lookup table format in the ICPRB (2005) demand study. These tables were used in the Extend™ modeling environment to determine expected inflow given inputs of current inflow percentiles and time of year. The lookup tables that were developed for this purpose can be found in Prelewicz *et al*. (2004).

Based on a recommendation by Bill Haines (Baltimore District COE), the expected inflow calculations are no longer used for most inflow calculations in the current version of the PRRISM. In place of using expected inflows, Savage Reservoir assumes that inflows equal the current inflow and is evaluated on a daily basis. Similarly, Jennings Randolph Reservoir also assumes inflows equal to current inflow values, but only during the non-recreation season (a modified version of the expected inflow calculations are still used during Jennings Randolph's recreation season).

The methods used to calculate Jennings Randolph expected inflows have been changed to account for updated forecast intervals important to the recreation season. Expected inflow calculations are now based on Table E-1and have been programmed into the Extend™ (Imagine That!, 2005) modeling environment for the current demand study. The values in Table E-1 are used to determine the average daily expected inflow for the months of May, June, July, and August by using input values equal to the previous month and the current flow percentile. For example, given a 5 percentile flow in May, the model would output an expected inflow of 251 mgd, which is equal to the expected inflow for a 5 percentile flow in April. For the days between May 1 and September 1, these daily average expected inflows are then multiplied by their respective number of days in each month to get a monthly average expected inflow. The monthly expected inflows are then summed to calculate the total flow starting on the current model simulation day (earliest being May 1 for the recreation season) and ending on each of the following dates: September 1, August 15, August 1, July 15, and July 4. For example, the expected flow between May 1 and September 1 is calculated by multiplying May, June, July, and August expected flows by their respective 31, 30, 31, and 31 days; these monthly total expected inflows are then summed to get the a total flow between May 1 and September 1. Inflows for months not included between May 1 and September 1 are looked at on a daily basis and are assumed to equal the current flow baseflow approximation as described earlier.

Table E-1: Inflow percentile by month for Jennings Randolph Reservoir.

Month	Jennings Randolph Reservoir Inflow Percentile													
	1%	3%	5%	7%	10%	15%	20%	30%	40%	50%	60%	70%	80%	90%
	Flow (mgd)													
January	74	90	146	154	161	184	211	268	325	372	431	538	598	682
February	136	147	169	172	199	283	297	343	420	520	546	592	694	789
March	241	340	354	361	380	427	446	486	554	617	686	788	912	1061
April	182	233	251	261	285	324	340	389	469	536	618	659	708	786
May	112	126	143	145	153	169	190	253	294	390	451	487	553	665
June	44	46	54	58	64	79	87	115	146	167	225	288	354	395
July	21	26	27	34	40	48	58	65	83	117	153	182	235	378
August	19	21	23	25	34	38	42	49	69	98	110	136	187	255
September	15	19	20	21	23	27	32	40	46	55	77	91	147	251
October	16	17	19	24	25	29	34	55	67	78	99	139	206	292
November	22	27	32	38	58	81	92	116	149	171	201	257	309	408
December	45	53	67	77	105	145	174	250	277	318	360	430	523	597

The Jennings Randolph reservoir forecast intervals are important for ensuring that lake elevations and flows between May 1 and September 1 are adequate to support lake and downstream activities. The ICPRB (2005) demand study included an intermediate September 1 target, as the Baltimore District COE makes efforts to maintain reservoir storage at Jennings Randolph Reservoir at levels allowing use of the boat ramp through Labor Day weekend. The forecast intervals have been expanded to include conservation pool, beach, West Virginia boat ramp, and Maryland boat ramp targets agreed upon by the Baltimore District COE and the North Branch Potomac River Advisory Committee. See Table E-2 for target details.

E4 Rule Curves/Expected Available Storage

The Baltimore District COE uses rule curves to define target reservoir storage levels for different times of the year. During the drawdown season, the storage available for release is the difference between current storage and target storage. During the refill season, if reservoir storage is below the target storage, there is no storage available for release and the difference between current storage and target storage must be met by inflow.

The rule curves defining target storage levels throughout the year are shown in Figure E-2 and Figure E-3 for Savage Reservoir and Jennings Randolph Reservoir, respectively. Multiple rule curves exist for each reservoir: the Jennings Randolph rule curves are modified from Plate 7-01 in *Appendix A* of the *Master Manual*; the Savage rule curves were taken directly from Plate 7-01 in *Appendix B* of the *Master Manual* with adjustments to the flow releases. The Baltimore District COE's use of the different curves and their implementation in the model are described in the sections below.

E4.1 Savage Reservoir Rule Curves

The Baltimore District COE currently follows a rule curve that defines target storage levels throughout the year for Savage Reservoir (Figure E-2). Savage Curve A defines the upper limit of storage while Savage Curve C defines the lower limit of storage levels. However, in very dry conditions, storage may drop below Savage Curve C, at which point releases are limited to the legal minimum of 20 cfs. If storage drops below Savage Curve D or a volume of 652 mg, water supply withdrawals by the Town of Westernport are priority and releases are limited to the minimum of either the inflow or 20 cfs. The rules between Curve A and Curve C were modified in PRRISM so that a minimum flow of 55 cfs could be maintained most of the year to support downstream fisheries. When elevations are getting low, a modified curve equal to 125 percent of Curve C elevations is used to drop releases from 55 cfs down to 40 cfs. The 125 percent adjustment was arbitrarily chosen by ICPRB and may change in the future.

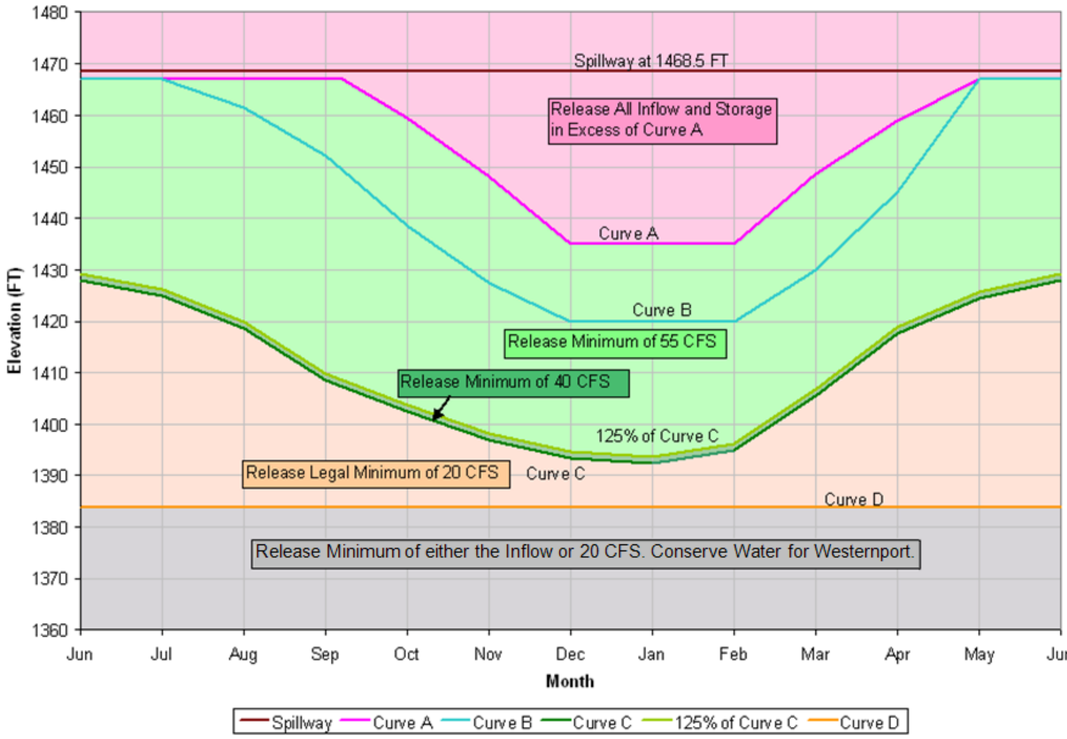

Figure E-2: Savage Reservoir Rule Curves

Curve B is no longer used in the Savage Reservoir Rule Curves and is a significant difference between the PRRISM models used in the ICPRB (2005) demand study and the current study. Curve B had acted as the reservoir's optimal storage target. The 2005 PRRISM model had used Curve B to set target storage and expected available storage rates. The target storage was determined by adding 30 days to the current day's timestep and finding the Curve B storage value associated with that date. This target storage was subtracted from the current storage in the reservoir to obtain the expected available storage. This quantity was divided by the number of days to the storage target to get the largest release rate possible from expected available storage. This release rate was added to the expected inflow to obtain the total calculated release rate. The calculated release rate at Savage Reservoir was overridden if storage dropped below Savage Curves C or D, when releases were limited to the specified minimums. The calculated releases were also overridden if storage rises above Savage Curve A, the upper limit of storage. Any storage above Savage Curve A was quickly released to draw the reservoir down. These methods posed a problem to downstream fisheries because they allowed flow rates less than 55 cfs. The new methods summarized in Figure 2 correct this problem for the current demand study.

E4.2 Jennings Randolph Rule Curves

At Jennings Randolph Reservoir, the Baltimore District COE has published rule curves based on the available storage in the water quality portion of the reservoir storage. These curves make the implicit assumption that water supply storage is 100% full. To get total storage that could be converted to lake elevation, water supply storage must be added back into the published rule curves. The published curves are available from Plate 7-01 in *Appendix A* of the *Master Manual*.

In actual operations, the Baltimore District COE incorporates a set of lake elevation and reservoir outflow targets needed for both lake and downstream activities. When water supply releases are made, the total storage in the reservoir is affected, and affects the ability of the Baltimore District COE to meet these targets. The actual rule curves, therefore, are based on a combined water supply and water quality storage because the water supply storage helps the Baltimore District COE to meet these targets.

ICPRB has incorporated a set of rule curves into the PRRISM model that are a modification of the Baltimore District COE published rule curves. The rule curves explicitly accounts for total reservoir storage during the fall drawdown and spring refill periods (Figure E-3). A stepped rule table accounts for the total reservoir storage during the recreation season between May 1 and September 1 (Table E-2). Both the rule curve and the stepped rule table were developed by Bill Haines and Barry Flickinger of the Baltimore District COE.

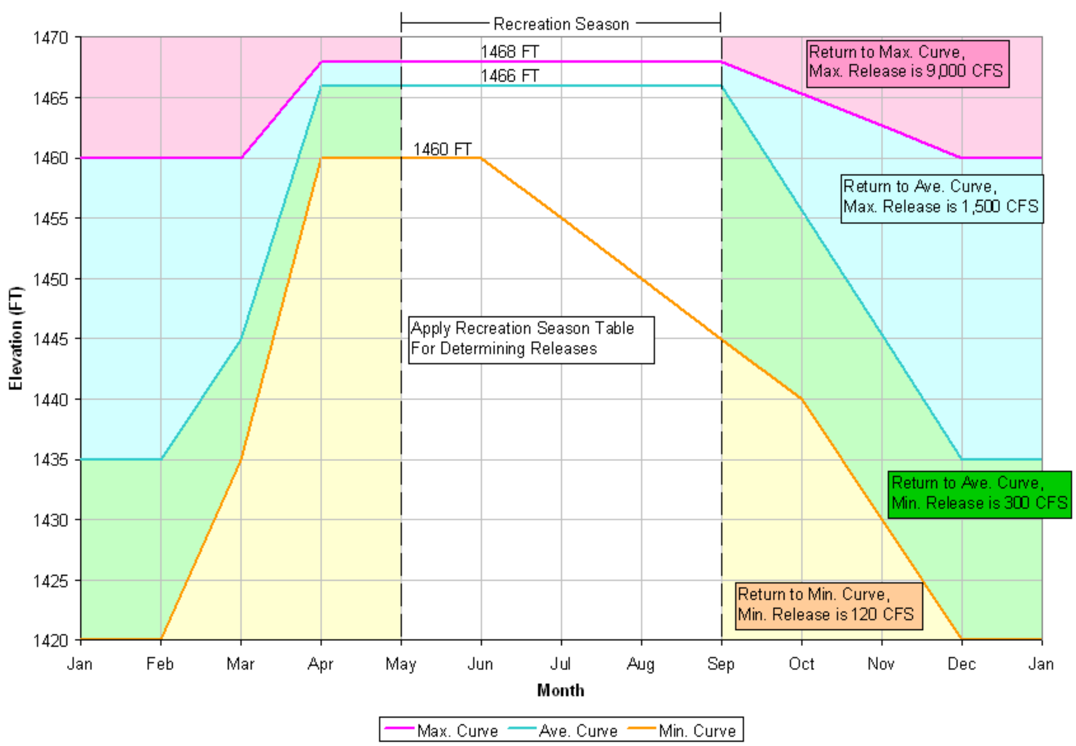

Figure E-3. Jennings Randolph Reservoir modified rule curves for the fall drawdown and spring refill periods.

Table E-2: Jennings Randolph Reservoir stepped rule table for the summer recreation season between May 1 and September 1.

Priority	Date	Elevation Target	Reservoir Outflow Target	Luke Flow Target
1	May 1 through September 1	1466 FT (Conservation Pool)	300 cfs	300 cfs
2	…through September 1	1455 FT (Beach)	300 cfs	300 cfs
3	…through August 15	Greater than 1455 FT (Beach)	300 cfs	300 cfs
4	…through August 15	Greater than 1455 FT	250 cfs	300 cfs
5	…through August 1	Greater than1455 FT	250 cfs	300 cfs
6	…through August 1	Greater than 1455 FT	200 cfs	250 cfs
7	…through July 4	Greater than 1455 FT	200 cfs	250 cfs
8	…through July 4	Greater than 1455 FT	150 cfs	200 cfs
9	…through July 15	Greater than 1445 FT (West Virginia Boat Launch)	150 cfs	200 cfs
10	…through September 1	Greater than 1420 FT (Maryland Boat Launch)	150 cfs	200 cfs
11	…		100 cfs	120 cfs

The conservation pool elevation defines the upper limit of storage similar to the published rule Curve A. A maximum curve, however, defines the Baltimore District COE's preferred upper limit of storage. Any storage in excess of this amount is quickly released to bring the storage below the maximum curve. An average curve defines the optimal storage levels which are targeted in normal operations. A minimum curve defines the lower range of storage levels, and operations are designed to prevent storage from falling significantly below this curve. The average and minimum curves replace the published Curve B and Curve C, respectively. The maximum, average, and minimum curves were developed from historical reservoir storages observed in actual operations in an effort to make modeled parameters better match with historical parameters such as flow at Luke, outflow at Jennings Randolph, and lake elevations. The rule curves also set maximum and minimum release rates.

The stepped rule table allows Jennings Randolph Reservoir operations to better accommodate different reservoir conditions. The idea of the stepped table is to allow the model to modify targets for recreational closing dates, lake elevations, Jennings Randolph outflows, and Luke flows. For example, the Baltimore District COE tries to maintain the Jennings Randolph beach at a lake elevation greater than 1455 FT between April 1 and September 1. The PRRISM method used to fulfill this goal follows: The rule curve (Figure E-3) is used to refill the lake to a conservation pool elevation of 1466 FT by April 1. The stepped rule table (Table E-2) then tries to maintain the 1466 FT elevation between May 1 and September 1 with a Jennings Randolph outflow and Luke flow equal to 300 cfs. If conditions in the reservoir prohibit this, then the stepped rule table drops the elevation target to allow for any value between 1466 FT and 1455 FT while maintaining the same beach closing date and two flow targets as before. If conditions continue to limit these operations, the stepped rule curve systematically lowers the two flow targets and then cuts back the beach closing date; until eventually the stepped rule table gives up on the beach and drops the elevation target to 1445 FT for the West Virginia boat launch. The stepped rule table continues to systematically drop the targets until the reservoir reaches the minimum flow of 120 cfs at Luke, Maryland.

The rule curves and stepped table presented above were not included in the methods used in the ICPRB (2005) demand study. The methods used in the past study had incorporated a rule curve into the PRRISM model that was also a modification of the Baltimore District COE published rule curves. For example, the November 1 rule curve target was lowered below that of published Curve B to better reflect historical operations. These curves tried to keep the boat launch at 1445 feet through Labor Day weekend. These curves also tried to maintain a Jennings Randolph reservoir outflow of 300 cfs to support downstream boating and float fishing. However, these curves did not explicitly account for some of the other targets that are presented in Table E-2. Additionally, these curves did not have the built in flexibility of the stepped rule table. A detailed account of the Jennings Randolph rule curves used in the ICPRB (2005) demand study can be found in ICPRB Report No. 04-03.

E4.2.1 Artificially Varied Flows

The Baltimore District COE implements artificially varied flow periods when flows have been low for an extended period of time. During extended periods of low flow, suspended materials settle out and accumulate on the river bed. The artificially varied flow is a large release sustained for 1 to 2 days that is intended to prevent accumulation of these materials, which can degrade the aquatic habitat.

The artificially varied flows have not yet been implemented in the model.

E4.2.2 Whitewater Releases

Whitewater is formed in a rapid where turbulent, fast moving water becomes an unstable current moving around or over obstacles and the frothy water appears white. The term is also used as an adjective describing boating on such rivers, such as whitewater canoeing or whitewater kayaking.

Four Jennings Randolph whitewater releases are scheduled between late April and the first weekend in June. Whitewater releases on Memorial Day weekend are scheduled for odd years. The target releases rate is 1000 cfs for 6 hours on Saturday and 6 hours on Sunday. Whitewater releases can be canceled depending on drought triggers, which are based on antecedent rain, Palmer Drought Index, and Jennings Randolph inflow. Whitewater releases can also be canceled if whitewater releases cause the Jennings Randolph Reservoir total storage elevation to drop below 95% of Jennings Randolph's average curve (Figure 3).

Three Savage Reservoir whitewater releases are scheduled for the first Sunday of July, the first Sunday of August, the first Sunday of September (even year), the second Sunday of September (odd year). The target release rate is 1000 cfs for 6 hours. Whitewater releases can be canceled depending on drought triggers, which are based on antecedent rain, Palmer Drought Index, and

Jennings Randolph inflow. Whitewater releases can also be canceled if whitewater releases causes the Savage Reservoir total storage elevation to drop below 95% of Savage rule curve B (Figure 2).

E4.2.3 Luke Target Flow

The Baltimore COE has set flow targets just downstream of Jennings Randolph and Savage Reservoirs at Luke, Maryland. This flow target is known as the "Luke target". Adjustments to the release from either reservoir can be made to meet the Luke flow target. During the recreational season, reservoir releases can be adjusted either upwards or downwards to ensure that the Luke flow reflects the targets shown in Table 2. During a drought, ICPRB can set larger flow targets to guide the Baltimore COE in making needed water supply releases from the North Branch system.

E5 Model Validation

Using the operational rules described in previous sections, the model calculates reservoir releases from Jennings Randolph and Savage Reservoirs, reservoir storage, Luke flow, and a variety of metrics related to the simulation's success in meeting water quality, water supply, fisheries, and other goals. In this section, we will focus on the model validation, i.e., the ability of the model to reproduce historical reservoir releases, reservoir storage, and downstream flow.

Figure E-4: Baltimore District COE historical versus PRRISM modeled daily total storage elevations at Jennings Randolph Reservoir.

Figure E-4 shows the PRRISM modeled total storage elevations in Jennings Randolph Reservoir versus the historical values of Baltimore District COE. Figure E-5 shows the PRRISM modeled versus the Baltimore District COE historical outflow from Jennings Randolph Reservoir. The vertical axis shows only flows under 1000 cfs, as the analysis focuses mainly on simulation during lower flow periods. These figures show that in some years, for example the last couple years shown, the model does well in matching observed reservoir storage and outflows at low levels. It can also be seen that the model is not always able to emulate Baltimore District COE operations, as seen in the divergence between modeled and observed reservoir storage during fall and winter periods.

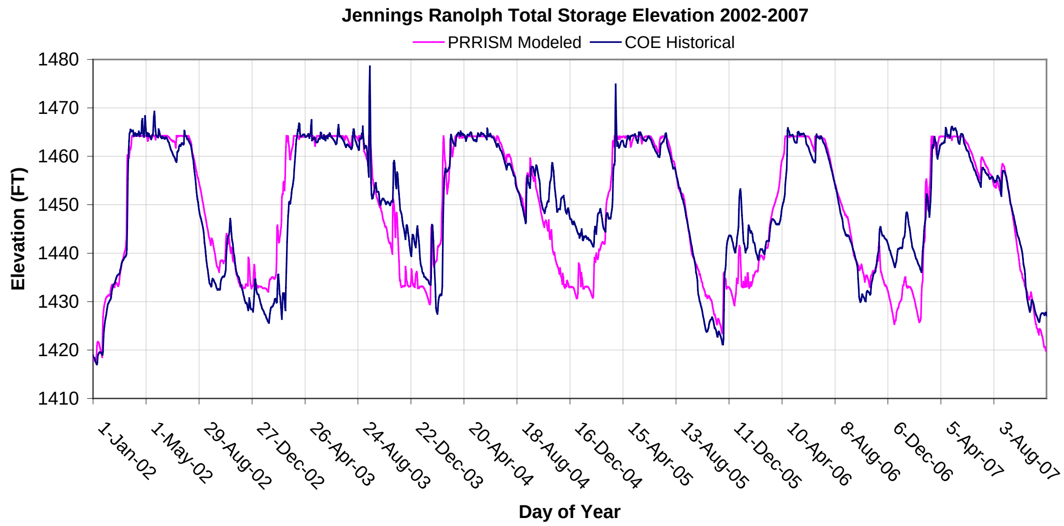

Figure E-4: Baltimore District COE historical versus PRRISM modeled daily total storage elevations at Jennings Randolph Reservoir.

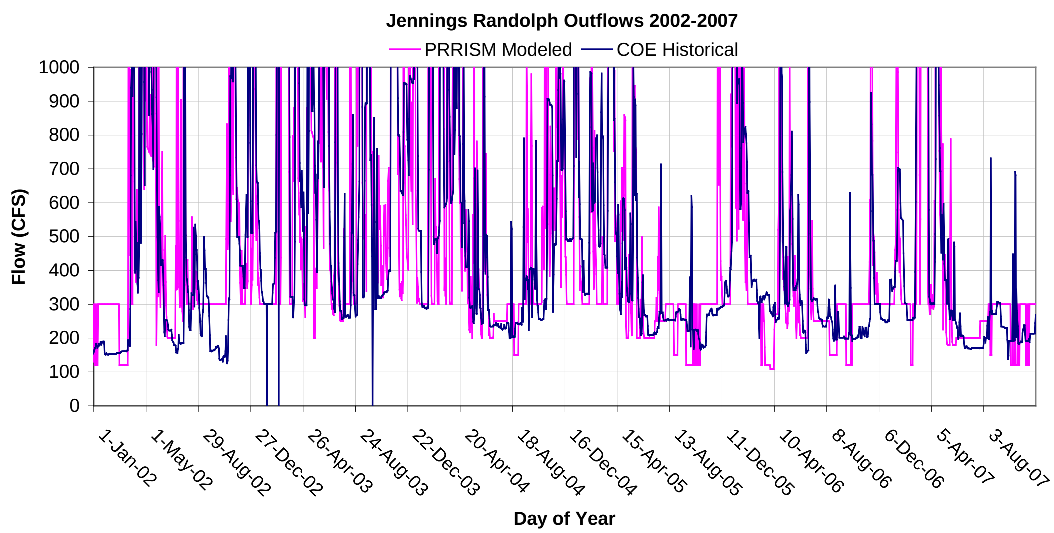

Figure E-5: Baltimore District COE historical versus PRRISM modeled daily outflow from Jennings Randolph Reservoir.

Figure E-6 and Figure E-7 show reservoir storage elevations and reservoir outflows at Savage Reservoir. These figures show that the model is able to simulate historical storage elevations and reservoir outflows well in most time periods, within acceptable tolerances, *i.e.*, they are close enough to historical levels to adequately represent the system.

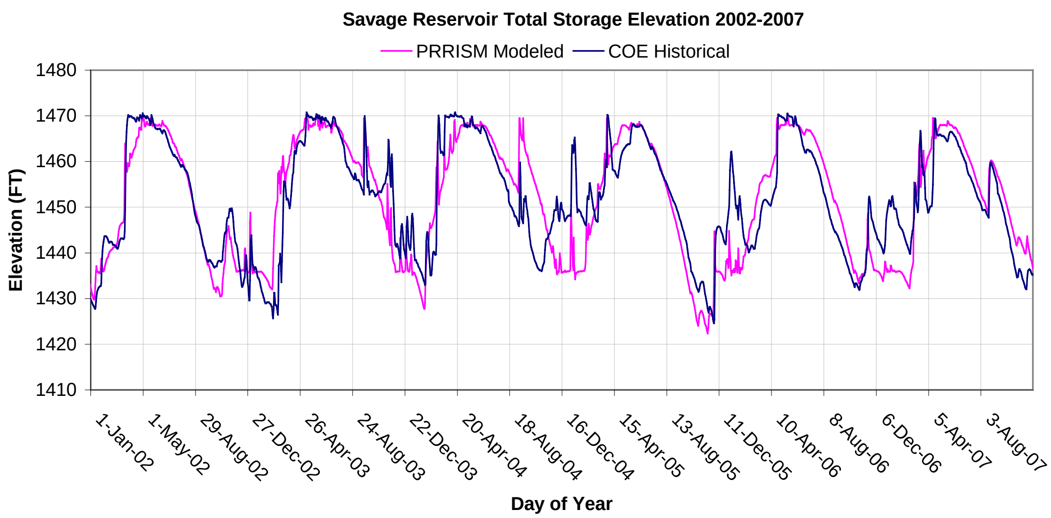

Figure E-6: Baltimore District COE historical versus PRRISM modeled daily total storage elevation at Savage Reservoir.

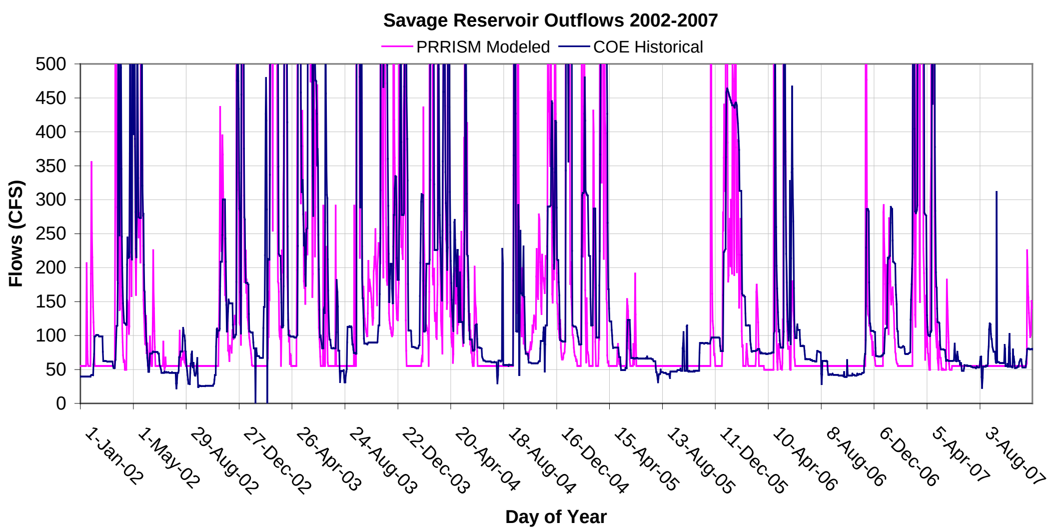

Figure E-7: Baltimore District COE historical versus PRRISM modeled daily outflow from Savage Reservoir.

Figure E-8 shows the USGS gage (01598500) historical versus PRRISM modeled flow at Luke, MD, downstream of both reservoirs. The model is able to simulate historical storage and releases well in most time periods.

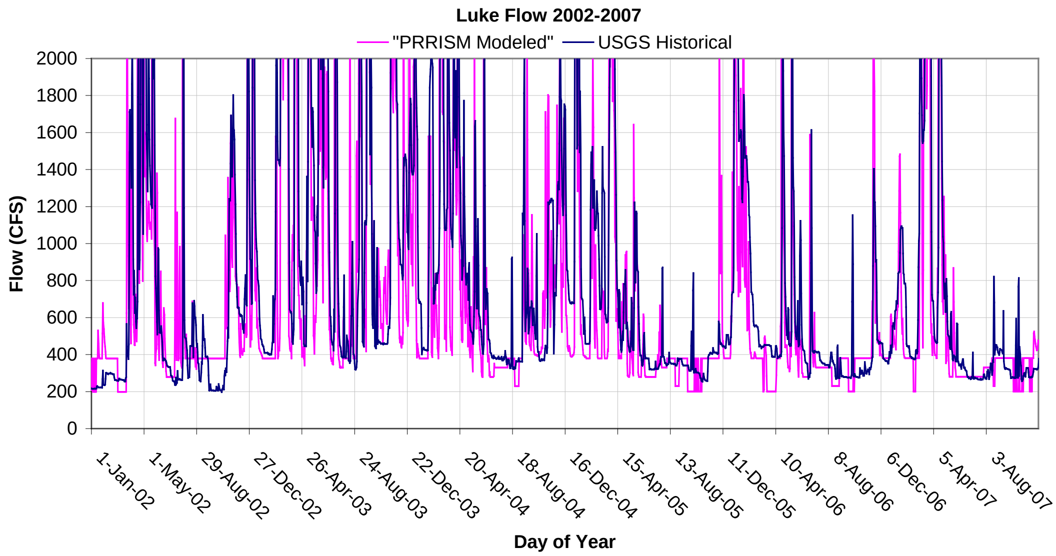

Figure E-8: USGS gage (01598500) historical versus PRRISM modeled daily flow on the North Branch Potomac River at Luke, MD.

Appendix F PRRISM Inputs

Model Input	2005 Study	2010 Study
General		
Potomac River historical flow time series (mgd)	Little Falls, 1929-2002	Little Falls, 1929-2007
Great Falls/Little Falls flow-bys (mgd)	300/100	300/100
Flow-by safety buffer (mgd)	30	30
Little Falls 9-day future flow predictions	Mainstem regression equation	Mainstem regression equation
Load shifting to Occoquan & Patuxent	Yes	Yes
Buffer for balance N Br/L Seneca releases	150	150
Random number seed for single runs	Not applicable	4426
North Branch reservoirs		
JR usable capacity, WS + WQ (MG)	13,262 + 16,501 as of year 2000	12,803 + 15,929 as of year 1997
JR sedimentation rate (MG/yr)	44 (distributed) as of year 2000	127 (distributed) as of year 1997
Savage usable capacity in 2000 (MG)	6331 as of year 2000	6331 as of year 2000
Savage sedimentation rate (MG/yr)	18	18
Savage match	Yes - 20% of JR release	Yes - 16% of JR release
Westernport withdrawal/cutbacks	1/No	1/No
North Branch Advisory Group Recommendations		
JR whitewater releases	No	Yes
Savage whitewater releases	No	Yes
Threshold for making Savage WW releases as percentage of Rule Curve B	NA	95%
Try to meet Luke flow target on non-WW weekends	NA	No
Little Seneca Reservoir		
Usable capacity in (BG)	3,785 as of year 2000	3,785 as of year 2000
Sedimentation rate (MG/yr)	15	15
Occoquan Reservoir		
Usable capacity (MG)	8,004 as of year 2000	8,004 as of year 2005
Sedimentation rate (MG/yr)	40	40
Rule curve	70 mgd + UOSA	70 mgd + UOSA; 70 mgd; 60 mgd; 50 mgd
Maximum treatment rate (mgd)	120	120 in 2010; to 140 in 2018; to 160 in 2040
Delta load shift (mgd)	40	35
Treatment plant water loss rate (percentage)	12%	12%
Cut back Occoquan withdrawals Jun 1 to Jul 15?	No	No
Reset Occoquan?	No	No

Model Input	**2005 Study**	**2010 Study**
Patuxent reservoirs		
Usable capacity (MG)	10,080 as of year 2000	10,080 as of year 2004
Sedimentation rate (MG/yr)	24	24
Patuxent rule curve, mgd	20/40/60	30/40/60
Maximum treatment rate (mgd)	100	100
Delta load shift (mgd)	40	40
Cut back Patuxent withdrawals Jun 1 – Jul 15?	No	Yes – to 27 mgd
Reset Patuxent reservoirs?	No	No
Consumptive Use & WWTP return flows (mgd)		
Upstream consumptive use for Jun-Aug (mgd)	Based on Steiner *et al*., (2000), plus 1 mgd for Mirant Dickerson	Based on Steiner *et al*., (2000), plus 1 mgd for Mirant Dickerson
Upstream consumptive use for Sep-May (mgd)	Based on Steiner *et al*., (2000), plus 1 mgd for Mirant Dickerson	Based on Steiner *et al*., (2000), plus 1 mgd for Mirant Dickerson
Broad Run WWTP return flows (mgd)	2005, 2010, 2015, 2020, 2025, 2030: 0, 0, 5.2, 7.8, 9.6, 11	Based on estimated Loudoun Water wintertime demand and consumptive use estimate (see Section 6.5)
Seneca WWTP return flows (mgd)	2005, 2010, 2015, 2020, 2025, 2050: 17.1, 18.8, 20.6, 22, 22.5, 27	2010, 2015, 2020, 2025, 2030, 2035, 2040: 18.82, 20.57, 22.13, 23.49, 24.58, 26.37, 27.86
UOSA WWTP return flows (mgd)	2005, 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, 2050: 29, 33.5, 38, 42.5, 47, 51.5, 56, 60.5, 65, 69.5	2010, 2015, 2020, 2025, 2030, 2035, 2040: 32.15, 36.35, 40.45, 44.45, 48.45, 52.45, 56.45
Water use restrictions		
Water use restrictions	Yes	Yes
Restriction triggers: JR and/or L Seneca storage <, Voluntary/Mandatory/Emergency	60%/25%/5%	60%/25%/5%
Assumed demand reduction, Jun-Sep, Voluntary/Mandatory/Emergency	5%/9.2%/15%	5%/9.2%/15%
Assumed demand reduction in other months, Voluntary/Mandatory/Emergency	3%/5%/15%	3%/5%/15%
Maximum change in demand reduction per time step	0.5%	0.5%