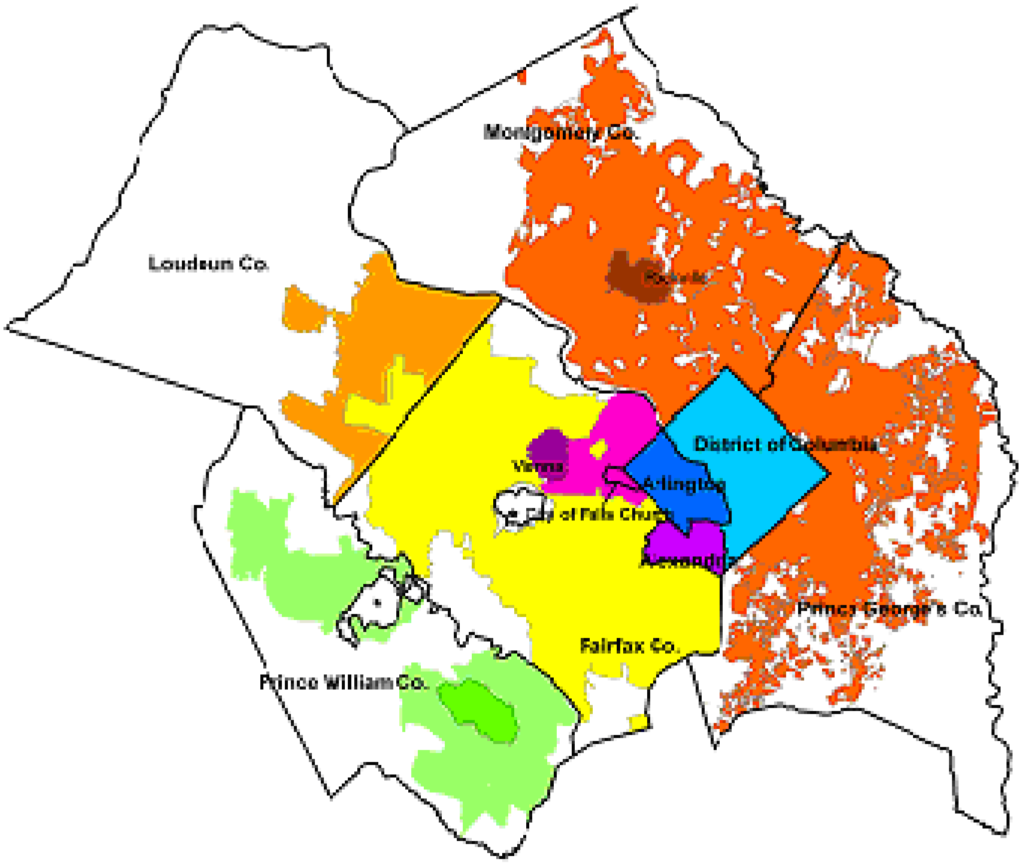
Water Supply Reliability Forecast
for the Washington Metropolitan Area
Year 2025

Prepared by

Ani Kame'enui
Erik R. Hagen
Julie E. Kiang

June, 2005

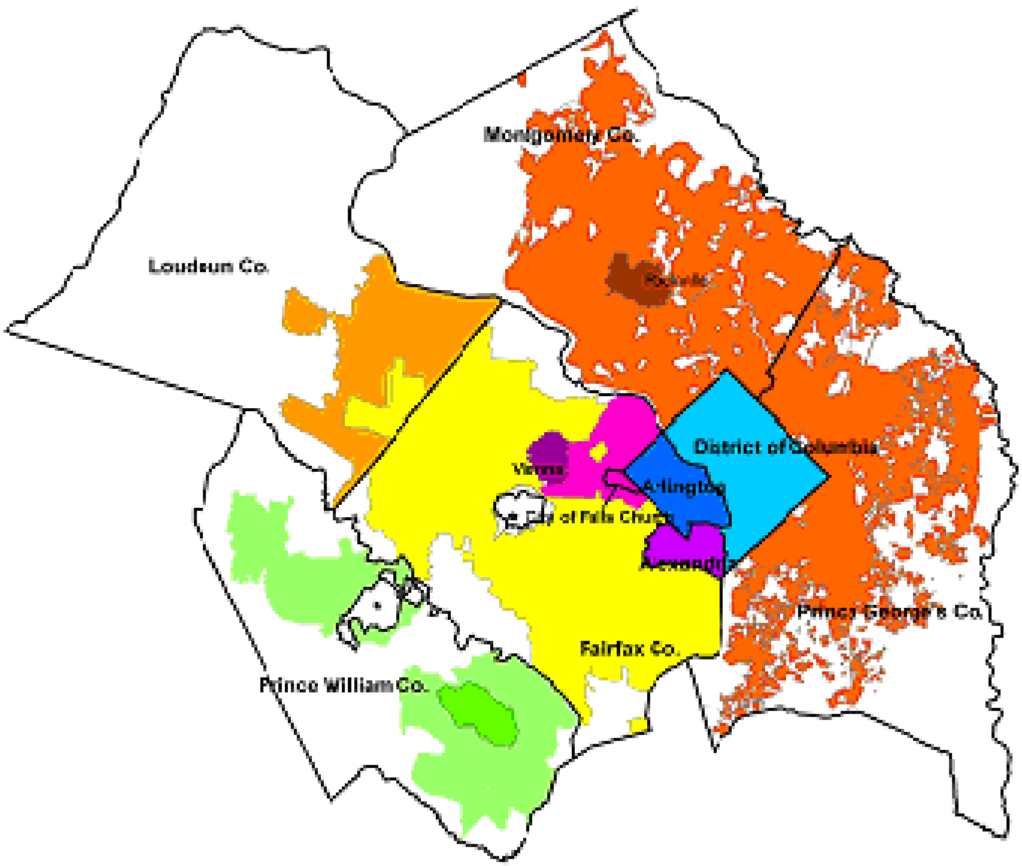



The Section for Cooperative Water Supply Operations on the Potomac

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

Report No. 05-06

The Interstate Commission on the Potomac River Basin




This report was prepared by the Interstate Commission on the Potomac River Basin, Section for Cooperative Water Supply Operations on the Potomac. Funds were provided for this report by the three major water suppliers: the Washington Suburban Sanitary Commission, the Washington Aqueduct Division of the U.S. Army Corps of Engineers, and Fairfax Water. The opinions expressed are those of the authors and should not be construed as representing the opinions or policies of the United States or any of its agencies, the several states, the Commissioners of the Interstate Commission on the Potomac River Basin, or the water suppliers.

# Table of Contents

# Table of Appendices

# Table of Tables

# Table of Figures

# Executive summary

**Introduction**

Twenty-five years ago, the Washington metropolitan area was faced with a looming water supply shortage. Area water suppliers developed a plan embodied in the Water Supply Coordination Agreement signed in 1982 to address water supply adequacy for the foreseeable future. This study provides a renewed assessment of the reliability of the Washington metropolitan area (WMA) supply. The study concludes that the water supply system is highly reliable and will be adequate to meet growing demand through the next 20 years.

The Low Flow Allocation Agreement, signed by the United States, Maryland, Virginia, the District of Columbia, the Washington Suburban Sanitary Commission (WSSC) and Fairfax Water in 1978, requires that "In April 1990 and in April of each fifth year thereafter ... the [WMA water suppliers and the District of Columbia] shall evaluate the adequacy of the then available water supplies to meet the water demand in the Washington Metropolitan Area which may then be expected to occur during the succeeding twenty year period." This report was prepared pursuant to that Agreement and is the fourth such report prepared by the Interstate Commission on the Potomac River Basin (ICPRB) Section for Cooperative Water Supply Operations on the Potomac (CO-OP).

Demand forecasting is critical to water resources planning. The time required to build new resources or implement demand management strategies is lengthy, and forecasts of future demand help managers and municipalities to plan for the future. Rather than providing a predetermined view of future demand, these forecasts provide supply managers with the tools to understand both the quantity of demand and factors that influence demand on water resources (Osborn et al., 1986). This study is primarily intended as an aid to long-range planning.

The study incorporates several changes to the prior studies. These include:

- improved system operations made possible by increases in treatment capacities at Patuxent and Occoquan reservoirs,
- an assessment of more-severe droughts than documented in the historical record,
- demand reduction percentages based on regional experience,
- water supply demand modeled as a function of weather and other variables,
- scenarios addressing impacts of potential regional climate change,
- an enhanced model of the North Branch water quality operations, and
- modified operations at Savage Reservoir.

**Background**

The majority of the WMA's population relies on water furnished by three water suppliers (collectively, WMA water suppliers):

- The Washington Aqueduct Division of the U.S. Army Corps of Engineers (Aqueduct) serving the District of Columbia and portions of northern Virginia.
- Fairfax Water, serving portions of northern Virginia.
- The Washington Suburban Sanitary Commission (WSSC) serving primarily the Maryland suburbs in Prince George's and Montgomery counties.

The WMA water suppliers provide treated water either directly to customers or through wholesale suppliers. In periods of low flow, the WMA water suppliers essentially operate as one entity, sharing water across the Potomac, Patuxent and Occoquan basins. This cooperative work is coordinated by ICPRB's CO-OP section.

The study focus includes the WMA water suppliers and their wholesale customers, including the Loudoun County Sanitation Authority, Prince William County Service Authority, Virginia American Water Company, Vienna Dept. of Public Works, D.C. Water and Sewer Authority, Arlington County Department of Public Works, and the Falls Church Department of Environmental Services/Public Works. In addition, the City of Rockville's demand was estimated.

The natural flow in the Potomac River supplies approximately 75 percent of the water demand in the WMA, with the remainder supplied by Fairfax Water's Occoquan Reservoir and WSSC's Patuxent reservoirs. All three suppliers continue to contribute to the cost of Jennings Randolph and Little Seneca reservoirs in the Potomac basin that augment Potomac flows during droughts.

**Demand projections**

The estimate of future demand is based on three types of water uses, namely single family household use, multi-family (apartment) water use, and employee water use. All governmental, industrial and other commercial water use is lumped into the "employee" category of water use. Projections of numbers of households and employees are based on the most recent Metropolitan Washington Council of Governments (MWCOG) projections, which were collaboratively developed by MWCOG and local government planners. Forecasts of growth for population, employees, and households show significant growth, as shown in Table ES-1.

Table ES-1: Net increase in demographics by service areas from 2005 to 2025.

| Service area | # Household increase, percent | | # Population increase, percent | | # Employee increase, percent | |
|---|---|---|---|---|---|---|
| Fairfax Water retail and wholesale | 142,006 | 27% | 366,518 | 26% | 302,945 | 42% |
| Aqueduct wholesale service area | 67,636 | 16% | 146,981 | 15% | 196,553 | 19% |
| WSSC service area | 130,389 | 22% | 273,835 | 17% | 310,374 | 40% |
| **Totals (plus Rockville)** | **343,092** | **22%** | **792,524** | **19%** | **831,919** | **32%** |

Coefficients were developed for each jurisdiction in the WMA to describe average daily water use by each type of water user. Demand estimates were developed by multiplying forecasts of the number of each type of water user by the coefficients describing average water use for each jurisdiction. In addition, unmetered water use was estimated for each jurisdiction. Per household water use is assumed to be lower in the future than it is today as a result of the *Energy Policy Act of 1992* (102D Congress, 2d session, 1992).

Current average annual water use for the WMA water suppliers during normal years is approximately 488 MGD and is projected to be 572 MGD in 2025. Demand during a hot and dry year in 2025 is projected to be approximately 587 MGD. The 2005 CO-OP forecast of annual average demand for 2020 is approximately 28 MGD less than the level forecast by the 2000 study (Figure ES-1). The lower forecast in this study is due primarily to updated demographic forecasts and lower calculated unit use rates. Population growth has increased at a faster rate than water demand in recent years.

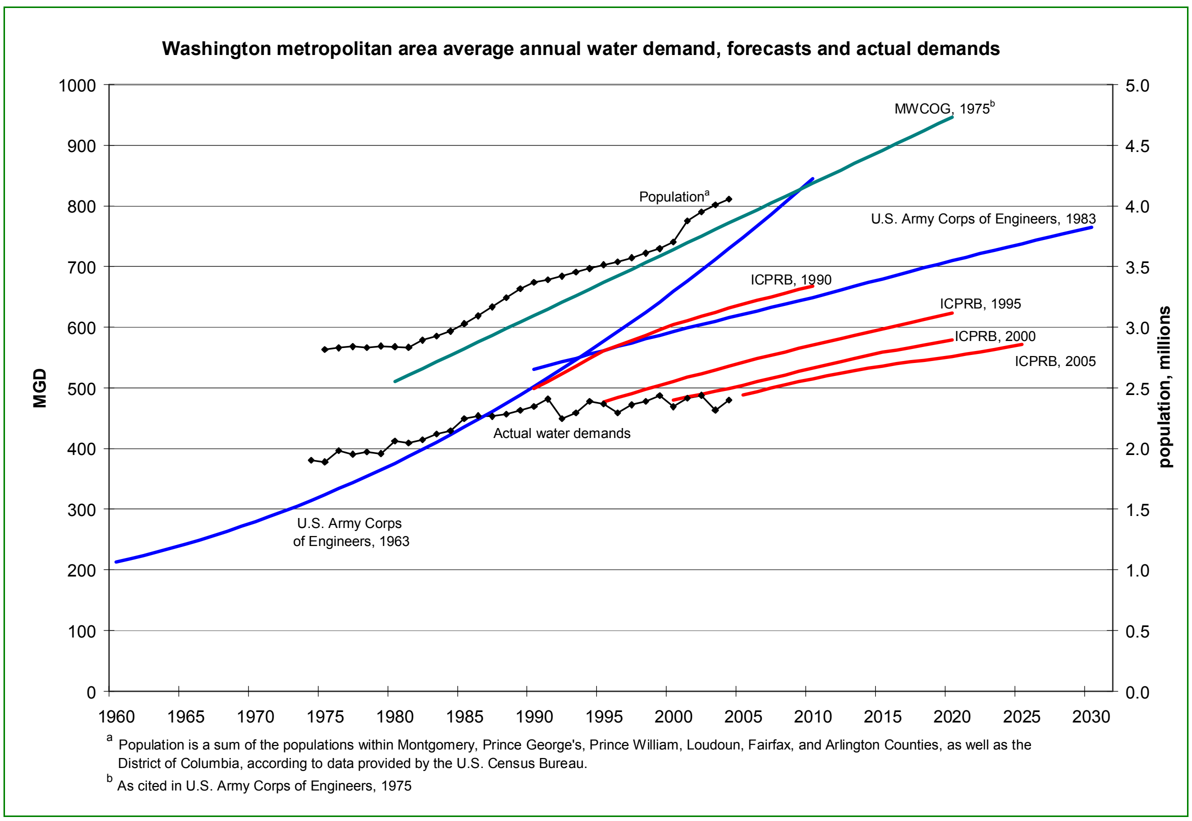



Figure ES-1: Comparison with forecasts from earlier studies for CO-OP Suppliers.

**Resource analysis**

The resource analysis examines the existing water system's ability to meet forecasts of future demand. The operation of the water resource system is modeled such that the Occoquan and Patuxent reservoirs are managed as part of a regional water supply system with Jennings Randolph and Little Seneca reservoirs, in order to maximize the reliability of the overall system.

Using the deterministic continuous simulation model, the Potomac Reservoir and River Simulation Model (PRRISM), several scenarios were examined. These scenarios include the most recently available MWCOG estimate of growth (Round 6.4a), the most recently available MWCOG estimate of high growth (Round 6 high), a climate change scenario, a scenario assuming no demand reduction due to the effects of the *Energy Policy Act of 1992*, a simulation over a drought worse than the drought of record, and demand scenarios beyond (greater than) those for year 2025. (Although the study horizon is through 2025, the forecast was extended to 2045 by assuming similar rates of growth in order to assess the response of the system to higher demand.) Chapter 6 documents the assumptions made in the resource analysis, including the following:

- Voluntary and mandatory restrictions are assumed to reduce demand during extreme droughts.
- Reservoir storage is reduced over time to account for siltation.
- The current recommended environmental flow rate for Little Falls is modeled.
- Stream flow resources are reduced to account for increasing upstream consumptive demand.

**Results/Conclusions**

*The current assessment of future water demand and water supply reliability for the metropolitan Washington area demonstrates that even with a high growth (MWCOG Round 6 high growth scenario), the water supply system developed twenty-five years ago is adequate to meet 2025 demand under a repeat of the worst meteorological and stream flow conditions in the historical record.* Results of this analysis are shown in Table ES-2, below. *Furthermore, the system is able to meet estimated future water supply demand in 2045 given a repeat of the same drought conditions.*

*Results of the current resource analysis show more storage remaining in system reservoirs under a repeat of the drought of record than those of the demand and resource study conducted five years ago.* There are several reasons for this difference which are quantified in Table ES-3.

*Estimates of future water demand are reduced in this study to account for water savings due to the Federal Energy Policy Act of 1992. An alternative scenario was developed to explore how resources would be affected if there was no such reduction in future unit use. Results showed that the water supply system is adequate to meet 2025 demand under a repeat of the worst meteorological and stream flow conditions on record.*

Table ES-2: Results for most likely (Round 6.4a) and high (Round 6) growth scenarios

| Results for MWCOG Round 6.4a and Round 6 high growth scenarios, 2025 demand | Round 6.4a | 6.4a Std. deviation | Round 6 high | 6 Std. deviation |
|---|---|---|---|---|
| **Reliability** | | | | |
| Percentage of years with no Potomac deficits | 100 | 0 | 100 | 0 |
| Number of days in which Potomac deficits must be allocated | 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 | 4.1 | 0.0 | 5.5% | 0.0% |
| Mandatory restrictions | 0.0 | 0.0 | 0.1% | 0.4% |
| Emergency restrictions | 0.0 | 0.0 | 0.0 | 0.0 |
| **Minimum reservoir storage, BG, (percent full)** | | | | |
| Little Seneca Reservoir | 2.9 (75) | 0.11 | 2.6 (70) | 0.15 |
| Jennings Randolph water supply account | 4.7 (36) | 0.14 | 3.4 (26) | 0.10 |
| Jennings Randolph water quality account | 1.5 (9) | 0.00 | 1.3 (8) | 0.00 |
| storage in Patuxent Reservoir | 2 (20) | 0.04 | 1.8 (18) | 0.08 |
| storage in Occoquan Reservoir | 1.6 (20) | 0.02 | 1.6 (20) | 0.01 |
| storage in Savage Reservoir | 0.7 (11) | 0.00 | 0.7 (11) | 0.00 |
| Little Seneca Reservoir and Jennings Randolph water supply account, combined | 7.6 (45) | 0.25 | 6.2 (36) | 0.17 |
| Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined | 12.2 (24) | 0.24 | 10.5 (20) | 0.28 |
| **Miscellaneous** | | | | |
| Number of years in simulation (10/1/1929 – 9/30/2002) | 73 | 0 | 73 | 0 |
| Average annual demand drought year (1930, MGD) | 587 | 3 | 622 | 4 |
| **Minimum average flow** | | | | |
| Average minimum natural flow summer (1930), MGD | 1,141 | NA | 1,141 | NA |
| Average minimum natural flow fall (1930), MGD | 606 | NA | 606 | NA |
| Average minimum summer flow downstream of intakes (1930), MGD | 574 | 5 | 556 | 6 |
| Average minimum fall flow downstream of intakes (1930), MGD | 252 | 5 | 225 | 8 |

Table ES-3: Differences between 2000 and 2005 Twenty-Year Demand Forecast and Resource Analyses.

| Difference between two studies | | Change in minimum storage in Jennings Randolph and Little Seneca Reservoirs |
|---|---|---|
| Changes in demand forecast | The 2000 forecast of 2020 demand is 597 MGD, and the 2005 forecast of 2025 demand is 572 MGD. | +0.4 BG |
| Water quality releases | More sophisticated modeling of Jennings Randolph/Savage water quality operations and releases. | +2.8 BG |
| Operational efficiency | Improved system operations made possible by increases in treatment capacity at Patuxent and Occoquan reservoirs. | +1.3 BG |
| Savage operations | A percentage of the Jennings Randolph Reservoir water supply release is matched by a concurrent water quality release from Savage Reservoir. | +0.6 BG |

*An assessment of potential impacts of climate change included the effects of potential changes to water demand due to forecasts of regional temperature changes, and a sensitivity analysis which reduced stream flow. The results suggest that the water supply system maintains a high degree of reliability over the 20-year forecast horizon of this study. It should be noted that the degree of uncertainty associated with the climate change analysis conducted for this study is high.*

*Results of simulations over a drought worse than the drought of record (i.e., over a 500-hundred year stream flow simulation) show that the system would be unable to meet all demand for approximately 6 days during one year of the 500-year simulation. The average shortfall over the six days was 41 MGD with an average total shortfall of 0.3 billion gallons and an average maximum shortfall of 90 MGD. Lower demand associated with 2020 was examined. In that case, the system would be adequate to meet 2020 demand without any supply shortfalls, although system storage would be significantly depleted.* All demand cannot be met with available streamflow when Little Seneca Reservoir and Jennings Randolph reservoirs are empty. When the existing resources are insufficient to meet demand, the suppliers would use existing agreements to place restrictions on demand and allocate available resources. The results must be interpreted with caution, as there is some uncertainty associated with the method and actual events could exceed simulated drought conditions.

*Flows are lower in the Potomac downstream of Little Falls as compared to natural conditions. Growth in demand over the next 20 years will not significantly change the frequency of low flows but will lower the magnitude of those flows that are already low. Reservoir releases increase flow in the 200-mile stretch of the Potomac River upstream of the water supply intakes during low flows as compared to natural conditions.*

*Per-household water use rates have changed significantly over the past 15 years, declining approximately 18 percent across single-family households from 1990 to 2000, and another 13 percent from 2000 to 2005.* These declining water use rates may be due to several factors. A poll by a MWCOG study shows the region's residents support conservation, with 80-90 percent of respondents describing conservation as "very" or "somewhat important." Each of the suppliers has programs in place to encourage moderation in water use. For example, WSSC's rate structure and plumbing code are both credited with reducing recent growth in demand. In the near term, the WMA water suppliers are addressing demand management through participation in the regional Wise Water Use Campaign to encourage year-round conservation. How much of the change in water use is due to these conservation programs is unknown. Some changes may also be due to changes in plumbing codes, social attitudes towards water use, availability of low energy and water use appliances as required in the *Federal Energy Policy Act of 1992*, or other factors.

*Water use rates and regional growth projections in the WMA may continue to change rapidly, suggesting that conducting the study regularly is of considerable value.* The selection of the five-year interval for the current study provides multiple additional benefits. It allows regular updates and incorporation of recent demographic forecasts, and increases visibility and understanding of the adequacy of the region's water resources. It provides adequate time to conduct research on the physical system and incorporate modifications in subsequent studies. It allows for improvements in system operation to be explored and implemented as low-cost alternatives to construction of future resources.

*The current study results suggest that there is time available to assess future water supply alternatives. Furthermore, the need for additional supplies may be delayed if further operational improvements are made and/or declines in unit use continue.* For the longer term, structural and non-structural methods can be explored to meet forecast increases in population. Operational improvements show promise and can continue to be refined through annual drought exercises. Potential structural enhancements to supply include the use of large rock quarries that may be available in future years for water storage. While analysis of the structural measures has received some recent attention, the non-structural ideas are the main focus of ongoing and recent efforts.

**Recommendations**

- *The high degree of uncertainty associated with climate change research in the Potomac basin is high and can be addressed through more focused study.* The existing regional climate research is oriented towards changes in average conditions, when precisely what is needed is an assessment of changes in extreme conditions. Additional study can clarify the potential impact of climate change on extreme hydrologic events such as drought.

- *The model used to predict demand that is based on weather and other variables can be further improved for operational and planning applications.*

- *Refine operational procedures in order to maximize water supply reliability.* This will result in two benefits. One, operational drought readiness will be improved. Second, operational improvements can offset growth in demand, perhaps delaying the time that new resources are needed.

- *Refine estimates of consumptive use in the basin.* Estimates of upstream consumptive use are highly uncertain, so additional study is warranted to check the accuracy of these estimates.

- *Explore the effects of changing historical land use on hydrology.* The Potomac basin is significantly more forested now than it was during the drought of 1930. Additional study can explore how land use changes affect low flow hydrology.

*The full report is available on the ICPRB website at*
*http://www.potomacriver.org/*

# 1 Study objective and background

## 1.1 Objective

The objective of this study is to forecast the water supply demand for the year 2025 and to assess the ability of the available regional water resources to meet the growing water supply needs of the Washington metropolitan area (WMA) population.

## 1.2 Introduction

Forecasts of future demand help managers and municipalities to plan for the future and to assess the adequacy of the present resources to meet future demand. Demand forecasting and resource assessments are critical to water resources planners and managers, since the time required to study, plan, and build new resources or implement demand management strategies is lengthy. Demand forecasts aid water suppliers in their ability to visualize future water demand and resource management. Rather than providing a predetermined view of future demand, these forecasts provide supply managers with the tools to understand both the quantity of demand and what controls demand on water resources (Osborn et al., 1986). This study is primarily intended as an aid to long-range planning, and can be compared with similar earlier studies (Holmes & Steiner, 1990; Mullusky, Schwartz & Steiner, 1995; Hagen & Steiner, 2000).

This study incorporates several improvements to the prior studies. Resources are assessed considering more extreme droughts than that recorded in the historical record by using stochastic (synthetic) stream flow. Analysis also includes reduced demand due to water use restrictions during drought, as based on regional demand reductions actually measured in 1999. This study integrates a more realistic simulation of the physical system, as the modeling tools have been improved since the prior study as documented in ICPRB 04-03 (Prelewicz et al., 2004). Chief among these improvements is that the simulation model used to assess resources now incorporates an improved simulation of water quality operating procedures in the North Branch Potomac, which affects downstream flow. The current study uses an improved algorithm to model demand as a function of weather and other variables, which allows for modelers to examine how the extreme weather conditions of the 1930 drought of record affect demand and to examine how potential climate change scenarios affect future demand. Operational improvements include increasing local flexibility between using the Potomac and Occoquan/Patuxent sources, made possible by increased treatment capacity at the Patuxent and Occoquan reservoirs. An additional change includes modification of Savage Reservoir operations to increase the water supply benefits of upstream reservoirs through modified operations.

The studies are conducted via an agreement among various jurisdictions and water suppliers. The Low Flow Allocation Agreement (LFAA), signed by the United States, Maryland, Virginia, the District of Columbia, the Washington Suburban Sanitary Commission, and the Fairfax County Water Authority, requires: "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 demand in the Washington Metropolitan Area which may then be expected to occur during the succeeding twenty year period." This study was prepared pursuant to this agreement and is the fourth of such reports prepared by ICPRB to reflect changes in growth and water use patterns.

### 1.3 Water suppliers

The urban populations in Maryland, Virginia, and the District of Columbia share the Potomac River as their primary source for municipal supply. The three major metropolitan water suppliers, Washington Suburban Sanitary Commission (WSSC), Fairfax Water (FW), and the Washington Aqueduct Division of the U.S. Army Corps of Engineers (Aqueduct), (collectively, WMA water suppliers) jointly own water storage in upstream Jennings Randolph and Little Seneca reservoirs that they have agreed to operate for their common benefit during droughts. These suppliers provide treated water either directly to customers or through wholesale suppliers.

### 1.4 History of cooperation

Population in the WMA grew from 672,000 in 1930 to two million in 1960, and forecasts in the early 1960s called for the population to grow to 5 million by 1985 (U.S. Army Corps of Engineers, 1963). The actual WMA population realized in 1985 was less than forecast by the U.S. Army Corps of Engineers, at approximately 3.1 million people (United States Census Bureau, 2004).

Historical flows have ranged from a low of about 0.3 billion gallons per day to a high of approximately 300 billion gallons per day. Drought induced rationing was a very real threat in the WMA through the 1960s and 1970s as demand was forecast to exceed the low flow of the largely unregulated Potomac (Potomac Basin Reporter, 1982). Drought rationing in the WMA did not occur in this period only because no serious droughts threatened the water supply system in the 1970s. WMA demand levels exceeded the 1966 low-flow of the Potomac River 41 times during 1971 through 1982 (Ways, 1993).

The first regional approaches to water supply management began in the 1960s. A number of potential measures for increasing supply were studied at that time. In particular, the Corps of Engineers conducted a study that identified 16 potential dam sites on the Potomac upstream of Washington, D.C. whose reservoirs could augment water supply during low flow periods (U.S. Army Corps of Engineers, 1963). There was significant public opposition to many of these sites; only one, Jennings Randolph Reservoir near Bloomington, Md., was ever constructed. Other measures that were studied included estuary treatment plants, interconnections in the distribution systems, and inter-basin transfers (Ways, 1993).

The water suppliers and local governments searched for other solutions. Research at Johns Hopkins University in the late 1970s developed a basis for use of the stored water in a way that would allow for cooperative operations during droughts while meeting growing demand well into the next century (Palmer et al., 1979; 1982; Sheer, 1977). This research revealed that 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 flow through about 2020. Gains in reliability were obtained by operating rules which specified the 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 Patuxent and Occoquan reservoirs. This strategy is physically 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, controversial structural measures.

Key agreements governing this cooperative approach were forged at this time:

- In 1978, the states and the WMA water suppliers signed the LFAA, which allocates the amount of water each supplier can withdraw from the river when total flow is not sufficient to meet all needs.

- In 1982, the WMA water suppliers and ICPRB signed the Water Supply Coordination Agreement (WSCA). This agreement provides for the coordination of all the major supply facilities in the region, including those on the Patuxent and Occoquan rivers, to minimize the potential for triggering the LFAA's allocation mechanism due to low flow levels in the Potomac. The WSCA also describes the major functions of the CO-OP Section within the ICPRB under the agreement.

The WMA water suppliers cooperate on water supply operations in the Potomac, essentially operating as one entity in sharing 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).

The WMA water suppliers have paid the capital and operating costs for maintaining a portion of the water stored within the Jennings Randolph Reservoir as well as water impounded within Little Seneca Reservoir in Montgomery County, Md. Together, these sources can provide over 17 billion gallons (BG) to augment naturally occurring flows in the Potomac.

In the WSCA, CO-OP agreed 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 the 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. Each water supplier realized that by cooperating to make operating decisions, each could meet their demand and collectively meet the demand of the region.

The three major regional water suppliers' decision to seek a joint solution to the water supply shortage through ICPRB CO-OP has made it possible to provide adequate water supply for the WMA. The means of achieving this end not only satisfy the water demand but are hundreds of millions of dollars less costly than previously proposed courses of action.

The summer of 2002 marked the second year that stored water has been used to augment the natural flow of the Potomac River for water supply purposes, the first year occurring during the summer of 1999. Cooperative operations among the ICPRB and the WMA water suppliers ran smoothly, and the augmented flow of the Potomac provided all the water required by the suppliers.

Each summer, Drought Exercises are conducted by ICPRB’s CO-OP staff, the WMA water suppliers, and the Baltimore District of the Corps of Engineers. These exercises simulate operating procedures during drought conditions and contribute tremendously to the improvement of operational models as well as communication between ICPRB staff, water supplier managers, and Corps personnel. A detailed account of the September 2004 Drought Exercise is documented in ICPRB report number 05-1.

# 2 General description of the WMA water supply system

## 2.1 Introduction

A general overview of the WMA water supply system is provided in this chapter. The chapter begins with a description of WMA study area, the WMA water suppliers, and their wholesale customers (Section 2.2). The system of reservoirs is described in Section 2.3. WMA water supplier peak demand is described in Section 2.4.

## 2.2 Study area

The study area for the water demand forecast is the service area of those suppliers in the WMA that withdraw water from the Potomac River and generally return treated wastewater downstream of Little Falls in the tidal Potomac estuary. These include the WMA water suppliers (the Aqueduct, Fairfax Water and WSSC) and the wholesale customers that are provided with treated water by the WMA water suppliers. This forecast also includes the City of Rockville, Maryland. The WMA water suppliers and their wholesale customers together provide water to nearly 4.1 million WMA residents.

Figure 2-1 shows an overview of the study area and resources. The non-tidal Potomac River as well as the Occoquan and Patuxent reservoirs provide source water for the WMA water suppliers. The WSSC serves the Maryland suburbs; the Aqueduct sells water to wholesale customers in DC and portions of Virginia; and Fairfax Water serves other suburbs of northern Virginia. The major wholesale customers of the CO-OP member water suppliers include the Loudoun County Sanitation Authority, the Prince William County Service Authority, the Virginia American Water Company, the Vienna Department of Public Works, the District of Columbia Water and Sewer Authority, the Arlington County Department of Public Works, and the Falls Church Department of Public Works.

## 2.3 WMA water resources

Most of the residents of the WMA rely on the Potomac River as their primary source of drinking water. On average, the Potomac River accounts for about 75 percent of the water treated by the WMA water suppliers. In addition to the Potomac, the two suburban suppliers own reservoirs that do not fill from the Potomac but are regularly used in combination with Potomac withdrawals to meet about 25 percent of the regional demand. The Potomac is the sole source of supply for the Aqueduct.

The three major regional water suppliers have collaborated to pay for storage in Jennings Randolph Reservoir and Little Seneca Reservoir, at an original cost of more than $96 million dollars plus annual operation and maintenance costs since construction. These reservoirs augment Potomac flow. The major components of the metropolitan water supply system are shown in Figure 2-2.

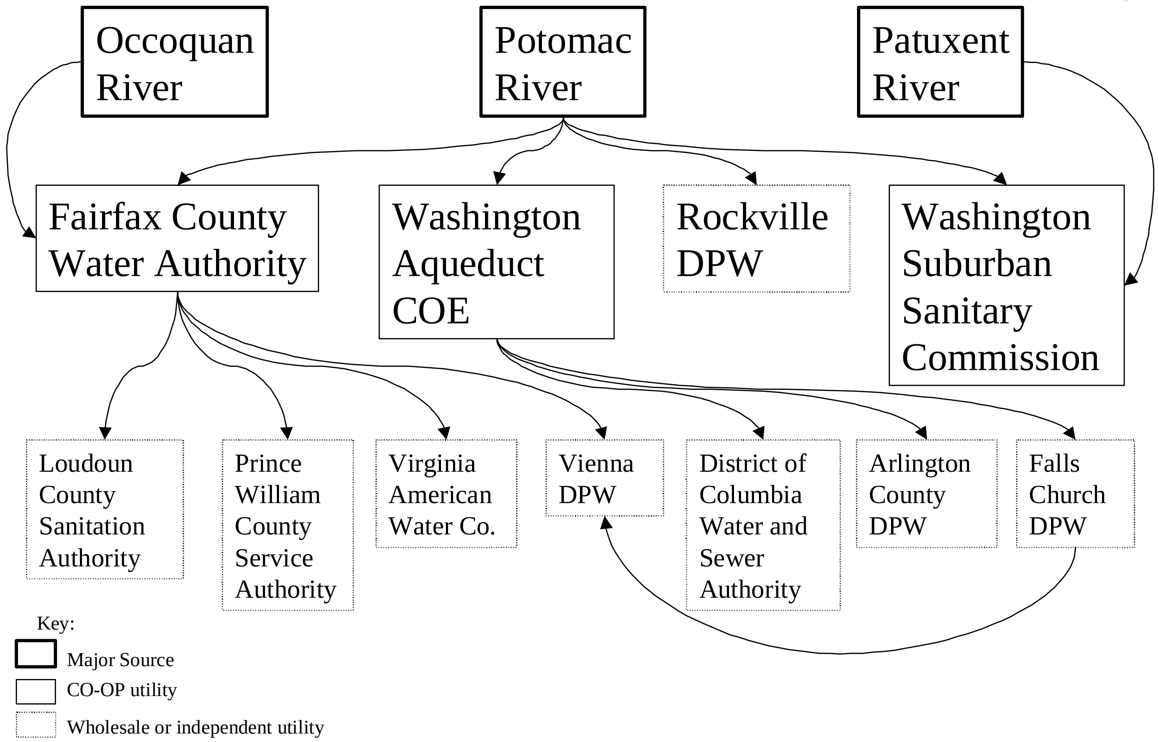



Figure 2-1: Schematic of study area and resources

*2.3.1 Shared resources*

- **Jennings Randolph Reservoir.** This reservoir can be viewed as the area's "savings account." It holds 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 some 200 miles upstream of the suppliers' intakes, and releases take more than a week to travel to them during times of low flow. The watershed area of Jennings Randolph is about 263 square miles.
- **Little Seneca Reservoir**. This smaller reservoir can be viewed as the region's "checking account" and is about a day's travel time from the most downstream intake in Montgomery County, Md. It stores 3.8 BG for the benefit of the WMA water suppliers and is used to "fine tune" the larger releases from Jennings Randolph, which then can be operated more conservatively. Little Seneca's watershed area is about 21 square miles.
- **Savage Reservoir**. 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 (Commission). The Commission operates the dam with guidance from the U.S. Army Corps of Engineers, 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 watershed area of Savage Reservoir is about 105 square miles.

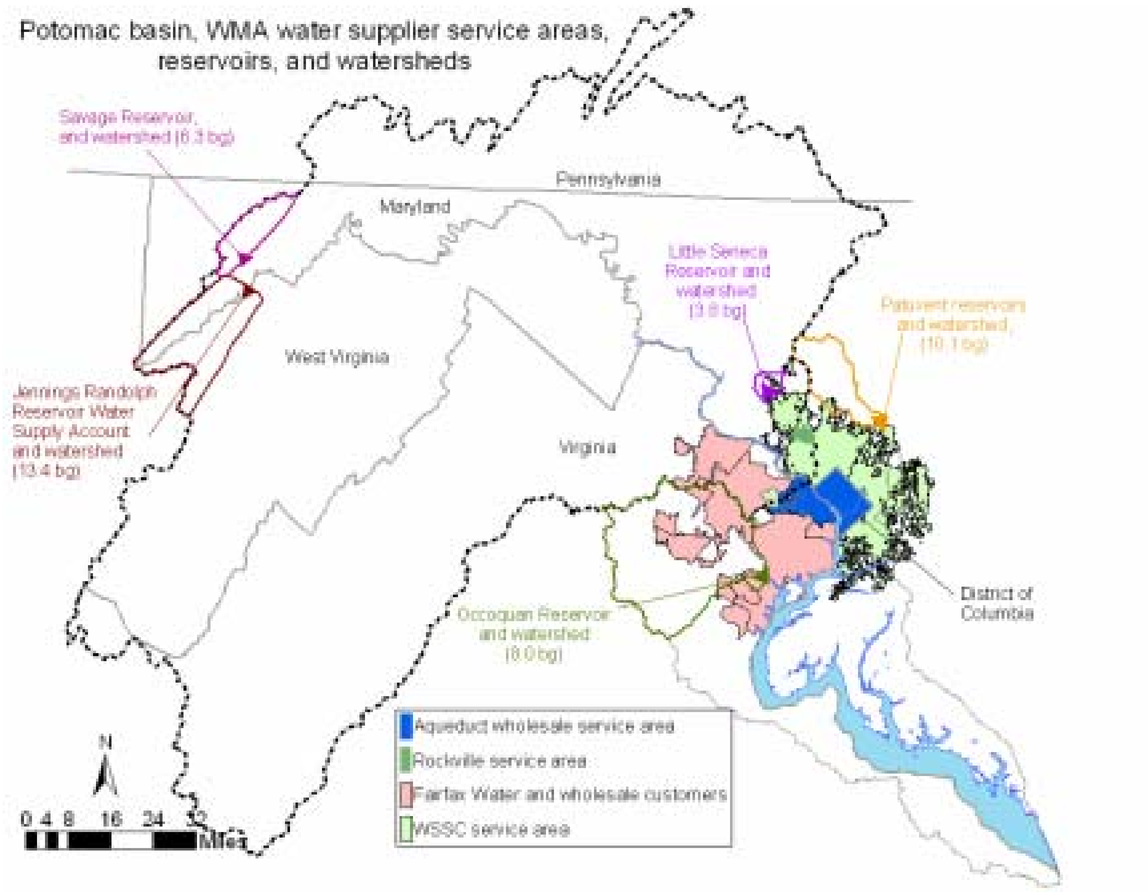



Figure 2-2: Potomac basin, WMA water supplier service areas, reservoirs, and watersheds

### *2.3.2 Other reservoirs*

- **Patuxent Reservoirs**. The WSSC operates two reservoirs in the neighboring Patuxent River watershed. Total usable storage at these reservoirs is about 10.2 BG. WSSC uses this stored water in tandem with Potomac withdrawals throughout the year. The watershed 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 withdrawals. The watershed area of the Occoquan is about 592 square miles.

### *2.3.3 The Potomac River*

The Washington metropolitan area depends primarily on the non-tidal Potomac River for most of its water. The watershed area of the Potomac River at the most downstream intake near Little Falls is 11,560 square miles. Potomac River flow is usually higher in the winter months and lower in the summer months. Generally, water supply withdrawals from the Potomac are a small fraction of the river's flow. Average flow of the river over a year is about 7 billion gallons per day (BGD); average summer demand by the WMA water suppliers on the river is about 500 million gallons per day (MGD), or 0.5 BGD. Chapter III provides a more detailed comparison of Potomac River flow as it compares to WMA water supplier demand.

## 2.4 Historical WMA water supplier demand

The Aqueduct and WSSC treated an average of 175 MGD and 169 MGD, respectively, in 2004. Fairfax Water demand was slightly less, averaging 141 MGD in 2004. (Data for 2004 includes the months of January through October.) A significant portion of the WSSC and FW demand is satisfied by the Patuxent and Occoquan reservoirs, respectively. In 2004, 24 percent of WSSC's production came from the Patuxent reservoirs and 39 percent of Fairfax Water's production came from the Occoquan Reservoir.

WSSC's peak production of 267.3 MGD occurred on July 8, 1988. Fairfax Water's peak production of 222.5 MGD occurred on August 19, 2002. The Aqueduct's peak production of 281.1 MGD occurred on July 7, 1999. The combined maximum peak production of Fairfax Water, WSSC, and the Aqueduct of 741.4 MGD occurred on June 8, 1999. The combined average annual and peak daily production of Fairfax Water, WSSC, and Aqueducts' production over the period 1990-2004 is shown in Figure 2-3. Figure 2-3 shows that the peak day demand can be significantly greater than the annual average demand. For the period 1990 through 2004, the peak day demand was on average 26 percent higher than the annual average demand and a maximum of 35 percent higher than the annual average demand (1999). Chapter III provides additional detail on current patterns of water production for the WMA water suppliers.

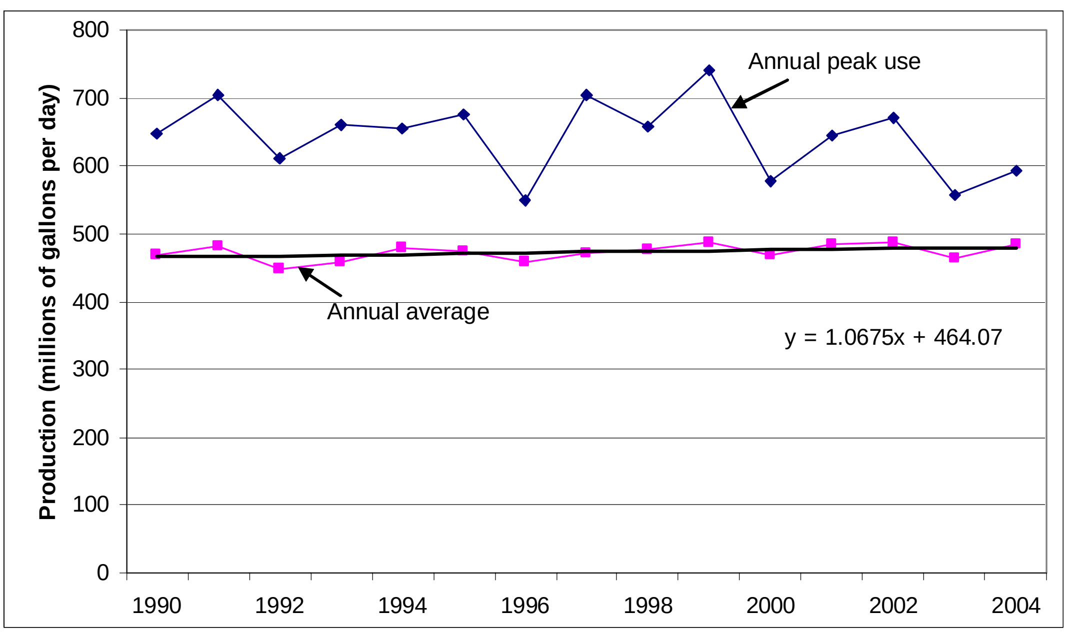



Figure 2-3: WSSC, the Aqueduct, and Fairfax Water total annual average and peak day demand.

# 3 Estimating daily demand

## 3.1 Introduction

The method used to convert forecasts of average annual demand, a single number, to a time series of daily demand that varies by season and by historical weather and other variables is described in this chapter.

WMA water supplier demand patterns are described in Sections 3.2 and 3.3. 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 3.4. Daily variability in the WMA demand is described along with its effect on system efficiency of operations, which is why effort to capture this variability accurately is a part of the daily demand model, Section 3.5. A significant amount of effort is devoted to documentation of the model used to develop a daily demand data set, Section 3.6. Documentation is presented in Section 3.7 to describe how the dataset of daily demand is modeled in the daily Potomac Reservoir and River Simulation Model. The advantages of using the detailed demand model developed in this chapter are summarized in Section 3.8. The model is applied to the WSSC service area to estimate the percentage reduction in demand due to mandatory restrictions experienced during the drought of 1999, Section 3.9.

## 3.2 Patterns of 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 considerably through the summer months due to outdoor water uses (Figure 3-1). Figure 3-1 shows that the average daily water production for the three WMA water suppliers over the period 1990 through 1999 was not much different from average production from 2000 through 2004. 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 demand can be significantly higher during droughts, as occurred during the drought year of 2002 (Figure 3-1). *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 the drought years in the historical record.*

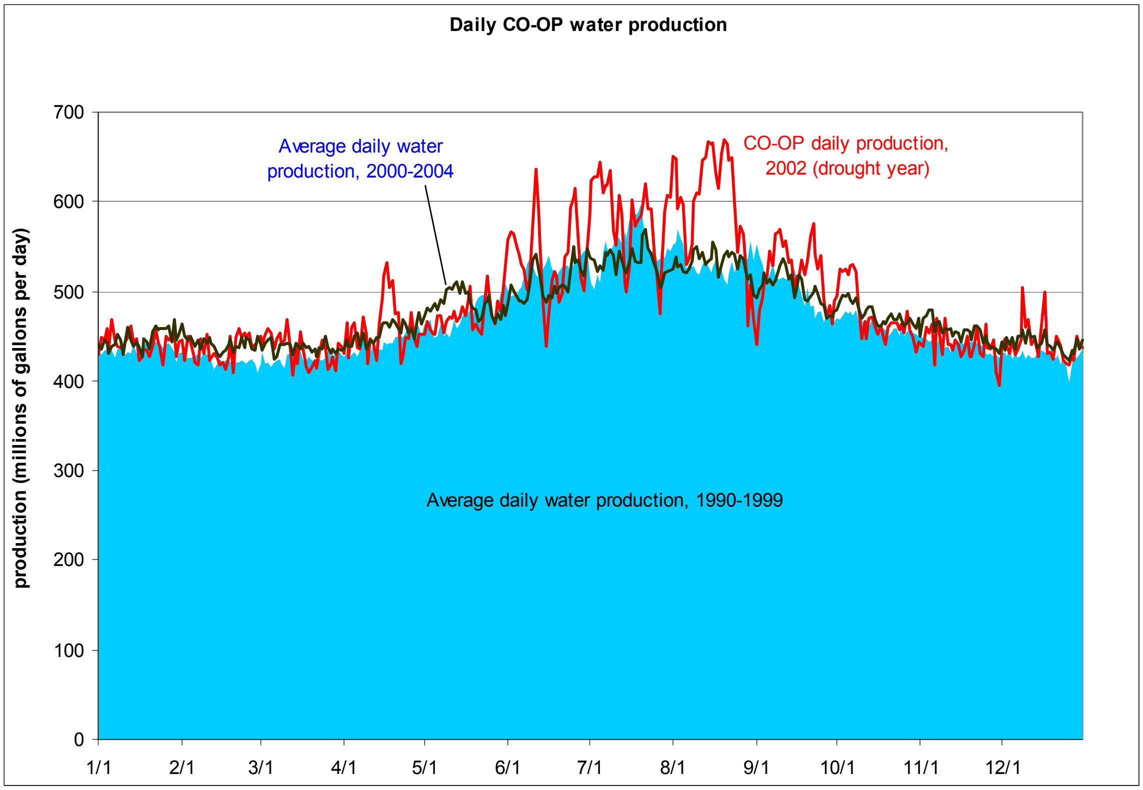



Figure 3-1: Recent daily WMA production.

## 3.3 Patterns of recent monthly demand

Monthly water production factors were calculated for each water supplier. The ratio of monthly average demand to average annual demand for each water supplier is provided from 1990 through the most recent year for which a complete year's data set is available (Table 3-1, Table 3-2, Table 3-3 and Table 3-4). The average monthly production factors (Table 3-4) are used to convert the annual demand forecast to a forecast of monthly demand. Additional statistics of water production data are provided in Appendices A through D.

Table 3-1: Fairfax Water monthly average production / annual average production.

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.89 | 0.91 | 0.89 | 0.88 | 0.89 | 0.87 | 0.89 | 0.85 | 0.84 | 0.88 | 0.89 | 0.87 | 0.84 | 0.96 |
| February | 0.85 | 0.90 | 0.89 | 0.86 | 0.84 | 0.86 | 0.89 | 0.83 | 0.82 | 0.82 | 0.91 | 0.84 | 0.83 | 0.93 |
| March | 0.88 | 0.89 | 0.92 | 0.87 | 0.82 | 0.89 | 0.89 | 0.82 | 0.85 | 0.84 | 0.90 | 0.86 | 0.82 | 0.93 |
| April | 0.95 | 0.94 | 1.00 | 0.88 | 0.92 | 1.00 | 0.98 | 0.88 | 0.91 | 0.89 | 0.93 | 0.94 | 0.91 | 0.97 |
| May | 0.98 | 1.12 | 1.06 | 1.02 | 1.02 | 0.99 | 1.02 | 0.98 | 1.00 | 1.11 | 1.07 | 1.12 | 0.98 | 0.98 |
| June | 1.15 | 1.27 | 1.11 | 1.17 | 1.32 | 1.06 | 1.15 | 1.14 | 1.04 | 1.27 | 1.11 | 1.09 | 1.14 | 1.04 |
| July | 1.15 | 1.19 | 1.16 | 1.37 | 1.22 | 1.16 | 1.11 | 1.35 | 1.19 | 1.31 | 1.12 | 1.14 | 1.27 | 1.16 |
| August | 1.11 | 1.10 | 1.07 | 1.21 | 1.07 | 1.36 | 1.14 | 1.28 | 1.29 | 1.20 | 1.05 | 1.13 | 1.32 | 1.13 |
| September | 1.10 | 1.05 | 1.03 | 1.06 | 1.10 | 1.17 | 1.05 | 1.08 | 1.22 | 0.98 | 1.04 | 1.10 | 1.11 | 1.03 |
| October | 1.02 | 0.93 | 0.99 | 0.93 | 0.99 | 0.94 | 0.99 | 1.01 | 1.00 | 0.91 | 1.04 | 1.03 | 0.98 | 1.00 |
| November | 0.98 | 0.86 | 0.95 | 0.88 | 0.91 | 0.86 | 0.95 | 0.92 | 0.93 | 0.90 | 0.98 | 0.99 | 0.90 | 0.95 |
| December | 0.93 | 0.84 | 0.93 | 0.86 | 0.90 | 0.83 | 0.93 | 0.86 | 0.90 | 0.87 | 0.94 | 0.88 | 0.90 | 0.93 |

Table 3-2: WSSC Monthly production factor (monthly average/annual average).

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.93 | 0.91 | 0.96 | 0.88 | 1.02 | 0.95 | 1.01 | 0.94 | 0.89 | 0.95 | 0.97 | 0.95 | 0.93 | 0.99 |
| February | 0.90 | 0.90 | 0.94 | 0.88 | 0.94 | 0.95 | 1.00 | 0.92 | 0.88 | 0.90 | 0.98 | 0.92 | 0.90 | 0.97 |
| March | 0.92 | 0.90 | 0.93 | 0.88 | 0.92 | 0.94 | 0.96 | 0.91 | 0.90 | 0.92 | 0.95 | 0.95 | 0.90 | 0.97 |
| April | 0.97 | 0.93 | 0.97 | 0.90 | 0.94 | 0.97 | 0.98 | 0.96 | 0.93 | 0.94 | 0.94 | 1.01 | 0.95 | 0.98 |
| May | 0.99 | 1.09 | 1.01 | 0.99 | 0.99 | 0.96 | 1.01 | 1.01 | 1.01 | 1.10 | 1.04 | 1.07 | 0.99 | 0.99 |
| June | 1.10 | 1.18 | 1.10 | 1.12 | 1.15 | 1.02 | 1.08 | 1.05 | 1.04 | 1.22 | 1.07 | 1.08 | 1.11 | 1.02 |
| July | 1.13 | 1.14 | 1.14 | 1.26 | 1.10 | 1.10 | 1.05 | 1.19 | 1.15 | 1.23 | 1.06 | 1.06 | 1.16 | 1.06 |
| August | 1.07 | 1.10 | 1.08 | 1.15 | 1.05 | 1.20 | 1.05 | 1.16 | 1.17 | 1.03 | 1.04 | 1.06 | 1.17 | 1.07 |
| September | 1.06 | 1.04 | 1.05 | 1.06 | 1.04 | 1.09 | 1.02 | 1.05 | 1.14 | 0.96 | 1.01 | 1.06 | 1.03 | 1.03 |
| October | 1.01 | 0.97 | 0.98 | 0.97 | 0.98 | 0.96 | 0.98 | 0.99 | 1.00 | 0.93 | 0.99 | 0.99 | 0.96 | 0.98 |
| November | 0.96 | 0.93 | 0.95 | 0.97 | 0.95 | 0.94 | 0.93 | 0.92 | 0.97 | 0.91 | 0.96 | 0.95 | 0.93 | 0.98 |
| December | 0.94 | 0.90 | 0.91 | 0.94 | 0.92 | 0.93 | 0.92 | 0.90 | 0.93 | 0.91 | 0.98 | 0.90 | 0.96 | 0.97 |

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

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.88 | 0.88 | 1.01 | 0.89 | 1.02 | 0.91 | 0.99 | 0.97 | 0.89 | 1.00 | 0.94 | 0.91 | 0.94 | 0.97 |
| February | 0.89 | 0.83 | 0.97 | 0.87 | 0.95 | 0.92 | 0.97 | 0.97 | 0.86 | 0.93 | 0.95 | 0.88 | 0.94 | 0.95 |
| March | 0.92 | 0.87 | 0.95 | 0.90 | 0.91 | 0.90 | 0.96 | 0.93 | 0.90 | 0.93 | 0.93 | 0.89 | 0.94 | 0.93 |
| April | 0.94 | 0.92 | 0.97 | 0.95 | 0.94 | 0.92 | 0.98 | 0.95 | 0.93 | 0.93 | 0.95 | 0.94 | 0.96 | 0.95 |
| May | 1.01 | 1.03 | 0.97 | 1.01 | 0.96 | 0.94 | 1.00 | 0.96 | 0.95 | 0.99 | 1.00 | 1.08 | 0.96 | 0.95 |
| June | 1.09 | 1.15 | 1.03 | 1.09 | 1.14 | 1.04 | 1.06 | 1.05 | 1.05 | 1.12 | 1.05 | 1.10 | 1.08 | 1.01 |
| July | 1.17 | 1.17 | 1.14 | 1.24 | 1.13 | 1.12 | 1.08 | 1.18 | 1.10 | 1.21 | 1.09 | 1.10 | 1.16 | 1.10 |
| August | 1.12 | 1.15 | 1.07 | 1.17 | 1.07 | 1.20 | 1.07 | 1.14 | 1.15 | 1.13 | 1.11 | 1.11 | 1.22 | 1.10 |
| September | 1.09 | 1.10 | 1.05 | 1.11 | 1.05 | 1.11 | 1.02 | 1.06 | 1.17 | 0.99 | 1.06 | 1.07 | 1.08 | 1.05 |
| October | 1.03 | 1.00 | 0.98 | 0.98 | 0.99 | 1.01 | 0.99 | 0.98 | 1.05 | 0.96 | 1.03 | 1.00 | 0.98 | 1.02 |
| November | 0.96 | 0.97 | 0.95 | 0.89 | 0.95 | 0.95 | 0.94 | 0.93 | 0.99 | 0.92 | 0.95 | 1.00 | 0.88 | 1.01 |
| December | 0.90 | 0.91 | 0.90 | 0.89 | 0.89 | 0.96 | 0.94 | 0.88 | 0.96 | 0.90 | 0.93 | 0.92 | 0.87 | 0.97 |

Table 3-4 Average of monthly production factors for each supplier, 1990 through 2003.

| Month | WSSC | Fairfax Water | Aqueduct |
|---|---|---|---|
| January | 0.948 | 0.882 | 0.944 |
| February | 0.926 | 0.864 | 0.920 |
| March | 0.925 | 0.871 | 0.919 |
| April | 0.955 | 0.937 | 0.945 |
| May | 1.019 | 1.033 | 0.986 |
| June | 1.095 | 1.147 | 1.075 |
| July | 1.132 | 1.208 | 1.143 |
| August | 1.100 | 1.176 | 1.128 |
| September | 1.046 | 1.081 | 1.072 |
| October | 0.978 | 0.984 | 1.002 |
| November | 0.947 | 0.925 | 0.950 |
| December | 0.929 | 0.894 | 0.916 |

## 3.4 Time period of interest

Demand is potentially higher than Potomac flow for only a short period of time (approximately four months) from about mid-July through late October or early-November (Figure 3-2). This time period is when Potomac augmentation releases are most likely to occur in order to ensure adequate flow. Because the critical period for comparing demand to resources is during the summer through fall, it is important to accurately develop an estimate of how demand might look in the summer through fall of 2025. 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).

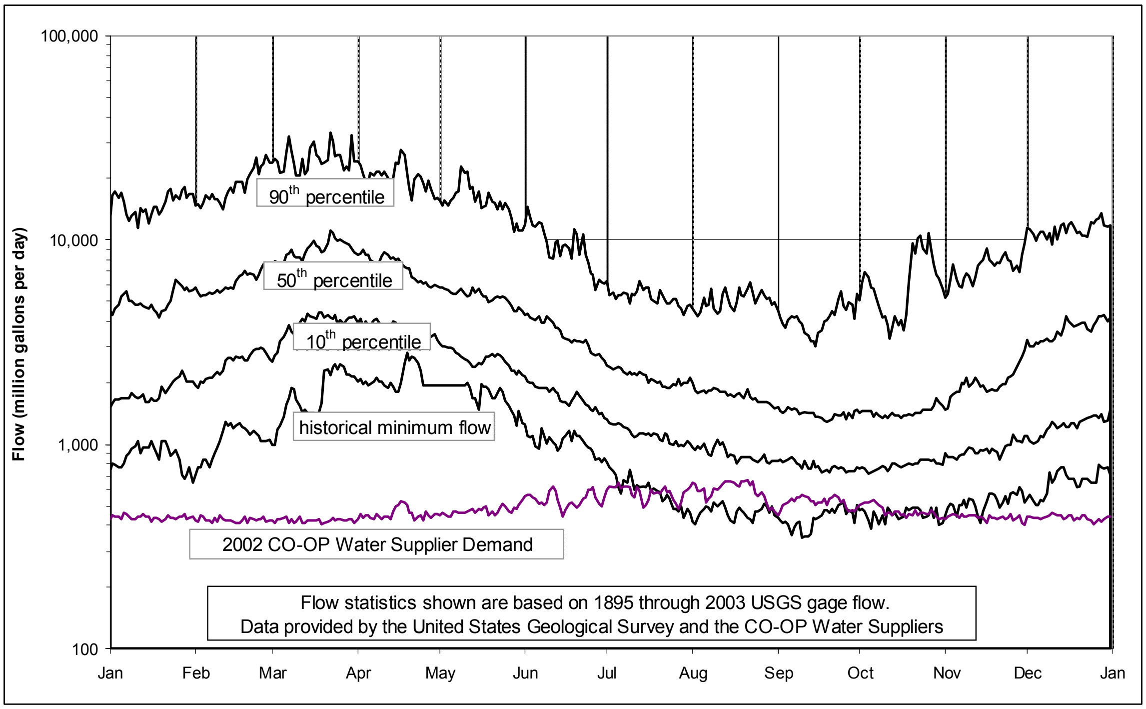



Figure 3-2: Flow on the Potomac River at Point of Rocks and water supplier demand.

## 3.5 The importance of modeling daily variability in the CO-OP system

In Potomac system operations, releases are made to meet demand that fluctuates on a daily basis. CO-OP system demand can be quite variable, especially during droughts (Figure 3-1). Daily variability in demand affects the efficiency of upstream reservoir releases. Reservoir releases from Jennings Randolph can take up to 9 days to reach the intakes, and in a 9-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 extra demand must be met with releases from

Little Seneca Reservoir, requiring a day of travel time to the most downstream water supply intake. Since the variability of daily demand is important in determining operational efficiency, monthly demand must be converted to estimates of daily demand. 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 sections which follow.

## 3.6 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 (1986) provides a useful summary. Regional trends in climate variables are further discussed below and in Section 4.10. For this study, a model is developed that relates daily water demand for the WMA water suppliers to independent variables, including temperature, precipitation, soil moisture, and day of week.

The model development involves several steps which are discussed in more detail in following sections. First, seasonal water use patterns are used to convert the forecast of annual average demand into monthly average demand. Second, the historical data are detrended[1]. Third, a regression model is employed to relate daily departures from monthly average conditions to weather and other variables. Fourth, 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. (Autocorrelation describes the correlation between values of the same time series at different time periods. For example, daily stream flow data are typically autocorrelated—when stream flows are high, subsequent days' flows are likely to stay high—when they are low, subsequent days' flows are more likely to be low.) The resulting model can be used to see how the WMA water suppliers' demand varies as a function of historical and forecasted weather variables.

### *3.6.1 Method used in prior studies*

Mean monthly production factors, peak 7-day, and peak 1-day production factors were used in prior studies (ICPRB, 1990, 1996) 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 Demand 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 specification of which year of demand patterns (1991, 1997, or 1998) to use in modeling demand. Reservoir storage was relatively insensitive to which years' demand pattern was

[1] Stationarity in the mean of the data prior to derivation of model parameters is necessary in order to remove the effects of long-term changes in factors which are not included in the model. The effects of those factors are emobodied in the time trend which is removed.

used, but model results were presented for that year which most depleted reservoir storage.

The current study models demand as a function of weather and other variables, which allows for an examination of what today's demand would be, given a repeat of the extreme weather conditions of the 1930 drought of record. The development of this model is discussed in the following sections.

### *3.6.2 Converting average annual demand into monthly average demand*

The ratio of monthly average demand to average annual demand for each water supplier was calculated from 1990 through the most recent year for which a complete year's data set was available (Table 3-4).

The average monthly production factor is multiplied by the forecast of average annual demand to convert average annual demand into an estimate of demand that varies by month for each supplier. Additional steps are required to explore the causes of variation in daily demand from these monthly average values.

### *3.6.3 Detrending the data*

Before a regression can be conducted, the raw data must be detrended. The procedure by which the water supplier data is detrended is discussed in this section, and is based on the same method employed by Steiner (1984). We take this opportunity to acknowledge the Steiner report for its contribution to the documentation of this section.

Stationarity in the mean of the data must be 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:

$$Y(t) = B + Mt + e(t) \qquad \textit{(Equation 1)}$$

Where: Y = untransformed water use data, in units of MGD
t = index of days (1 to 5051, for 13+ years)
B = constant
M = slope of regression line
e = residual error.

The resulting equations for each WMA water supplier are:

Aqueduct: $Y(t) = 190.248 - 0.003301t$
WSSC: $Y(t) = 167.677 - 0.000552t$
FCWA: $Y(t) = 105.70 + 0.007116t$

The raw data and linear regression over time are shown in Figure 3-3 for each supplier. 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 2:

$$Y(t') = B + Mt' \qquad \textit{(Equation 2)}$$

Where: $t'$ = the time index of the most recent observation

The detrended time series $Y'(t)$ is constructed by adding the residual term from Equation 1 to the value calculated in Equation 2 for each t, as represented by Equation 3.

$$Y'(t) = Y(t') + e(t) \qquad \textit{(Equation 3)}$$

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 3-4).

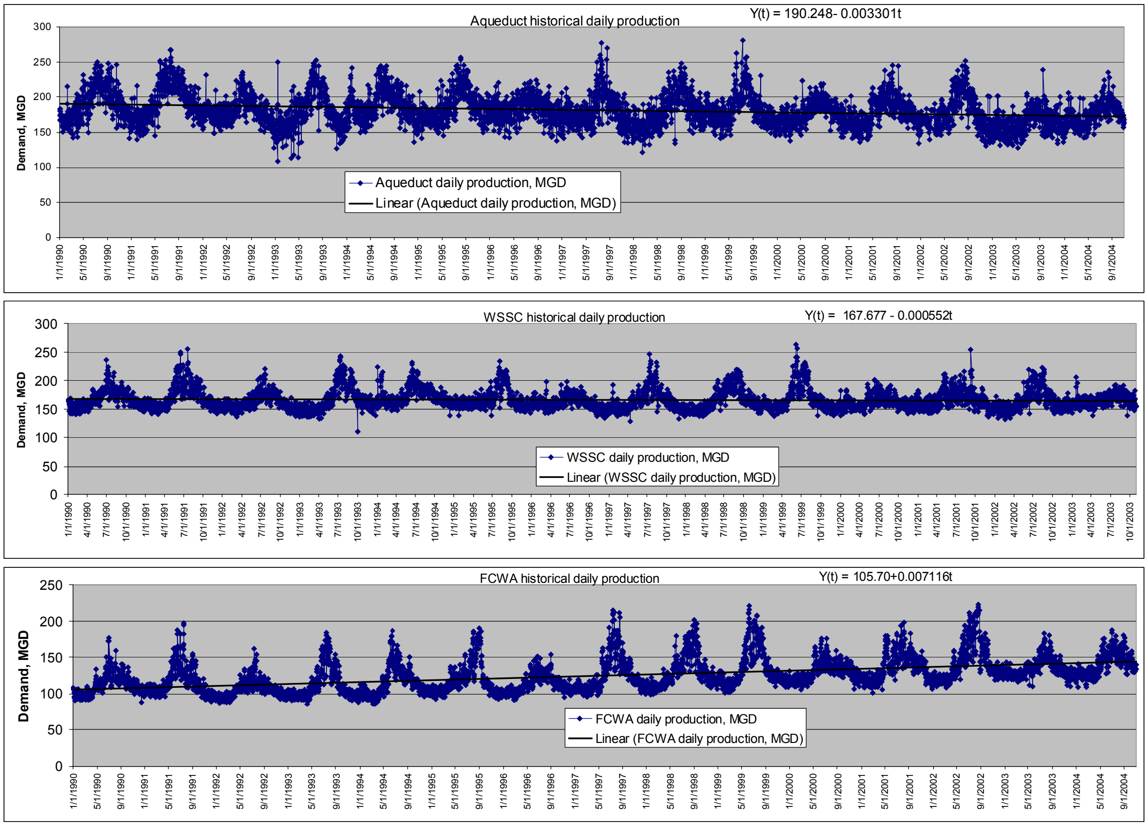



Figure 3-3: Daily water production data and linear regression over time for each supplier.

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 3-4) are multiplied by the long-term stationary mean value calculated in Equation 2. The resulting detrended average monthly demand is shown in Figure 3-4. 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.

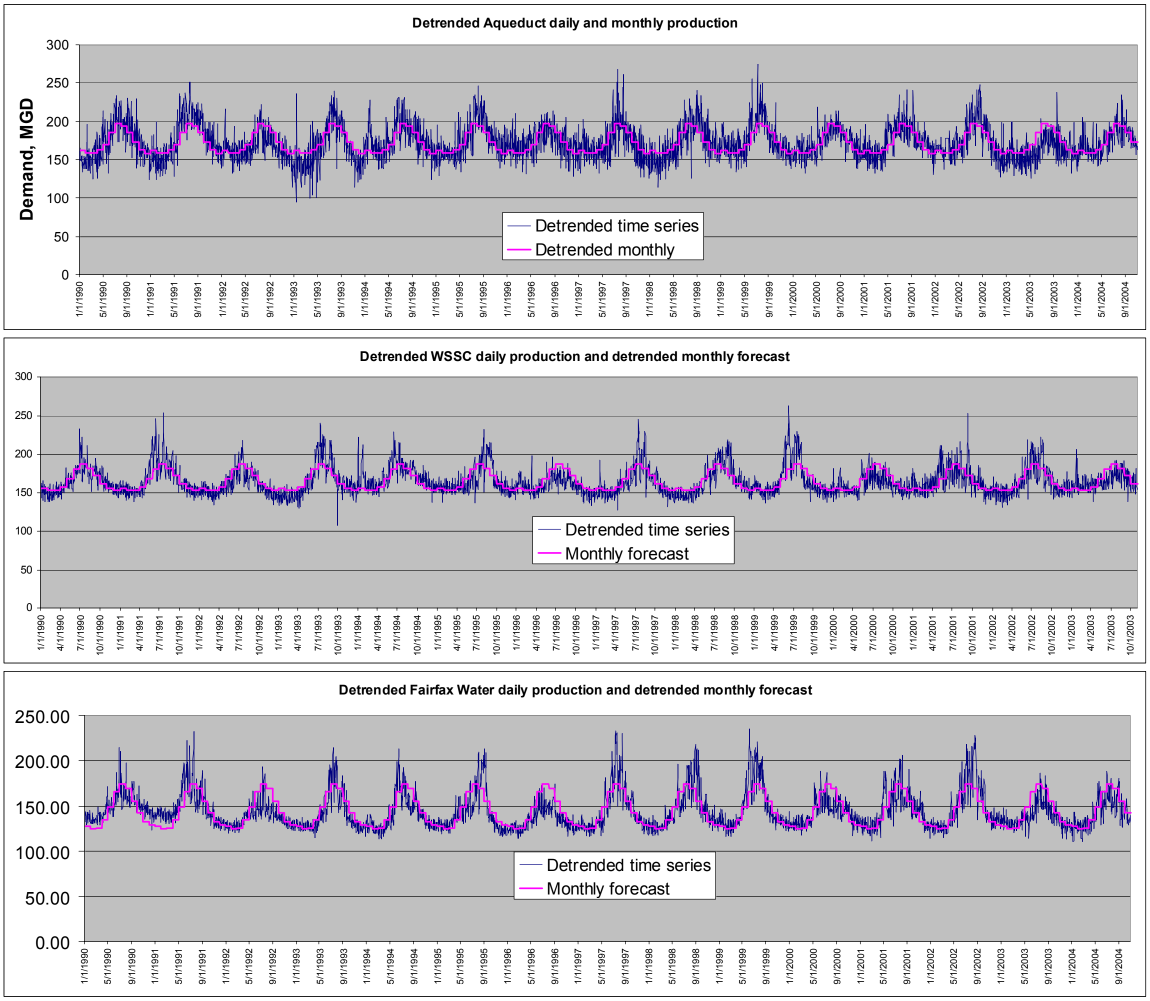



Figure 3-4: Detrended daily and monthly water production for the three WMA water suppliers.

### *3.6.4 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:

$$Y_t = b_0 + b_1 X_{1,t} + ... + b_k X_{k,t} + N_t \qquad \textit{(Equation 4)}$$

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

The dependent variable Y is taken as the departure of detrended daily demand from detrended monthly average conditions. Variables examined as explanatory variables in the regression for the WMA water suppliers included temperature, both forecast and lagged by one through five days, precipitation, both forecast 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 our 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). Select independent variables are further discussed in Section 4.10.

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. An examination of temperature versus demand for forecast temperature, temperature, and temperature lagged one day demonstrate 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. This evaluation was completed for forecast temperature, temperature, and temperature lagged one day variables. 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 forecast precipitation, current day's precipitation, precipitation lagged by one day, and precipitation lagged by 2 and 3 days illustrated that demand is a non-linear function of precipitation, with a breakpoint ranging from 0.2 inches (WSSC) to 0.3 inches (FCWA, Aqueduct). 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 the FCWA and for the 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 the Aqueduct and for FCWA. For precipitation lagged by approximately 4 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 supplier. Demand increases linearly for days from 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* variable 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, or the modeler otherwise risks over-predicting historic demand for those periods where many days in a row may occur without significant precipitation.

A backward stepwise linear regression model was used for parameter selection, to assist in determining which variables were significant factors in determining water demand. Many of the potential explanatory variables were discarded as they did not significantly add to the ability of the model to predict demand. The software used for the analysis was SPLUS®2000 (Mathsoft, 2000). The variables examined are shown in Table 3-6, with those variables retained marked with an "x." Those variables not marked with an "x" were discarded in the backward stepwise linear regression. 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 3-5: Independent variables examined for each water supplier. Those variables retained in the regression are marked with an "x" for summer months.

| Independent variable | Water supplier | | |
|---|---|---|---|
| | WSSC | Aqueduct | FCWA |
| Maximum daily temperature, one-day forecast | x | | x |
| Maximum daily temperature | x | x | x |
| Maximum daily temperature, one-day prior | x | x | x |
| Maximum daily temperature, two-days prior | x | 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 | | x |
| Daily precipitation, one-day prior | x | x | x |
| Daily precipitation, two-days prior | x | x | x |
| Daily precipitation, three-days prior | | x | 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 | 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 coefficients for each water supplier are given in Table 3-6 and Table 3-7. The application of the coefficients given in Table 3-7 can be interpreted using Fairfax Water as an example. The formula is provided below in Equation 5:

$$Y_t = -85.08 + (0.1838 \text{ or } 0.1648)*TFcst_t + (0.5601 \text{ or } 0.5052)*T_t + (0.2671 \text{ or } 0.2424)*T1_t - 26.50*P_t - 21.52*P1_t - 15.71*P2_t - 8.27*P3_t - 8.54*P4_t - 11.40*P5_t - 2.345 \text{ (if Tuesday)} - 1.734 \text{ (if Thursday)} + 2.639 \text{ (if Saturday)} + 2.997 \text{ (if Sunday)} - 2.288*Palmer_t + 0.9257*NoDaysP_t + N_t$$

*(Equation 5)*

Where:

$Y_t$ = dependent variable, variation from monthly average demand, MGD
$TFcst_t$ = Tomorrow's forecast maximum temperature, degrees Fahrenheit
$T_t$ = Today's maximum temperature, degrees Fahrenheit
$T_t1$ = Maximum temperature one day prior, degrees Fahrenheit
$P_t$ = Today's precipitation, inches
$P1_t$ = Precipitation one day prior, inches
$P2_t \ldots 5_t$ = Precipitation two to five day's prior, inches
$Palmer_t$ = Palmer Drought Severity Index
$NoDaysP_t$ = Number of days in a row without precipitation of 0.15 inches or more
$N_t$ = error term

*Note that the precipitation variable input is constrained at a maximum of 0.3 inches*

Table 3-6: Regression coefficients developed for WMA water suppliers, summer months.

| Independent variable | Water supplier | | |
|---|---|---|---|
| | WSSC | Aqueduct | FCWA |
| Intercept, b | -108.17 | -106.98 | -85.08 |
| Maximum daily temperature >90, one-day forecast | 0.2033 | | 0.1838 |
| Maximum daily temperature <90, one-day forecast | 0.1843 | | 0.1648 |
| Maximum daily temperature >90 | 0.3868 | 0.4591 | 0.5601 |
| Maximum daily temperature <90 | 0.3416 | 0.4434 | 0.5052 |
| Maximum daily temperature >90, one day prior | 0.5617 | 0.532 | 0.2671 |
| Maximum daily temperature <90, one day prior | 0.5508 | 0.4874 | 0.2424 |
| Maximum daily temperature, two-days prior | 0.1052 | 0.3232 | |
| Daily Precipitation | -11.50 | | -26.50 |
| Daily precipitation, one-day prior | -22.66 | -14.1553 | -21.52 |
| Daily precipitation, two-days prior | -11.04 | -13.79 | -15.71 |
| Daily precipitation, three-days prior | | -5.859 | -8.27 |
| Daily precipitation, four-days prior | | | -8.54 |
| Daily precipitation, five-days prior | | | -11.40 |
| Day of week - Monday | | -6.207 | |
| Day of week - Tuesday | | | -2.345 |
| Day of week - Thursday | | | -1.734 |
| Day of week - Saturday | | -4.093 | 2.639 |
| Day of week - Sunday | | -11.63 | 2.997 |
| Palmer Drought Severity Index | -1.093 | -1.353 | -2.288 |
| Number of days in a row without significant precipitation | 1.024 | 0.54 | 0.9257 |

Table 3-7: Regression coefficients developed for WMA water suppliers, fall months.

| Independent variable | Water supplier | | |
|---|---|---|---|
| | WSSC | Aqueduct | FCWA |
| Intercept, b | -17.5631 | -18.5232 | -18.2296 |
| Maximum daily temperature | 0.1415 | | 0.1298 |
| Maximum daily temperature, one-day prior | 0.1128 | 0.2925 | 0.0962 |
| Daily precipitation, one-day forecast | -1.964 | | -2.1758 |
| Daily Precipitation | -3.0492 | | -4.2409 |
| Daily precipitation, one-day prior | -3.7749 | -4.1253 | -2.788 |
| Daily precipitation, two-days prior | -2.8441 | -1.7969 | -2.8376 |
| Daily precipitation, three-days prior | -3.4186 | -2.4828 | -1.9507 |
| Daily precipitation, four-days prior | -3.153 | -1.8952 | -2.4399 |
| Daily precipitation, five-days prior | -1.8199 | | -1.2323 |
| Day of week - Monday | 6.5274 | -4.3052 | 4.6922 |
| Day of week - Tuesday | 2.2007 | | |
| Day of week - Thursday | -1.4344 | | |
| Day of week - Saturday | -1.9557 | -5.8026 | 2.7583 |
| Day of week - Sunday | 4.7168 | -7.4696 | 6.037 |
| Palmer Drought Severity Index | -0.5442 | -1.0813 | -0.8793 |
| Number of days in a row w/o significant precipitation | 0.1962 | 0.3624 | 0.3728 |

The error term shown in Equation 4 and Equation 5 is $N_t$. One of the key assumptions is that $N_t$ is an uncorrelated series, i.e., "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 4 is still valid but $N_t$ is modeled as an ARIMA process (Madrikas et al., 2003) and is discussed in more detail in the following section.

### *3.6.5 ARIMA model used to account for autocorrelation in 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 4 that the overall form of the regression is:

$$Y_t = b_0 + b_1X_{1,t} + \ldots + b_kX_{k,t} + N_t$$

The ARIMA modeling process separates the $N_t$ term from Equation 4 into random and non-random components:

$$N_t = Arima_t + random_t \qquad \textit{(Equation 6)}$$

where

$Arima_t$ = that non-random portion of $N_t$ calculated by ARIMA process at time t

$random_t$ = random component of $N_t$ at time t

The error term, $N_t$, from each of the multivariate regression models for the FCWA, Aqueduct, and WSSC models was autocorrelated. Each error term series was examined for partial autocorrelation and found to have partial autocorrelation significant at three timesteps. ARIMA models were developed to model the autocorrelation in the error term for each supplier, and for the CO-OP system. The software used for the analysis was SPLUS®2000 (Mathsoft, 2000). Several ARIMA models were analyzed and the (3,0,1) model was found to perform the best for Fairfax Water, the Aqueduct, WSSC, and for the CO-OP system as well. Figure 3-5 through Figure 3-8 show actual and modeled demand for each water supplier and for the CO-OP system. The coefficients for the ARIMA models are given in Table 3-8.

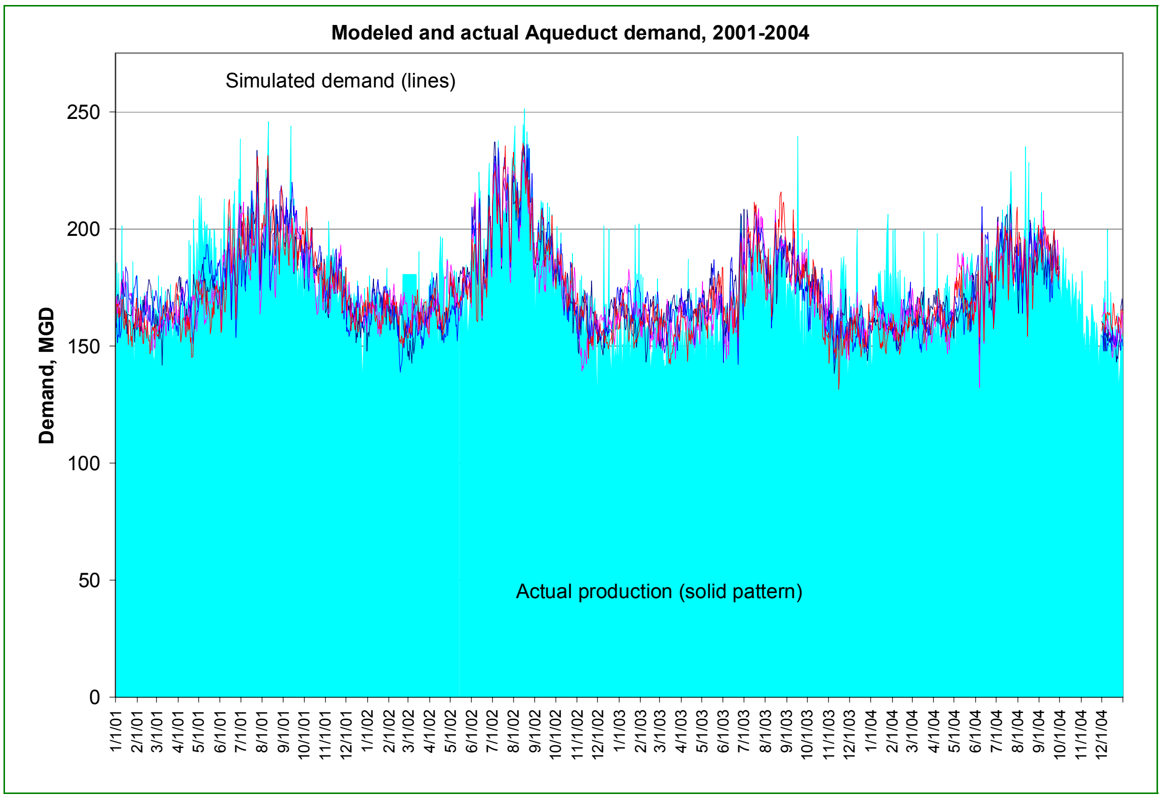



Figure 3-5: Aqueduct summer 2002 demand, modeled and predicted.

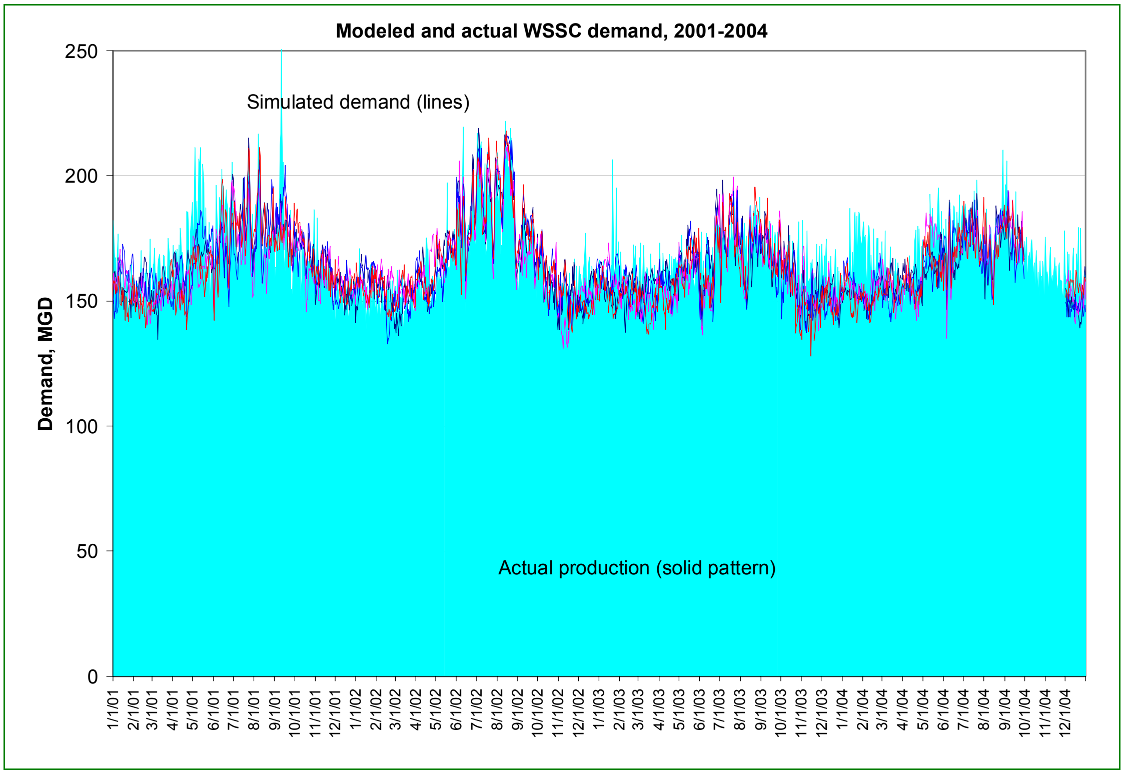



Figure 3-6: WSSC summer 2002 demand, modeled and predicted.

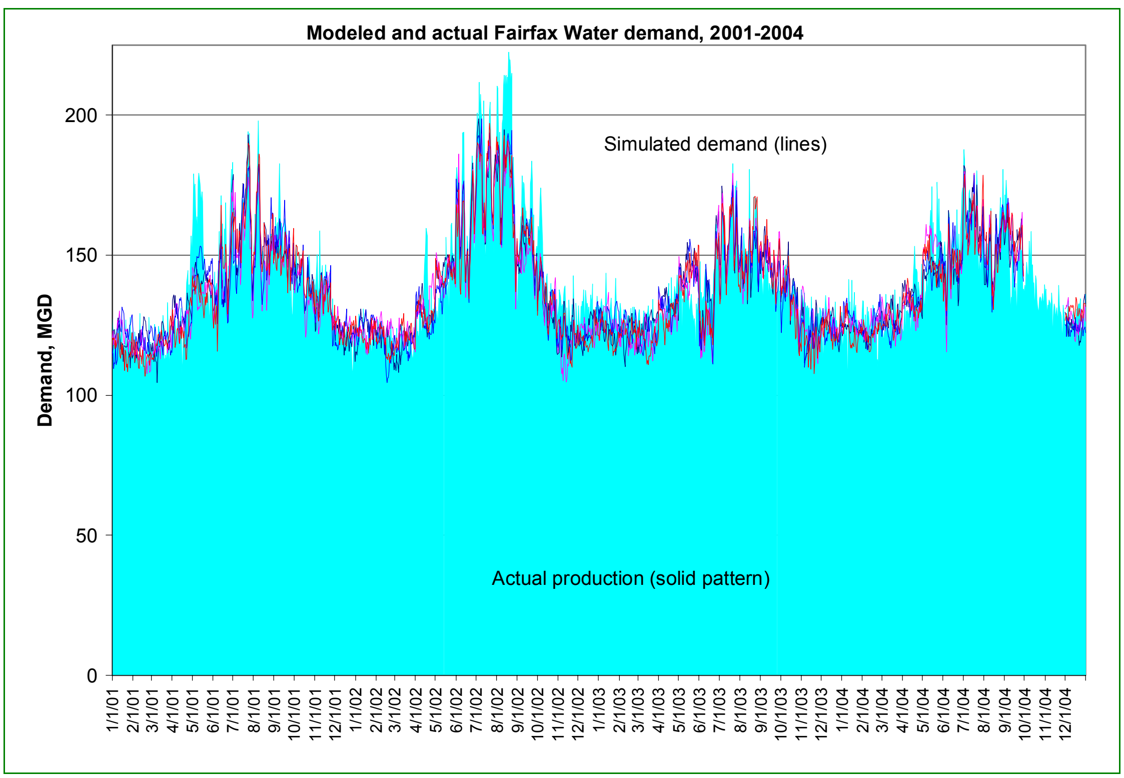



Figure 3-7: Fairfax Water summer 2002 demand, modeled and predicted.

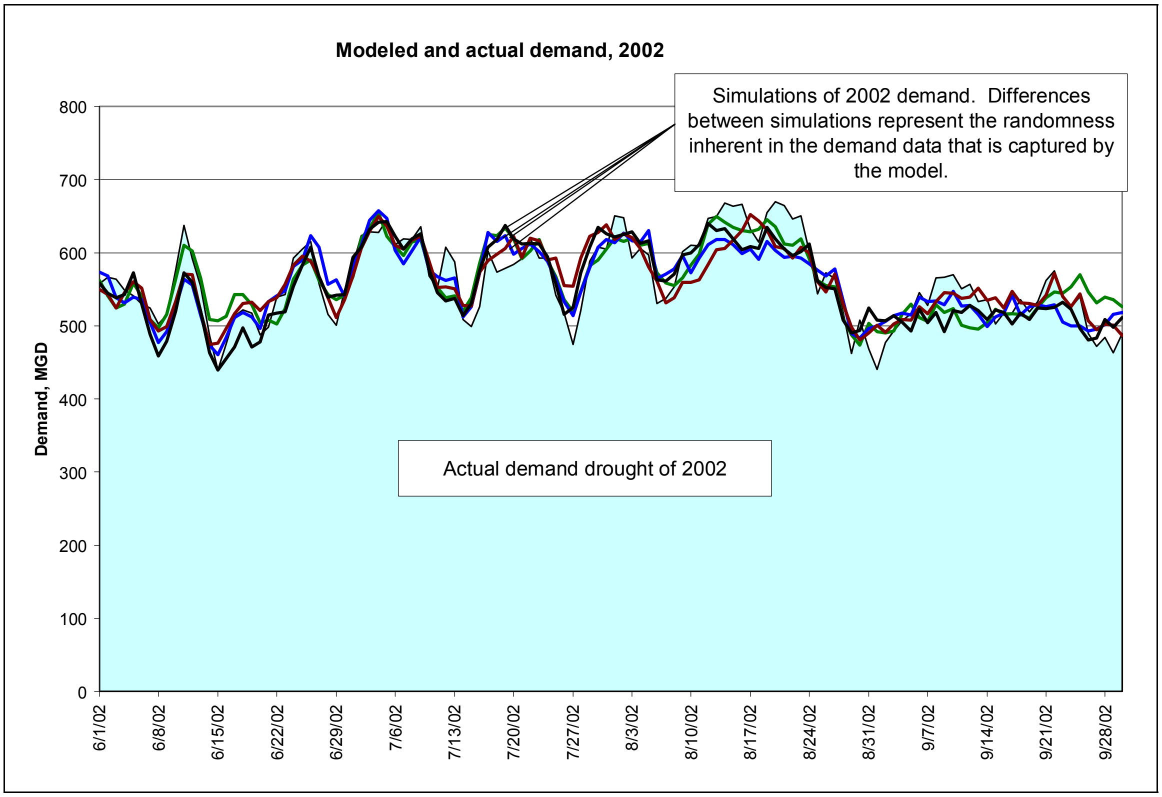



Figure 3-8: CO-OP system summer 2002 demand, modeled and predicted.

Table 3-8: ARIMA model coefficients.

| | ARIMA Coefficients | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| FCWA summer coefficients | | | |
| AR | 1.47127 | -0.46242 | -0.02529 |
| MA | 0.88902 | | |
| WSSC summer coefficients | | | |
| AR | 0.65691 | 0.01326 | 0.12446 |
| MA | 0.37043 | | |
| Aqueduct summer coefficients | | | |
| AR | 0.8077 | -0.00659 | 0.05003 |
| MA | 0.63129 | | |
| CO-OP system summer coefficients | | | |
| AR | 0.94845 | -0.12532 | 0.0238 |
| MA | 0.4772 | | |
| CO-OP system fall coefficients | | | |
| AR | 0.26479 | 0.45374 | 0.00708 |
| MA | -0.5476 | | |

For verification the time series corresponding to $random_t$ 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 $random_t$ time series mean and a standard deviation is provided in Table 3-9. The standard deviation of the random term is important because it is used when forecasting future demand as described in the next section. The overall Pearson Correlation Coefficient between actual and modeled demand is also given in Table 3-9 and is a measure of how well the models perform in estimating demand. Statistics are provided primarily for the summer model for each supplier, as that is the time period of highest demand and greatest interest. The model performs much better in the summer when demand is more responsive to variables like temperature and precipitation than it is in the fall, as can be seen by the lower Pearson Correlation Coefficient for the WMA water suppliers for fall months (Table 3-9).

Table 3-9: Standard deviation of error term (random component), average of error term, and coefficient of determination for demand models (summer months unless otherwise noted).

| | Standard deviation of random component of $N_t$ (MGD) | Average of random component of $N_t$ (MGD) | Coefficient of determination ($r^2$) |
|---|---:|---:|---:|
| WSSC | 11.0 | 0 | 0.71 |
| Aqueduct | 14.1 | 0 | 0.58 |
| FCWA | 12.5 | 0 | 0.81 |
| CO-OP | 22.6 | 0 | 0.81 |
| CO-OP (fall) | 30.5 | -0.7 | 0.63 |

## 3.7 Calculating the daily demand forecasts

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. These variables are used to drive the regression models developed for each supplier.

A random number generator is used to develop the random component of $N_t$, assuming a normal distribution, mean of zero, and the standard deviations provided in Table 3-9. (The error term for the CO-OP system is normally distributed). Seed values for $N_{t-1}$ , $N_{t-2}$ , $N_{t-3}$ and $\text{random}_{t-1}$ were assumed, which allows for calculation of the first ARIMA term, $\text{Arima}_t$ in Equation 4. Since the random component at time t is a given ($\text{random}_t$), the first $N_t$ is calculated as simply $N_t = \text{Arima}_t + \text{random}_t$ (Equation 6). Since the regression model coefficients and independent variables are all known, the $b_0 + b_1X_{1,t} + ... + b_kX_{k,t}$ portion of Equation 4 can be solved and added to the $N_t$ term already calculated in order to arrive at an estimate of $Y_t$, the demand that would have occurred given current levels of demand. Once $N_t$ is known, it is straightforward to solve for $N_{t+1}$, and $Y_{t+1}$ and so on.

To calculate the demand that would occur given future demand levels, the current demand was multiplied by the ratio of future average annual demand to current average annual demand.

Figure 3-9 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 variations of current levels of demand are shown since each trace is perturbed 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.

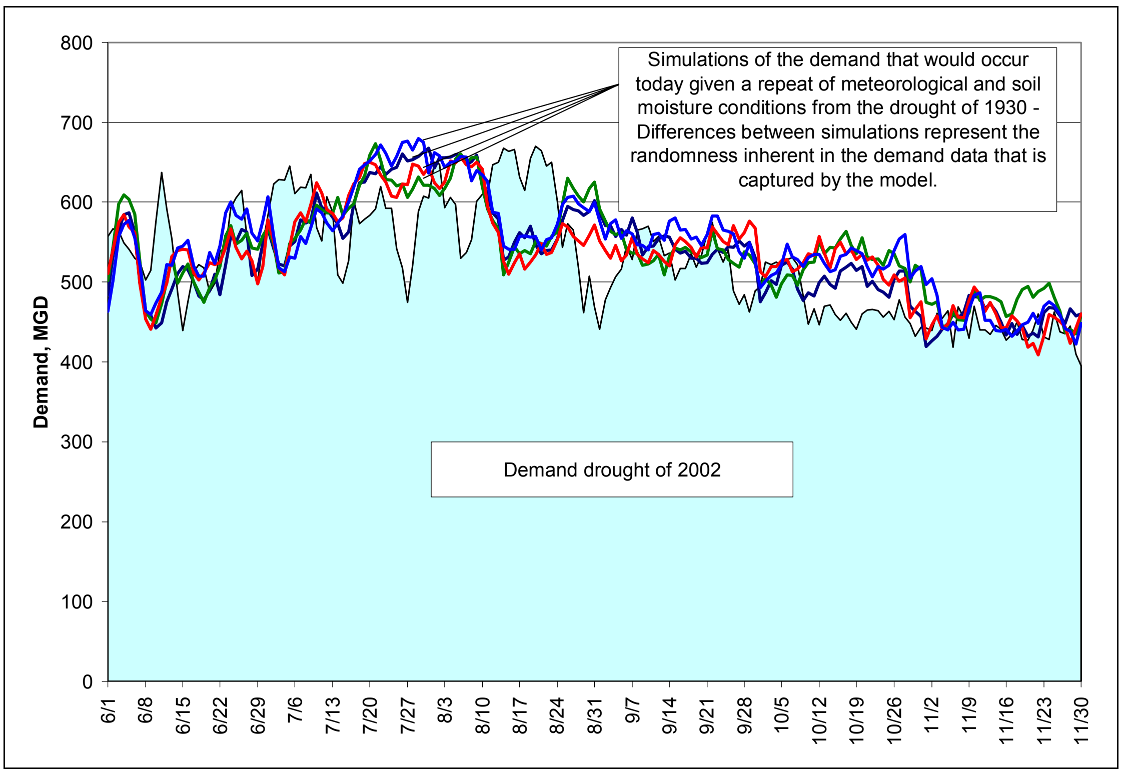
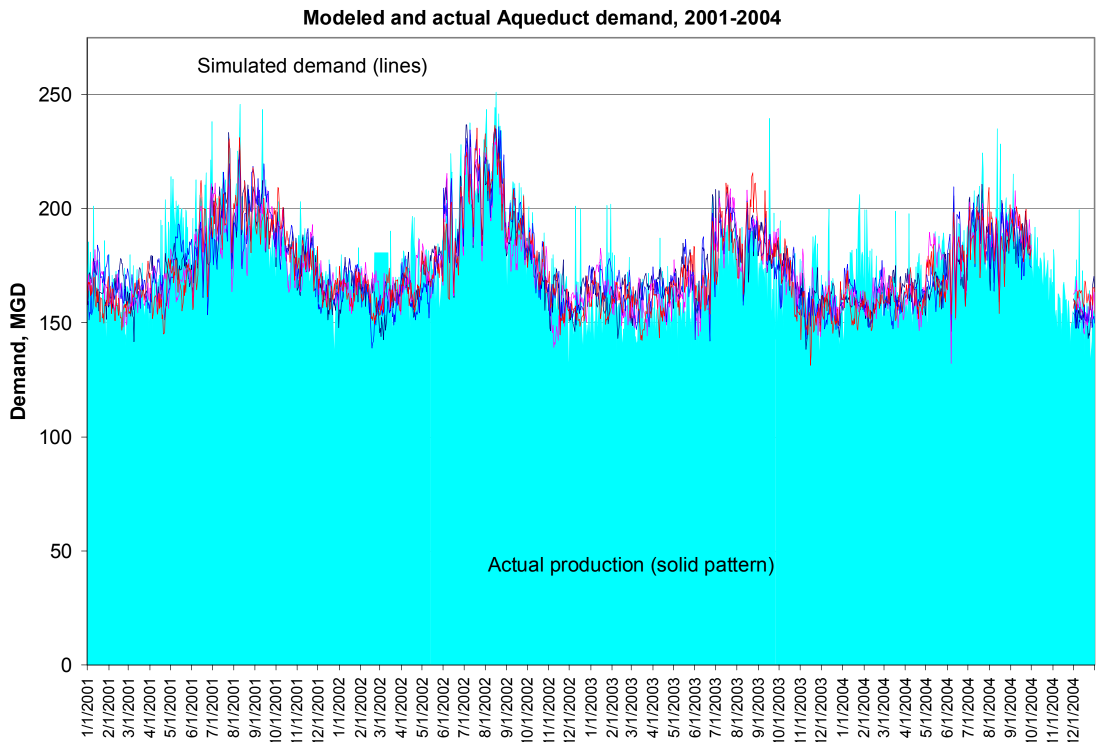



Figure 3-9: Modeled demand that would occur today given meteorology of 1930. Also shown is the demand that actually occurred in the drought year of 2002.




## 3.8 Additional advantages of using the detailed demand model

It is critical to preserve the autocorrelation and random characteristics of the original data series as the realistic representation of system demand has a direct relationship to how reservoir releases are made and to system efficiency. Another advantage in carefully determining the statistical properties of the original data set is that this knowledge can be useful for 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. A significant advantage is that this method allows for the use of weather information to more accurately portray demand likely to occur during extreme droughts (as during the conditions experienced during the drought of record). An additional advantage of this method is that it can be used to explore how changes in climate affect current and future demand.

## 3.9 Application of the regression models to estimate water reduction during mandatory restrictions in the drought of 1999

WSSC experienced mandatory water restrictions from August 5$^{th}$ to September 2$^{nd}$, 1999. In this analysis a regression model has been developed to calculate the unrestricted demand WSSC would have experienced given the explanatory variables introduced above. This unrestricted demand was compared to the actual, restricted demand experienced in 1999 to determine the relative effectiveness (percentage reduction in demand) of restriction measures (Figure 3-10). In this way, one can account for the fluctuations in demand that are due to the influence of weather or other factors, and better determine a true measure of how restrictions affect demand. The 1999 data was withheld from the calibration of the WSSC regression model, so that the calibration model could be used to determine the effects of voluntary restrictions. The net effect of mandatory restrictions in WSSC over the period August 5th through September 2nd is a reduction in demand of 9.2 percent.

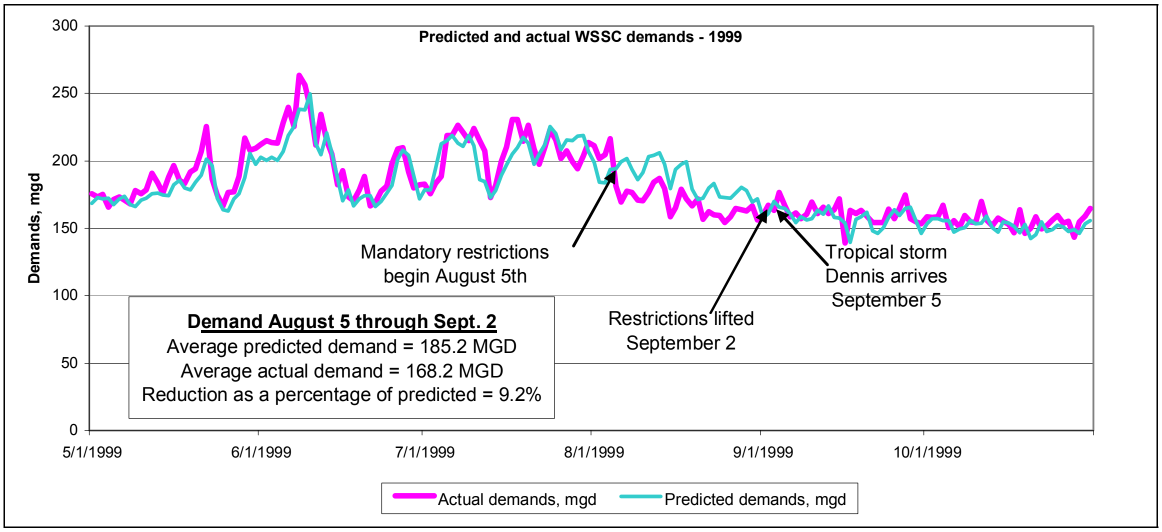



Figure 3-10: Predicted and actual WSSC demand, drought of 1999.

# 4 Development of the Demand Forecast

## 4.1 Introduction

The development of the demand forecast for the 2005 Demand Study is a multi-step process. An overview of the research process used to develop the forecast is provided in Section 4.2. This research process includes the derivation of water supplier service areas (Section 4.3), dwelling unit ratios (Section 4.4), service area populations (Section 4.5), and unit use and unmetered water calculations (Section 4.6). Additional factors that have the potential to affect demand are also discussed. These include the impacts of the *Energy Policy Act of 1992* (Section 4.7), changes in customer demand due to conservation education (Section 4.8), the affects of water use restrictions (Section 4.9), and the impacts of climate change and variability in the Northeast Atlantic region (Sections 4.10 and 4.11).

## 4.2 Method

The determination of current and future water demand is dependent on highly disaggregated water use and demographic data. The process of estimating this demand can be tracked in Figure 4-1 below. These steps are detailed in the discussion that follows. The estimate of future demand is based on a grouping of all water use categories into three types of water uses: single family household use, multi-family (apartment) water use, and employee water use. Projections of numbers of households and employees are based on the Metropolitan Washington Council of Governments (MWCOG) Round 6.4a Cooperative Forecast (MWCOG, 2004) and on a delineation of current and future supplier service areas using GIS techniques. Information on the number of single family and multi-family homes was obtained for each jurisdiction from local planning agencies. This information is used to separate the MWCOG household forecasts into single family and multi-family units. Coefficients or “unit use factors” are developed for each jurisdiction in the WMA to describe average daily water use by each type of water user. Unit use factors are determined via surveys of individual suppliers water use. Per household water use is assumed to be lower in the future than it is today due to the increasing installation of water conserving fixtures and fittings as prescribed in the *Energy Policy Act of 1992.* Geographic information, demographic data, and water use billing information are collected to determine unit use and to estimate future water demand for 11 wholesale and retail suppliers.

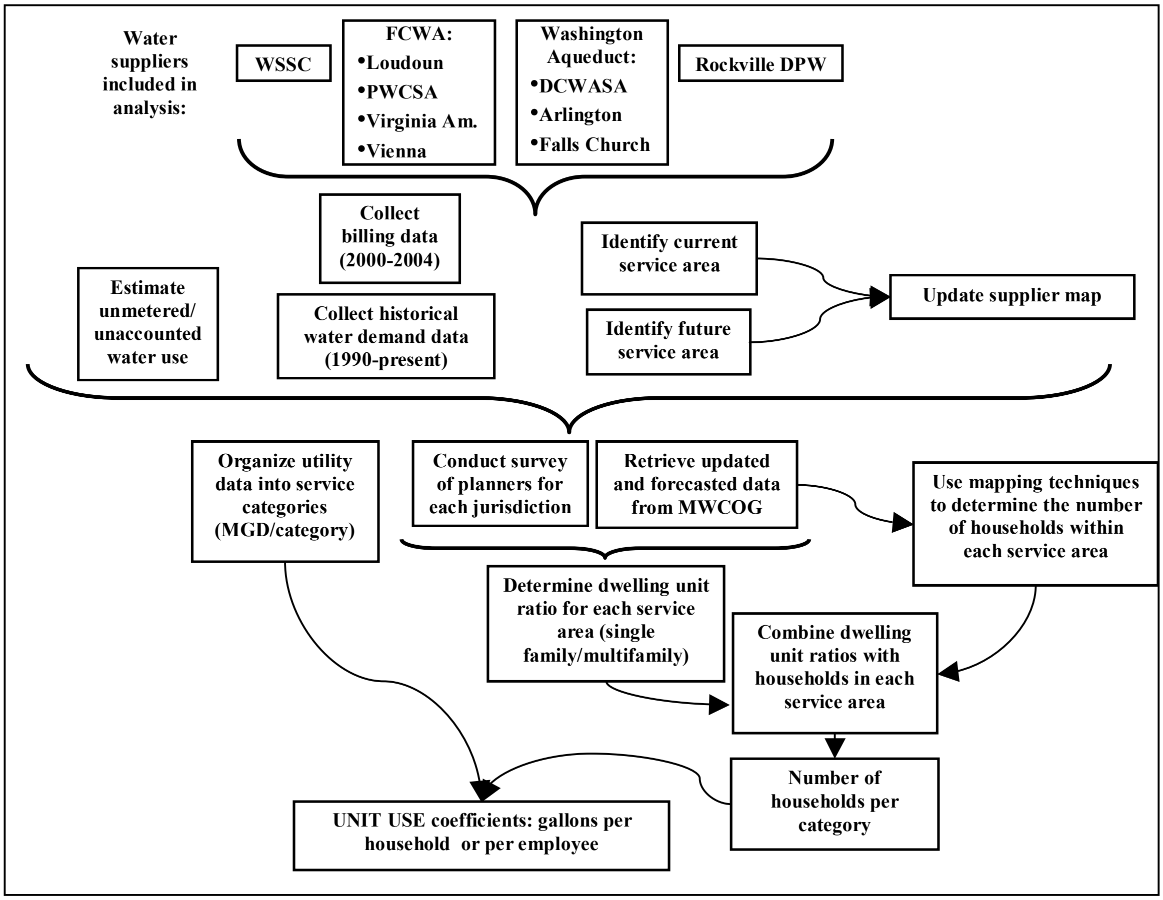



Figure 4-1: Research process for determining unit use coefficients.

## 4.3 Delineation of water supplier service area

Each water supplier was contacted to help delineate current and future (2025) service areas. The current and projected service area for the Washington Metropolitan Area is shown in Figure 4-2 and in Figure 4-3. The service area footprints were critical in the determination of service area population, as discussed in Section 4.4.

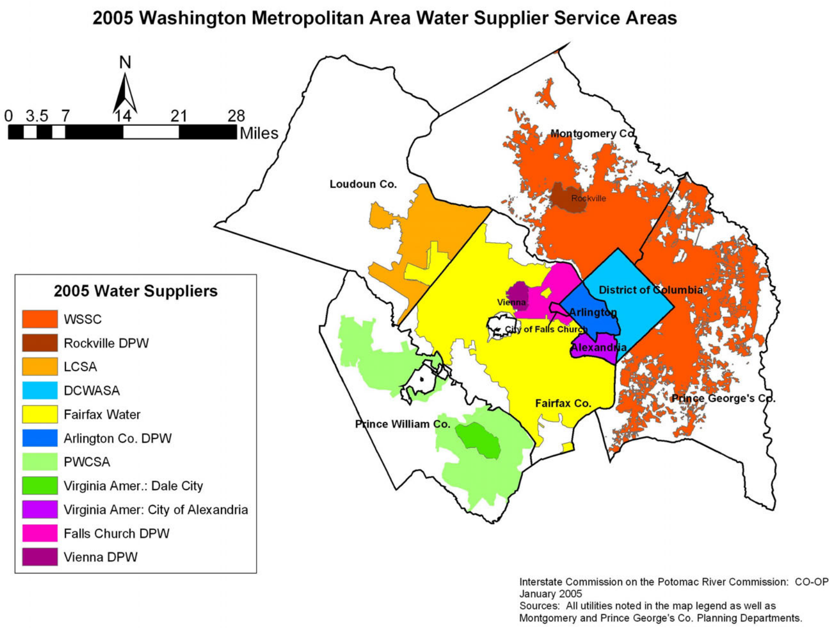



Figure 4-2: Water supplier service areas in the Washington metropolitan area, 2005.

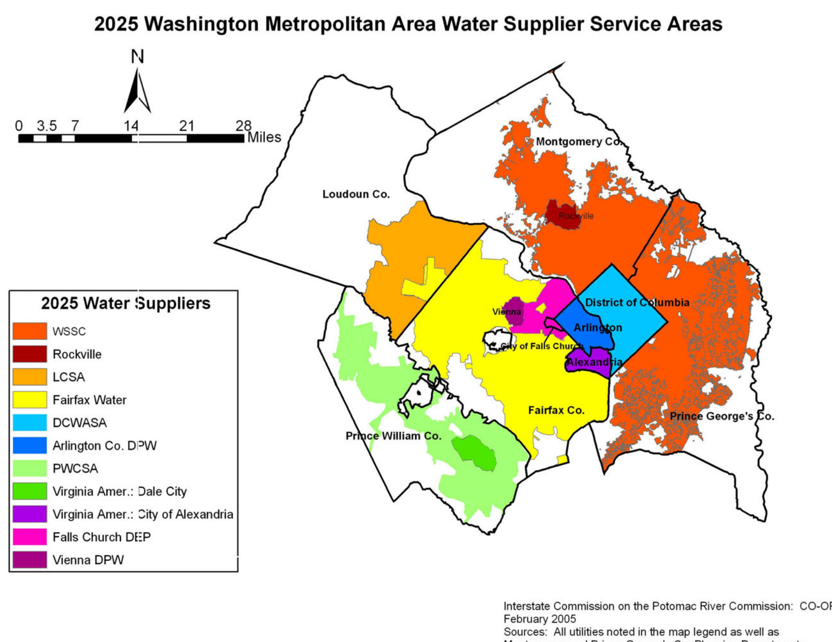



Figure 4-3: Water supplier service areas in the Washington metropolitan area, 2025.

## 4.4 Dwelling Unit Ratios

Dwelling unit ratios are developed for each region within the CO-OP Suppliers' service area. These ratios are equal to the number of single family households divided by the number of multi-family households. Information on the number of single family and multi-family (apartment) homes was obtained for each jurisdiction from local planning agencies. These ratios are used to separate the MWCOG household forecasts into single family and multi-family units. Dwelling unit ratios for the major jurisdictions in the WMA are shown in Table 4-1 below. The ratios were compiled using information from the City of Alexandria's Department of Planning and Zoning, Prince William County's Office of Information Technology GIS, the City of Rockville Community Planning and Development Services, District of Columbia Office of Planning, the U.S. Census Bureau, Arlington County Department of Community Planning, Housing and Development, Fairfax County Department of Systems Management for Human Service and the Department of Planning and Zoning, the Loudoun County Department of Economic Development, the Montgomery and Prince George's offices of the Maryland National Capital Park and Planning Commission, and the Falls Church Planning Division.

Table 4-1: Dwelling unit ratios by service area.

| | **Dwelling Unit Ratios** | | | | | | |
|---|---|---|---|---|---|---|---|
| **Jurisdiction** | **2000** | **2004** | **2005** | **2010** | **2015** | **2020** | **2025** |
| Arlington County | 0.73 | 0.67 | 0.66 | 0.62 | 0.59 | 0.56 | 0.54 |
| District of Columbia[d] | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| City of Alexandria | 0.56 | 0.53 | 0.53 | 0.53 | 0.52 | 0.50 | 0.49 |
| City of Rockville[f] | 3.16 | 2.38 | 2.23 | 1.68 | 1.66 | 1.64 | 1.63 |
| Falls Church | 1.82 | 1.80 | 1.74 | 1.10 | 0.83 | 0.72 | 0.69 |
| Fairfax County[b] | 2.63 | 2.56 | 2.89 | 2.86 | 2.94 | 2.96 | 2.96 |
| Montgomery County[a, f] | 2.23 | 2.14 | 2.12 | 1.99 | 1.89 | 1.80 | 1.70 |
| Prince George's County | 1.81 | 2.10 | 1.91 | 1.96 | 1.98 | 2.03 | 2.07 |
| Loudoun County[c] | 3.62 | 3.31 | 3.29 | 3.29 | 3.31 | 3.32 | 3.32 |
| Prince William County[f] | 3.67 | 3.69 | 3.69 | 3.65 | 3.17 | 2.84 | 2.70 |
| Dale City[f] | 13.95 | 13.10 | 12.71 | 9.73 | 8.66 | 8.66 | 8.92 |
| Vienna[e] | 6.74 | 5.61 | 6.38 | 6.31 | 6.49 | 6.53 | 6.54 |

Notes:

[a]Ratios exclude Rockville, Bennet, Patuxent, Martinsburg, Poolesville.
[b]Ratios exclude subplanning regions of Fairfax and Vienna.
[c]Ratios include Potomac, Dulles, Ashburn, Sterling, and half of the Leesburg and 15S planning regions.
[d]Ratios were calculated using US Census 2000 data. Additional updates to the ratio were unavailable.
[e]Ratios for 2000-2004 were calculated from actual Vienna household data. The ratios during years 2005-2025 were calculated under the assumption that future single and multifamily households in Vienna will represent the same percentage of total Fairfax Co. single and multifamily households in 2004.
[f]Ratios for 2001-2004 were calculated based on interpolation from ratios during 2000 and 2005; 2000 and 2005-2025 ratios were calculated using County Planning TAZ data.

For some jurisdictions, the water supply distribution area boundaries do not correspond exactly with the political jurisdiction boundaries associated with county planning data. For example, WSSC does not serve all of Montgomery County. Therefore, as much as possible, the dwelling unit ratios were calculated specific to the service areas within each jurisdiction as shown in the footnotes of Table 4-1.

## 4.5 MWCOG cooperative forecast

Estimates of population, households, and employment for years 2005-2025 are based on the MWCOG Round 6.4a Cooperative Forecast (Desjardin et al., 2004). These forecasts were developed through a cooperative process involving the Council of Governments, its member jurisdictions, the Baltimore region, and the states and other planning agencies. The Cooperative Forecasting Program, established in 1975 and administered by the MWCOG, allows for coordinated local and regional planning using common assumptions about future growth and development. The most recent set of forecasts available at the beginning of this study, Round 6.4a, was completed in December of 2004 and is used in this study.

The development of the MWCOG forecast uses both regionally and locally derived information as inputs to predict the location and magnitude of future population, households and employment. On a regional scale, local and national demographics and economic trends are used to create a statistical benchmark for the area as a whole. Local jurisdictions also develop their own local forecasts based on such information as building permits, site plans, or local policy using an agreed-upon set of guidelines. Regional projections are then reconciled with the jurisdictions' totals to produce local forecasts that are technically sound and politically acceptable. The final product is an estimate of population, employment 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 service area.

The demographics of each CO-OP supplier service areas are derived through a process that combines TAZ data and water suppliers' regional service areas. Using GIS ArcMap™ (ESRI), the aforementioned supplier service areas are compared with TAZ maps and demographic data specific to each service area is extracted for the current and forecasted years (2005-2025).

Population, households, and employment data for each service area were extracted. A summary of the population, household, and employment data for each regional water supplier is provided in Table 4-2. A summary of the net increase in population, household, and employment data for the WMA water suppliers is provided in Table 4-3. Forecasts of growth for population, employees, and households are significant, ranging from +15 to +19 percent in the Aqueduct wholesale service area, +26 to +40 percent in the WSSC service area, and +26 to +42 percent in Fairfax Water's retail and wholesale service areas. Within the WMA water supplier service area, the number of households is forecast to increase by 22 percent, the population by 19 percent, and the number of employees by 32 percent.

Table 4-2: CO-OP regional suppliers' households, population, and employment by service areas and MWCOG Round 6.4a forecast.

| | 2005 | | | 2025 | | |
|---|---|---|---|---|---|---|
| | **Households** | **Population** | **Employment** | **Households** | **Population** | **Employment** |
| Fairfax Water - Dulles | 26 | 68 | 15,229 | 0 | 0 | 32,144 |
| Fairfax Water - Ft. Belvoir | 489 | 8,014 | 26,567 | 3,659 | 16,184 | 40,943 |
| Fairfax Water - Herndon | 7,309 | 19,595 | 24,093 | 8,987 | 24,028 | 27,188 |
| Fairfax Water - Lorton | 0 | 0 | 383 | 731 | 1,974 | 1,075 |
| Fairfax Water - Loudon Co. Sanitation Authority | 54,932 | 155,445 | 72,425 | 99,766 | 277,860 | 143,227 |
| Fairfax Water - Prince William Co. Service Authority | 83,468 | 242,834 | 80,032 | 125,782 | 349,493 | 138,141 |
| Fairfax Water - Retail Service Area | 297,462 | 812,445 | 381,953 | 336,173 | 917,204 | 487,665 |
| Fairfax Water/Virginia American - Alexandria | 66,194 | 136,531 | 105,612 | 74,296 | 150,004 | 134,774 |
| Fairfax Water/Virginia American - Dale City | 19,574 | 59,721 | 9,132 | 22,065 | 64,424 | 13,215 |
| **Fairfax Water subtotal** | **529,454** | **1,434,653** | **715,427** | **671,460** | **1,801,171** | **1,018,372** |
| Aqueduct - Arlington Co. DPW | 92,643 | 198,246 | 165,329 | 113,138 | 234,386 | 222,819 |
| Aqueduct - Falls Church DEP | 48,962 | 122,828 | 122,939 | 54,515 | 136,227 | 141,686 |
| Aqueduct - Falls Church-Vienna DPW | 8,463 | 23,713 | 13,827 | 9,101 | 25,577 | 14,870 |
| Aqueduct - District of Columbia WASA | 262,309 | 601,478 | 741,026 | 303,137 | 696,313 | 860,242 |
| Aqueduct - Fort Meyers | 305 | 2,520 | 6,032 | 305 | 2,520 | 6,032 |
| Aqueduct - D.C. Soldiers Home & Howard Univ. | 1,628 | 5,524 | 3,225 | 1,750 | 6,267 | 3,282 |
| **Aqueduct subtotal** | **414,310** | **954,309** | **1,052,378** | **481,946** | **1,101,290** | **1,248,931** |
| WSSC - Prince George's County | 298,189 | 838,915 | 352,442 | 352,896 | 934,262 | 538,270 |
| WSSC – Montgomery | 297,589 | 798,569 | 421,752 | 373,271 | 977,057 | 546,299 |
| **WSSC subtotal** | **595,778** | **1,637,484** | **774,194** | **726,167** | **1,911,319** | **1,084,568** |
| **Fairfax Water, Aqueduct, WSSC total** | **1,539,543** | **4,026,446** | **2,541,999** | **1,879,573** | **4,813,780** | **3,351,872** |
| City of Rockville DPW | 16,186 | 44,048 | 69,787 | 19,248 | 49,237 | 91,834 |
| **Fairfax Water, Aqueduct, WSSC, Rockville total** | **1,555,729** | **4,070,494** | **2,611,786** | **1,898,821** | **4,863,018** | **3,443,705** |

Table 4-3: Net increase in demographics by service areas from 2005 to 2025.

| Service area | # Household increase, | percent | # Population increase, | percent | # Employee increase, | percent |
|---|---|---|---|---|---|---|
| Fairfax Water retail and wholesale | 142,006 | 27% | 366,518 | 26% | 302,945 | 42% |
| Aqueduct wholesale service area | 67,636 | 16% | 146,981 | 15% | 196,553 | 19% |
| WSSC service area | 130,389 | 22% | 273,835 | 17% | 310,374 | 40% |
| **Totals (plus Rockville)** | **343,092** | **22%** | **792,524** | **19%** | **831,919** | **32%** |
| **Totals - 2000 demand study -** **(Shown for comparison, increase shown was projected for period 2000 to 2020)** | **374,817** | **26%** | **887,385** | **24%** | **732,463** | **30%** |

A comparison of the household, population and employment estimates in the 2000 Demand Study and the current study reveals a dramatic increase in estimates of demographics for year 2000 (Table 4-4). This is a result of three primary factors: the release of the national 2000 Census, an improvement in the methods used to identify the number of households served by the WMA water suppliers within each traffic analysis zone, and the expansion of several water supplier service areas.

The MWCOG Round 6.1 Cooperative Forecast used in the 2000 Demand Study was produced prior to the release of the Census 2000 by the U.S. Census Bureau. The results of the Census 2000 identified significant underestimates, primarily in population, by regional planning agencies in MWCOG's Round 6.1 publication (Paul DesJardin, MWCOG, personal communication, February 15, 2005). Recall that demographic data for year 2000 in Round 6.1 was a forecast, while Round 6.4a includes refined historical 2000 data. Therefore, the data included in Round 6.4a for year 2000 is a more reliable historical baseline estimate of population for the region. As a result of this change, it is reasonable to assume that rather than a dramatic increase in population between 2000 and 2005, the population in 2000 was, in fact, higher than originally anticipated in 1999. Quite simply, this difference can be attributed to the improved estimates of regional planners and the incorporation of Census 2000 data. Table 4-4 details 2000 population by county (not service area) for both Round 6.1 and Round 6.4a MWCOG forecasts. The difference between the two forecasts is also included, illustrating the change in the 2000 baseline.

The most significant difference noted in Table 4-4 is in the District of Columbia. This may be attributed to a significant disconnect between regional and national planning data and actual District demographics (Paul DesJardin, MWCOG, personal communication, February 15, 2005). During the 1990s District planners depended entirely on annual updates by the U.S. Census Bureau to create city-wide forecasts of population and employment. The U.S. Census Bureau had provided the District with annual state estimates based on a top-down cohort planning model which essentially accounted only for local births, deaths, and migration. Households were calculated as a function of people per household, also an assumed estimate, and population. In 2000 the District performed household surveys and discovered serious flaws in the U.S. Census data they had depended on during the previous decade. The U.S. Census cohort model neglected to account for immigrants both within and beyond the District. On-the-ground surveys done by regional planners showed that this mistake resulted in an underestimate of over 50,000 people and 26,000 households within D.C., as noted in Table 4-4**.** Beyond D.C., regions that have high concentrations of immigrants were similarly underestimated by regional planners during the 1990s. More thorough regional surveys and the completion of the renewed 2000 Census improved these data considerably.

Table 4-4: Comparing Round 6.1 and Round 6.4a forecasts for 2000. Round 6.1 was used in the 2000 demand forecast, and Round 6.4a is used in the 2005 demand forecast.

| | **6.1 MWCOG forecast: 2000** | | | **6.4a MWCOG forecast: 2000** | | |
|---|---|---|---|---|---|---|
| | **Households** | **Population** | **Employment** | **Households** | **Population** | **Employment** |
| **Prince George's County** | 292,999 | 791,563 | 328,557 | 287,716 | 805,363 | 327,251 |
| **Montgomery County** | 314,919 | 850,955 | 509,833 | 325,411 | 875,930 | 480,076 |
| **District of Columbia** | 221,796 | 518,100 | 678,014 | 248,338 | 572,063 | 702,738 |
| **Loudoun County** | 58,313 | 166,063 | 72,734 | 59,900 | 169,599 | 87,046 |
| **Prince William County** | 107,633 | 325,249 | 113,710 | 109,581 | 326,238 | 114,290 |
| **Fairfax County** | 364,626 | 998,370 | 565,112 | 363,200 | 1,001,700 | 573,027 |

| **Forecast difference, 2000 (6.4a - 6.1)** | | | | | | |
|---|---|---|---|---|---|---|
| | **Households** | | **Population** | | **Employment** | |
| **Prince George's County** | -5,283 | (-1.8%) | 13,800 | (1.7%) | -1,306 | (-0.4%) |
| **Montgomery County** | 10,492 | (3.3%) | 24,975 | (2.9%) | -29,757 | (-5.8%) |
| **District of Columbia** | 26,542 | (12.0%) | 53,963 | (10.4%) | 24,724 | (3.6%) |
| **Loudoun County** | 1,587 | (2.7 %) | 3,536 | (2.1%) | 14,312 | (19.7%) |
| **Prince William County** | 1,948 | (1.8 %) | 989 | (0.3%) | 580 | (0.5%) |
| **Fairfax County** | -1,426 | (-0.4%) | 3,330 | (0.3%) | 7,915 | (1.4%) |

The Census 2000 revealed to local planners that they had drastically underestimated household size (e.g. Prince George's County), among other data. Regional planners have since corrected their method for this error. The difference in the employment category between Rounds 6.1 and 6.4a for Montgomery County is also significant. During Round 6.1, regional planners for Montgomery County mistakenly double counted several thousand self-employed workers. In addition, regional planners have revised their overall methodology for estimating employees throughout the county (Paul DesJardin, MWCOG, personal communication, February 15, 2005).

As can be expected, regional planning offices are continually revising their methods for tabulating households, population, and employment data. While the difference between Round 6.1 and Round 6.4a from MWCOG should not be attributed entirely to a change in methodology, improvements and changes to planning techniques are to be expected.

The second change in the current population estimates for each service area is the result of an improvement in the methods adopted by ICPRB. For those areas in which a TAZ is bisected by a water supplier service area, prior studies assumed that the number of households within the TAZ was allocated to a supplier service area based on the ratio of the TAZ's area within the service area. For example, if 50 percent of the area of a given TAZ was within the service area of WSSC, then 50 percent of its households and employees were assumed to be water customers of WSSC. With improved technology and access, satellite imaging was used to survey the perimeter of several utility service areas, including, WSSC, Fairfax Water, Loudoun County Sanitation Authority (LCSA), Prince William County Service Authority (PWCSA), Falls Church DEP, and Rockville DPW. Demographic data for service areas more precisely enclosed by city limits (e.g., District of Columbia, Arlington, etc.) were estimated more simply. This imaging technique was adopted in order to gather more precise data regarding the inclusion of households within the service area. For example, if a TAZ is only partially within the service area boundary, the satellite image was used to estimate what percentage of households within the TAZ are actually within the service area. Therefore, the demographic data associated with each TAZ is multiplied by a percentage that represents the actual amount of supplier coverage in that TAZ. While most TAZs are covered 100% by the service area, perimeter TAZs range in coverage. While time-consuming, this method allows ICPRB to make more informed estimates of the number of households that are clearly beyond the service are and secures the inclusion of perimeter residents connected to the utility system. The satellite imaging system used is Keyhole 2 LT™.

Also to be considered in the population figures for 2005 are the expanded service areas for several water suppliers. Significant changes to the WSSC, LCSA, and PWCSA service areas resulted in the inclusion of several new TAZs. Though most water suppliers provided the appropriate GIS ArcMap shapefiles to identify their current and future service areas, a few service area footprints were created by ICPRB, including WSSC and PWCSA. WSSC's service area is based on water categories or actual water line maps from either Prince George's or Montgomery County Planning offices. The detail associated with these county maps allows for an equally detailed account of households within the supplier service area.

The Round 6.4a forecasts include consideration of the effects of the development of the Inter-County Connector (ICC). Regional planners in Prince George's and Montgomery County concluded that the impact of the ICC would affect mainly the employment sector, with little effect on population or housing. Given the construction of the ICC in 2006, the impact of the ICC should be reflected in Prince George's and Montgomery County's employment data during 2010-2025 in Round 6.4a. Regional planners for the District considered the impacts of the ICC across all categories. Planners considered the possibility of reduced growth within city limits due to improved access to and the increased value of suburban areas. Though these effects are uncertain, they too are reflected in the District's data within and beyond 2010 in Round 6.4a.

More detail on development of estimates of unmetered water use, billing records, determination of single family and multi-family unit use factors, determination of employee unit use factors, and other notes is provided in Appendix E.

## 4.6 Calculation of unit use values

Average daily water consumption by single family, multi-family, and employee users are calculated in terms of gallons per household or employee per day. These values are calculated based on the aforementioned dwelling unit ratios, MWCOG housing and employment data, and water consumption billed by regional utilities. Unit use data are the primary input for the long-term water demand model, which assumes current unit use but utilizes forecasts of households and employment categories. Unit use values for 2004 are displayed below. The derivation of these values is further discussed in Appendix E. Calculated unit use values are summarized in Table 4-5.

Table 4-5: Year 2004 Unit Use values by service area (gallons per unit per day).

| **Service Area** | **Single Family unit use** | **Multi-family unit use** | **Employee unit use** |
|---|---|---|---|
| Fairfax Water - Dulles | 206.4 | 158.9 | 59.5 |
| Fairfax Water - Ft. Belvoir | 206.4 | 158.9 | 53.0 |
| Fairfax Water - Herndon | 206.4 | 158.9 | 37.6 |
| Fairfax Water - Lorton | N/A[a] | N/A[a] | N/A[a] |
| Fairfax Water - Loudoun Co. Sanitation Authority | 205.2 | 99.3 | 37.8 |
| Fairfax Water - Prince William Co. Service Authority | 207.8 | 158.9 | 45.0 |
| Fairfax Water - Retail Service Area | 206.4 | 158.9 | 45.0 |
| Fairfax Water/Virginia American - Alexandria | 149.9 | 150.2 | 45.0 |
| Fairfax Water/Virginia American - Dale City | 218.5 | 158.9 | 194.7 |
| | | | |
| Aqueduct - Arlington Co. DPW | 149.9 | 126.0 | 44.2 |
| Aqueduct - Falls Church DEP | 149.9 | 126.0 | 29.1 |
| Aqueduct - Vienna DPW | 149.9 | 126.0 | 77.1 |
| Aqueduct - District of Columbia WASA | 169.8 | 159.7 | 56.9 |
| Aqueduct - D.C. WASA - Fort Meyer | 146.5 | 123.6 | 61.3 |
| Aqueduct – D.C. WASA - District of Columbia Soldiers Home & Howard Univ. | 337.8 | N/A[b] | 58.6 |
| | | | |
| WSSC - Montgomery County | 178.9 | 175.2 | 46.6 |
| WSSC - Prince George's County | 178.9 | 175.2 | 46.6 |
| | | | |
| City of Rockville DPW | 178.9 | 175.2 | 19.1 |
| | | | |
| **Weighted Average (WSSC, Fairfax Water retail, DC WASA only)** | **185** | **168** | **51** |

Notes: [a]The Lorton facility has recently been relocated. Therefore it is no longer served by Fairfax Water. The property formerly occupied by Lorton has been returned to the county and will be developed for residential housing at some later date. [b]Water use for the District's Soilders Home and Howard University is assumed to occur in one residential category as "single" users, as the users were not disaggregated by DC WASA.

Billing data from regional utilities 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 utility's billing system. Where these data were not available is noted in Appendix E. The total amount of water consumed by each category was divided by the number of single or multi-family households or employees on a regional basis. In addition, an account of unmetered water was also calculated. This is the difference between the water produced (or purchased at the wholesale level) and the water billed to customers. These figures are also included in each utility summary in Appendix E.

## 4.7 Effects of *Energy Policy Act 1992*

A comparison of unit use values over time in the WMA shows that unit use values have generally decreased over time. The unit use values calculated in the 1990, 2000, and current demand studies (based on the years 1988, 1998, and 2004, respectively) are compared in Table 4-6. The “revised 2000” values are the results of recalculating unit use values for 2000 based on more recently revised household and population data. The percent difference between each pair of studies is displayed in Table 4-7

Table 4-6: Unit use values for 1990, 2000, and 2005 demand studies. Revised 2000 demand study unit use vales are provided, as based on revised estimates of demographic information.

| Demand study year | Aqueduct - Washington, D.C. area | Fairfax Water - retail area | WSSC | Weighted system average unit use[1] |
|---|---|---|---|---|
| | Single family (gallons per day) | | | |
| 1990 | 325 | 240 | 241 | 262 |
| revised 2000 | 279 | 227 | 179 | 214 |
| 2005 | 170 | 212 | 179 | 185 |
| | Multi-family (gallons per day) | | | |
| 1990 | 315 | 177 | 223 | 236 |
| revised 2000 | 279 | 165 | 184 | 201 |
| 2005 | 160 | 163 | 175 | 168 |
| | Employment (gallons per day) | | | |
| 1990 | 50 | 44 | 58 | 53 |
| revised 2000 | 43 | 44 | 45 | 44 |
| 2005 | 57 | 46 | 47 | 51 |

Notes: [1]Weighted by relative numbers of houses or employees in DC WASA, Fairfax Water, and WSSC service areas as estimated in 1990, 2000, or 2005.

Table 4-7: Percent differences between selected unit use values in Table 4-6

| Demand studies compared | Aqueduct - Washington, D.C. area | Fairfax Water - retail area | WSSC | System average (based on weighted averages, Table 4-5) |
|---|---|---|---|---|
| | Single family (percent difference) | | | |
| 1990 and revised 2000 | -14% | -5% | -26% | -18% |
| Revised 2000 and 2005 | -39% | -7% | 0% | -13% |
| | Multi-family (percent difference) | | | |
| 1990 and revised 2000 | -11% | -7% | -17% | -15% |
| Revised 2000 and 2005 | -43% | -1% | -5% | -16% |
| | Employment (percent difference) | | | |
| 1990 and revised 2000 | -14% | 0% | -22% | -16% |
| Revised 2000 and 2005 | 33% | 5% | 4% | 15% |

Values in Table 4-7 show that system unit use dropped by approximately 18 percent for single family housing, approximately 15 percent for multi-family housing (apartments) and about 16 percent for employees from the 1990 study to the 2000 study. Similar changes occurred between 2000 and 2005 for single- and multi-family housing, with an increase in unit use for employees. Some of the differences within the Aqueduct service area are due to a re-assignment of demand in WASA's service area by ICPRB from the multi-family to the employment category, as a result of better billing data categories provided by WASA. Therefore, the actual decrease in multi-family unit use is somewhat less than reported and the increase in employment unit use is also somewhat less than reported when comparing revised 2000 and 2005 unit use values. These differences are further discussed in Appendix E.

Water consumption behavior is likely to change in the future as well. Future unit use rates are modified to account for the increasing use of more efficient plumbing fixtures as a result of the *Energy Policy Act of 1992* (102D Congress, 2d session, 1992). Unit use in the WMA is forecast to decline 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 4-8 below gives an abbreviated estimate of savings per household based on water use and household totals in the WMA. A more detailed account of water savings due to the low flow toilet installation and shower retrofits is discussed in Appendix F.

Table 4-8: Summary of estimated effects of the *Energy Policy Act of 1992* on WMA household water use, 2005 and 2025.

| | 2005 | 2025 | Difference |
|---|---|---|---|
| Toilet use, gallons, per household | 36.5 | 26 | 10.5 |
| Shower use, gallons, per household | 35.3 | 31.3 | 4.0 |

The effects of the *Energy Policy Act of 1992* result in the savings of approximately 14.5 gallons per day per household from 2000 to 2025. This study does not attempt to quantify the water use savings associated with consumer trends towards the use of more energy and water efficient appliances (e.g., the Department of Energy and EPA's Energy Star Program, new efficiency standards adopted for clothes washers, etc.). Therefore, it is likely that savings exceed our calculations and that the estimates provided in Table 4-8 are conservative.

## 4.8 Potential changes in customer demand

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. Not addressed in the calculations of Appendix F are savings from other household fixture retrofits such as kitchen and bathroom faucets, or major appliance replacements, such as dishwashers and clothes washers. Evidence in Appendix F from regional conservation studies suggests customers are not only interested in conservation, but taking steps to save water within the home. Steps toward improving conservation by regional users also support the possibility that the attitude toward resource consumption is evolving. For example, in the Water Conservation Study initiated by MWCOG and produced by NuStats, the majority of WMA respondents responded that their primary motivation for installing low flow fixtures and appliances was conservation, efficiency, or because it was "the right thing to do."

Regional utilities such as WSSC and DC WASA have investigated major conservation efforts in the last five years. Overall, local utilities and planning organizations (e.g., MWCOG) have continued to make efforts to improve conservation efforts through outreach programs, public education, meter replacement, and inclining rate structures. As resources are stressed in coming decades due to a growing metropolitan population, and alternative sources are identified, extensive (and expensive) conservation programs may be viable water supply alternatives helping to ensure the long-term sustainability of water resources in the WMA. Until conservation is a priority by necessity, however, household conservation will be primarily motivated by individuals following trends in increasing availability and purchasing of energy and water efficient appliances, and the continued influence of the *Energy Policy Act of 1992*.

Using the operational tools available to ICPRB, a simulation of a range of demand values can be assessed. Such simulations can provide an estimate of demand based on varying climate conditions or population growth. These results can support regional utility managers in their decision making process regarding the role of future conservation programming in the selection of water supply alternatives. In addition, the effects of water use restrictions are implemented in ICPRB simulations. Water use restrictions, while rare, provide temporary reductions in demand and are typically only considered during serious drought periods.

## 4.9 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, etc.

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 model runs. The trigger level for mandatory restrictions is more complex and was not implemented in model runs since it would have required excessive computational demand in the daily timestep simulation model. Instead, when either Jennings Randolph or Little Seneca storage drops below 25 percent full, mandatory restrictions are modeled.

Demand reduction levels are estimated based on recent regional experience and are provided in Table 4-9. The City of Frederick assumes a 5 to 10 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 5.0 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 3 percent for other months.

Based on WSSC 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 as discussed and derived in Section 3-9.

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 4-9: Demand reduction percentages assumed for restrictions in model runs.

| 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).

## 4.10 Relating water demand to climate variables

As mentioned in Section 3.6, climate variables can play a significant role in determining water demand. In the models developed for demand in the WMA, there is evidence that temperature and precipitation can have a significant impact on water demand. Documentation regarding the use of climate variables in predicting demand is well established.

The brief, but comprehensive literature review provided in Maidment et al. (1985) demonstrates the validity of climate variables in demand forecasting models. Though the type of variables included in the models varied with study location, climatic components consistently strengthened the demand models. For example, Anderson et al. (1980) found that approximately half the decrease in water use during the period of study was a result of high precipitation. Similarly, in the evaluation of a short-term daily water demand model, Maidment and Miaou (1986) noted a dynamic response to rainfall and temperature for nine cities of study. In more recent research, Aly and Wanakule (2004) found the number of days since the last rainfall to be most significant. Modeling of WMA CO-OP suppliers' water demand concurs with several such findings of variable significance. The ability of the model to predict was improved with the addition of lag terms, days since the last rainfall, and the identification of breakpoints in both the temperature and precipitation terms (Section 3.6.4). Unlike econometric water demand models (e.g. IWR-MAIN) that isolate socioeconomic characteristics and require disaggregation of variables that can be less accessible and difficult to predict, the WMA forecast models accurately represents demand while incorporating both the demographic character of the region through the unit use calculations and climate variables through the regression model.

As research and concerns over climate variability and change in water resources planning increase, the inclusion of weather variables in a long-term demand model is a valuable addition. Though there is considerable uncertainty surrounding the impacts of long-term climate change on water resources in the WMA, the potential for significant changes in the region's hydrologic regime and weather-sensitive demand must be addressed. Potential impacts are addressed below and several regional trends in temperature identified.

## 4.11 Regional climate change research

An overview of efforts to evaluate the effects of climate change on temperature, precipitation, and stream flow for the region is provided in this section. Previous examinations of the impacts of climate variability and change on water resources in the region suggest that these impacts could be significant. Regional managers may take some small comfort in that as significant as these trends may be, as compared to water supply in warmer and drier regions of the United States, the Northeast's supplies are relatively less vulnerable to small changes in average climate conditions (Hurd et al., 1999).

### *4.11.1 Water Resources Management in the Potomac River Basin under Climate Uncertainty*

*Water Resources Management in the Potomac River Basin under Climate Uncertainty* examined several climate change scenarios and their effects on Washington metropolitan area system demand for the year 2030 (Steiner et al., 1997). Results from five general circulation models (GCMs) of predicted temperature and precipitation were examined. These altered meteorological conditions were used in a water balance model calibrated for water supply sources that serve the WMA. The water balance model was based on the Thornthwaite-Mather method (1955) and used to predict stream flow conditions under altered climate conditions. The water balance model is the key component to evaluating the potential climate change impacts to regional stream flow.

A summary of the inputs and outputs of this model is presented here. Using the primary inputs of temperature, precipitation, and soil moisture capacity and retention, a monthly average runoff record was created. In addition to these factors, the temperature, location, and annual heat index data were converted to potential evapotranspiration (PET). The excess of PET over effective precipitation defines the moisture deficit which has been shown to be a useful explanatory variable for seasonal water use in residential areas. Actual evapotranspiration (AET) was also calculated in the WMA water balance model in order to evaluate changes in runoff during hotter months accompanied by such soil moisture deficits. According to Steiner et al., as PET decreases, runoff increases, subsequently decreasing the rate of recession during hotter months. Given these parameters, each water balance model for the various regional water supply resources was calibrated and aligned with the historical stream flow record (Steiner et al., 1997).

Using forecasted demand, which was a function of climate change, and the new stream flow records generated for each of the five GCMs, resources were assessed and management operations were evaluated based on these outputs. Results indicated that the WMA could experience demand growth of 74-138 percent greater than 1990 values in 2030. Depending on the climate change scenario, resources were significantly stressed or deficient. This was accommodated under aggressive management plans that helped reduce demand with significant changes in conservation and operations policies. Under most scenarios, however, existing resources were sufficient through 2030, although the study recommended that water management consider the need to plan for mitigation of potential climate change impacts (Steiner et al., 1997).

### *4.11.2 Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change*

In 2000, the Mid-Atlantic Regional Assessment Team for the U.S. Global Change Research Program produced an overview of the Mid-Atlantic Region (MAR) entitled *Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change*. The MAR includes New York, New Jersey, Pennsylvania, Delaware, Maryland, West Virginia, Virginia, and the District of Columbia. While the study is a comprehensive assessment of various facets of the region's environment, including agriculture and forests, a review of the potential impacts on fresh water quantity and quality provide insight regarding impacts on the Potomac. Potential climate impacts on stream flow were estimated through the examination of a water balance model by Najjar (1999) for the Susquehanna River Basin.

GCMs from the Canadian Climate Center (CCC) and Hadley Centre for Climate Prediction and Research (Hadley) were used to draw conclusions regarding changes in temperature and precipitation in the MAR. For example, based on these models with a base year of 1990, temperature increases range from an additional 1.8 to 2.7 degrees Fahrenheit by 2030 and 4.9 to 9.5 degrees by 2095. The Hadley and CCC models were also used in Najjar's water balance model to project changes in stream flow during two periods, 2025-2034 and 2090-2099. Results indicate that changes in the amount, timing, and quality of water could be significantly altered and have multiple impacts. That is, increased spring runoff due to earlier and faster snowmelt could not only bring increased sediment into seasonally fragile watersheds and exhaust snowpack earlier in the season but could also increase nutrient loads from upstream agricultural areas, potentially causing increased eutrophication downstream. Hotter, drier summer seasons may decrease regional water supplies, although Najjar also suggests that increased levels of $CO_2$ may also increase the efficiency of plant absorption of water, therefore requiring less water overall and increasing stream flow. While this is only a sampling of the impacts assessed in both the MAR (2000) and Najjar (1999) studies, clearly the potential impacts of climate change are complex.

While temperature levels are predicted to rise with some certainty, changes in precipitation are less certain and changes in variability of precipitation are generally uncertain. Climate research in the neighboring Susquehanna basin suggests that regional precipitation will increase under increased $CO_2$ scenarios. The research must be interpreted cautiously in relating the results to the WMA, since the geographic domain described by the research is centered along the northern Pennsylvania border, well north of the WMA. One model shows a 13% increase in annual precipitation for a doubling of $CO_2$ concentration, mainly during the winter and spring (Jenkins and Barron, 1997 nested model, as cited in Najjar, 1999). Another model shows a 21-percent increase in annual precipitation for a $CO_2$ doubling scenario (Crane and Hewitson,1998, as cited in Najjar, 1999).

Model run results indicate a long-term trend towards warmer and wetter conditions. These conclusions must be interpreted with caution from the perspective of water supply management. An increase in average annual precipitation does not mean that every year will be wetter than normal—during dry years, it may be drier than normal. Global climate changes will not change local weather patterns or other regional factors that affect the weather. When regional weather patterns set up in ways not conducive to rain, warmer temperatures would lead to more evaporation, potentially pushing dry conditions toward drought or causing drought conditions to worsen.

## 4.12 Climate data for Washington metropolitan area

Several long-term weather station temperature records are examined for long-term trends in temperature. These trends were examined as evidence of potential climate change indicators. Data from weather stations in or near the Washington metropolitan area were gathered from the National Oceanic and Atmospheric Administration (NOAA), National Climatic Data Center (NCDC). The stations examined are given below and their locations are shown in Figure 4-4.

- Baltimore Customs, COOP ID 180470
- College Park Station, COOP ID 181995
- Frederick Police Barracks, COOP ID 183348
- Laurel 3W, COOP ID 185111
- Woodstock, COOP ID 189750

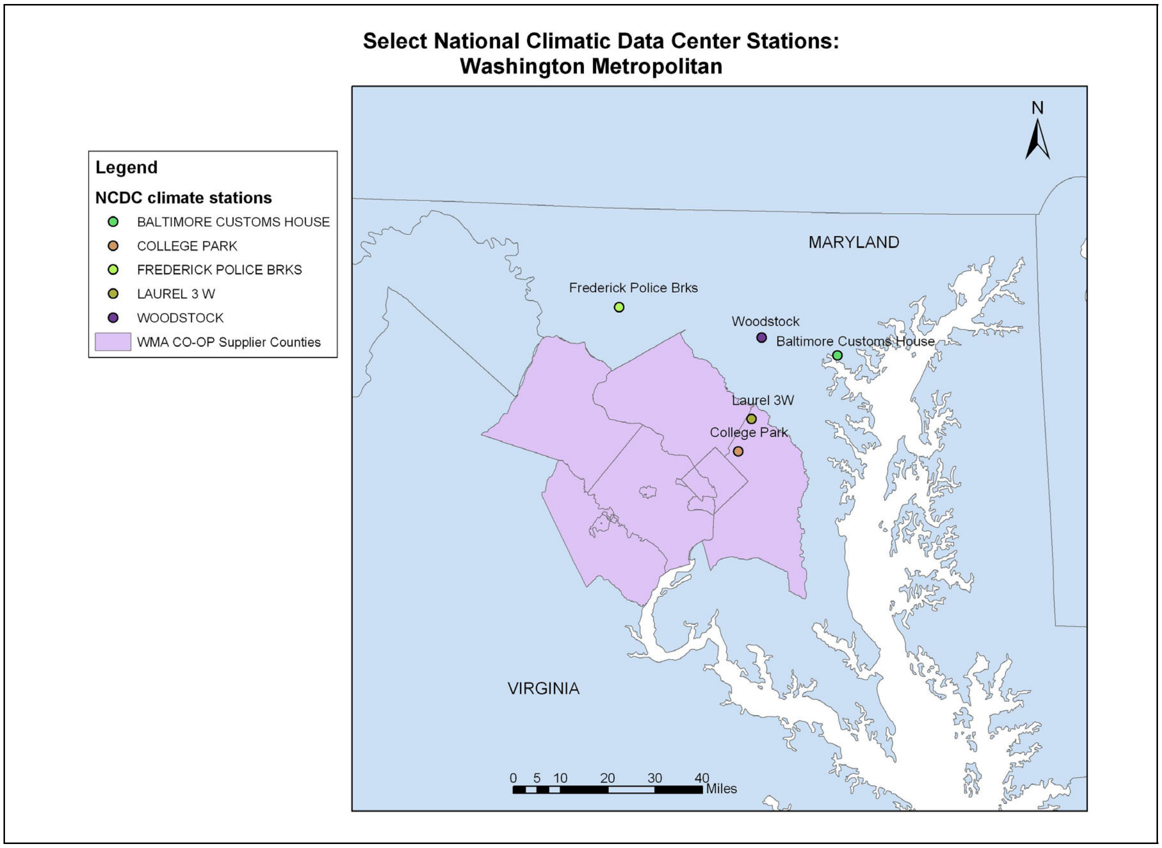



Figure 4-4: Location of long-term weather stations in the WMA.

The average of maximum daily temperature and precipitation for July, August, and September months are graphed. The data show a clear warming trend for July and August, but no distinct trend for September. Examples of these trends for these stations are shown below in Figure 4-5 through Figure 4-9, and the trends are summarized in Table 4-10. The Baltimore Customs House has the strongest trend, with a warming of about 5 degrees taking place over a 100-year period for July. However, the temperature gage for this station was located on a tar pitched roof, which may have skewed the record. The trends shown in these stations could be caused by heat-island effects of urbanization, warming due to changes in $CO_2$ concentration and global climate change, or natural variability in climate conditions.

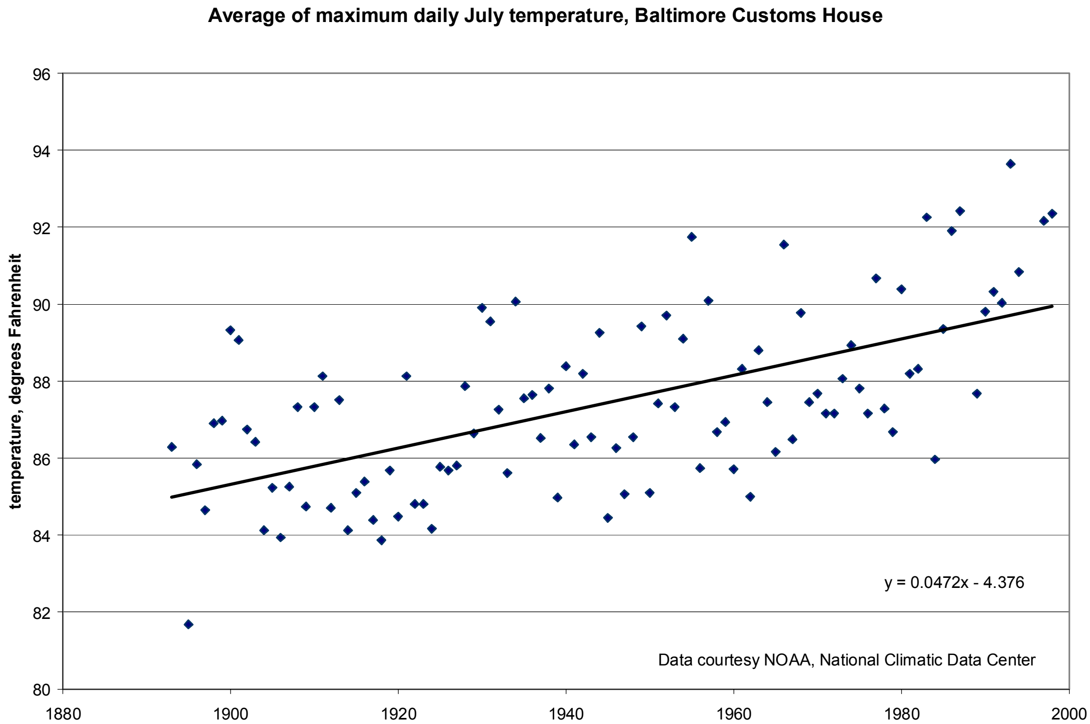



Figure 4-5: Mean of max. daily July temperature, Baltimore Customs House, 1893-1999.

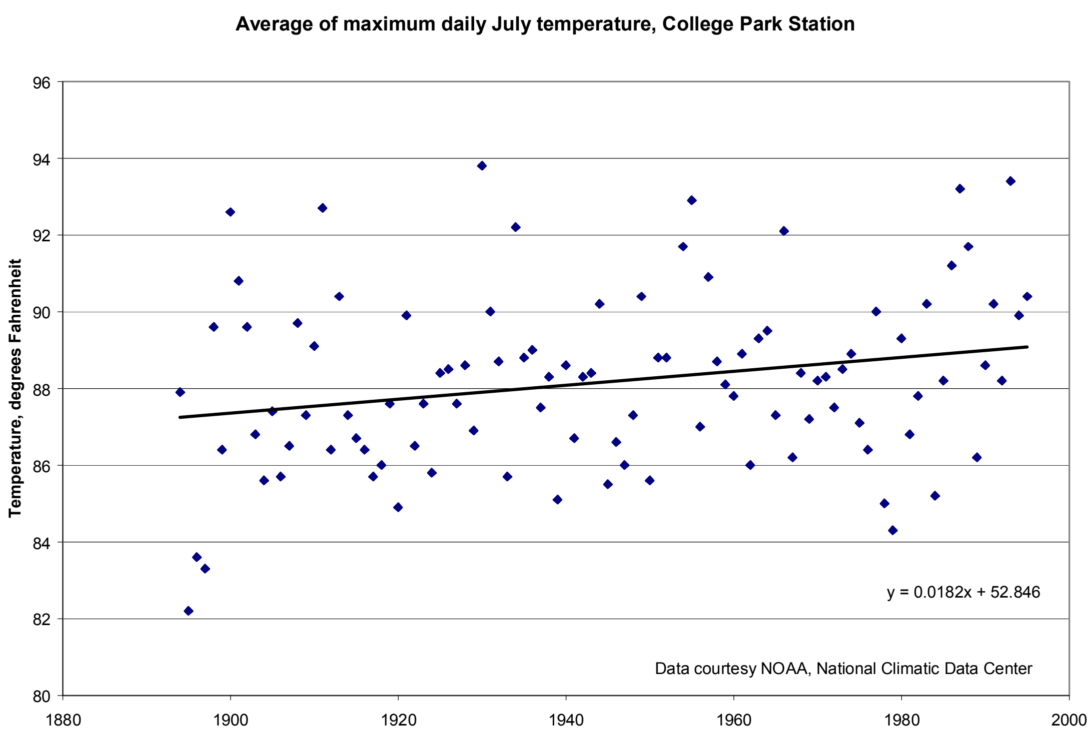



Figure 4-6: Mean of max. daily July temperature, College Park Station, 1894-1995.

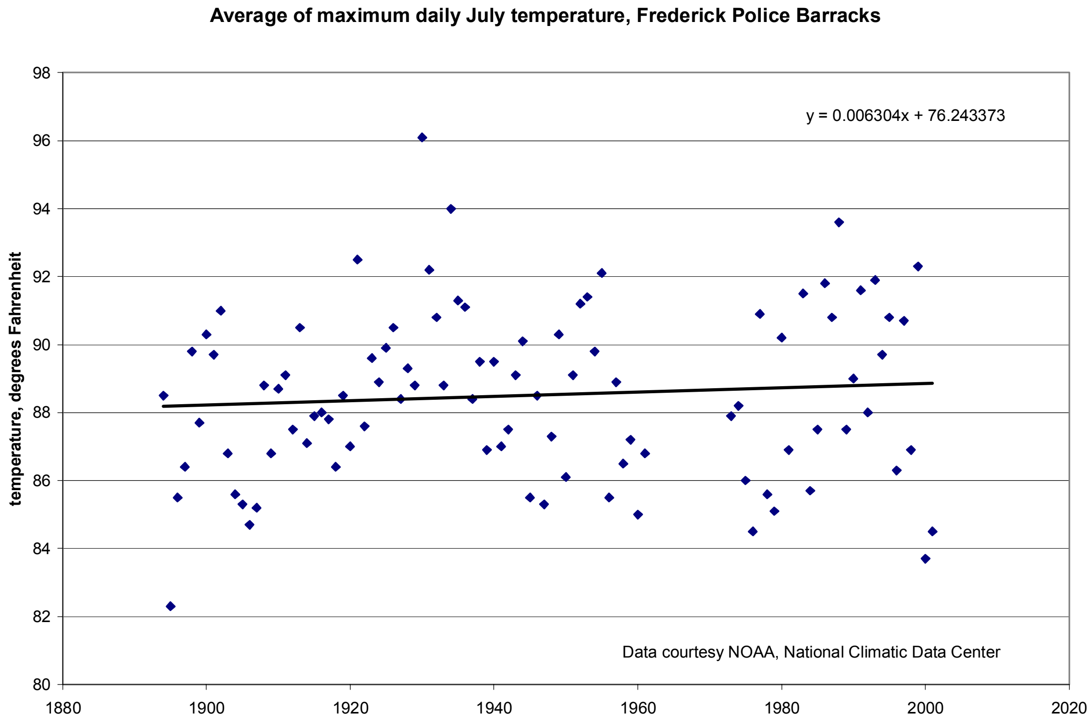



Figure 4-7: Mean of max. daily July temperature, Frederick Police Barracks, 1894-2001.

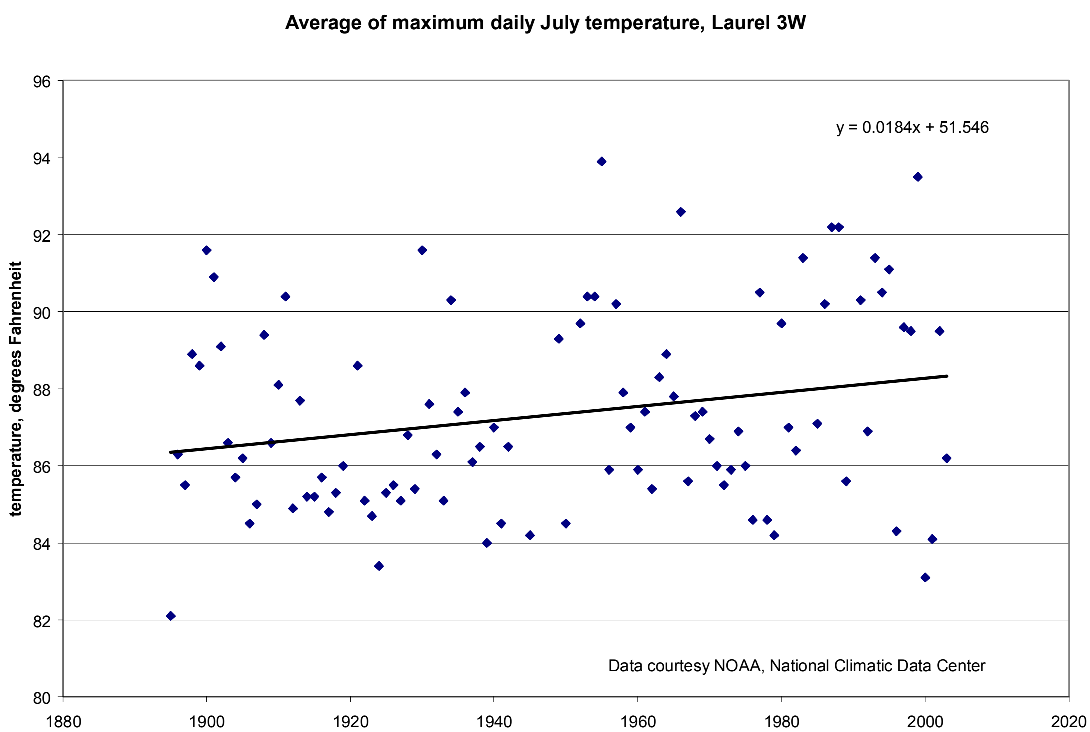



Figure 4-8: Mean of max. daily July temperature, Laurel 3W station, 1895-2003.

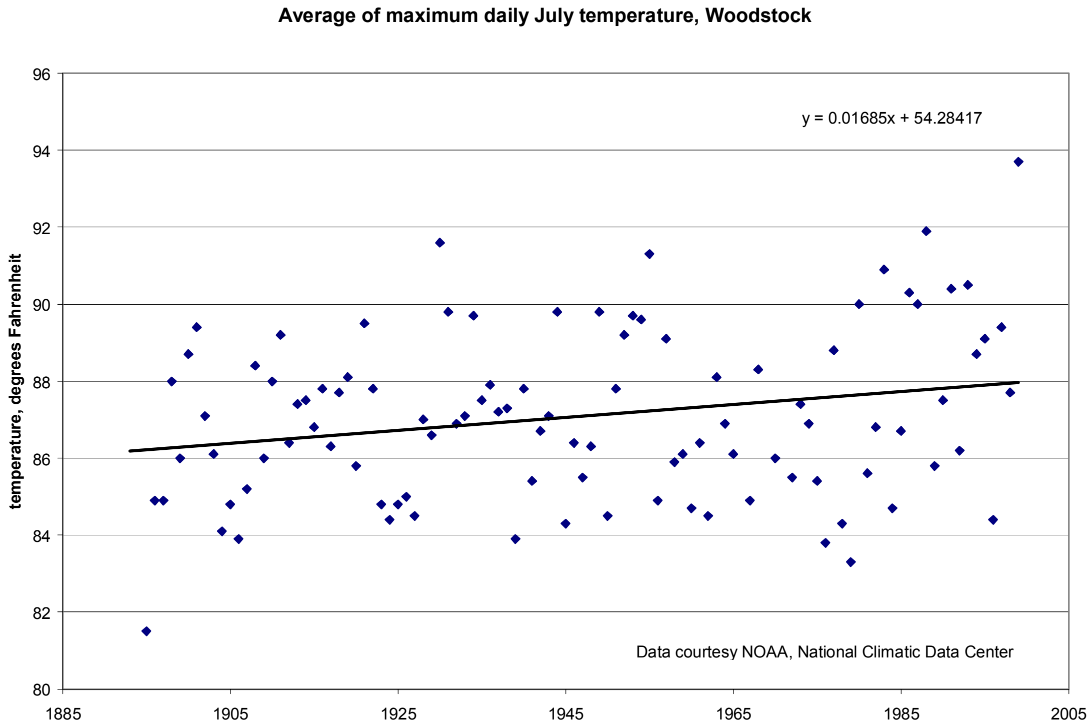



Figure 4-9: Mean of max daily July temperature, Woodstock, 1895-1999.

Table 4-10: Change in historical temperatures over time.

| Historical data, NCDC Weather Station | Change in average of daily maximum temperature, degrees (F) per 100 years | | |
|---|---|---|---|
| | July | August | September |
| Baltimore Customs | 4.7 | 4.6 | 2.7 |
| College Park Station | 1.8 | 1.6 | -0.9 |
| Frederick Police Barracks | 0.6 | 1.5 | -0.4 |
| Laurel 3W | 1.8 | 3.4 | -0.1 |
| Woodstock | 1.7 | 2.1 | 0.6 |
| Average (excluding Baltimore customs) | 1.48 | 2.15 | -0.2 |

Precipitation records are also examined for evidence of trend. Historical precipitation at the College Park weather station shows a slight positive trend in summer precipitation over the last hundred years or so, although given the variability of this record it is impossible to say if this trend is anything more than random (Figure 4-10).

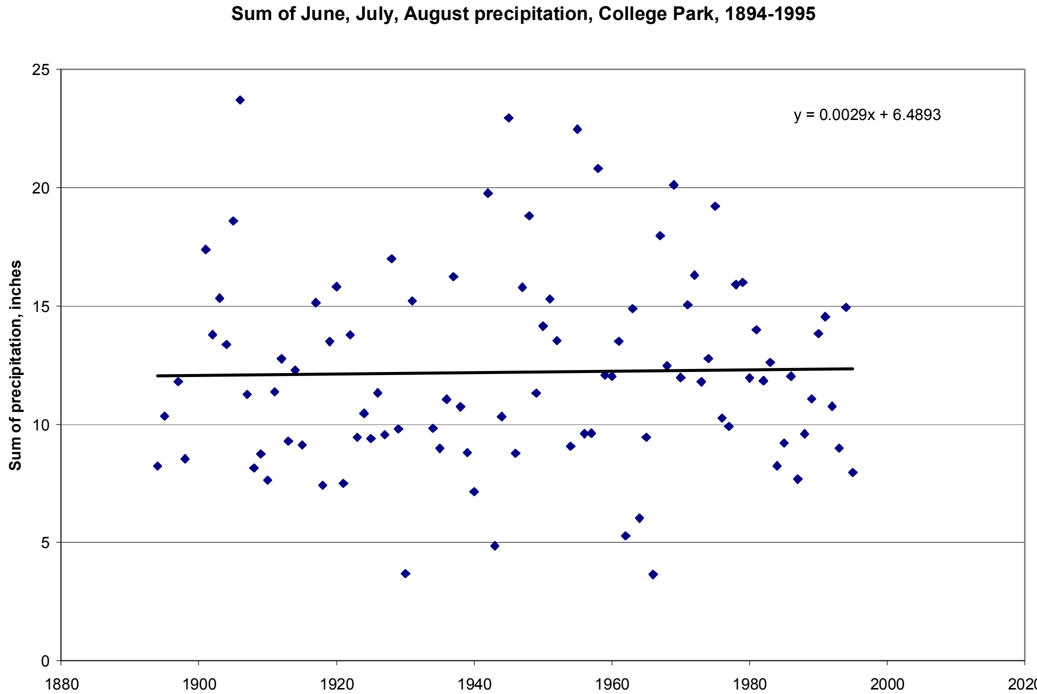



Figure 4-10: Summer precipitation at College Park, 1894-1996.

## 4.13 Developing a climate change scenario

Using evidence from previous regional research in climate change, such as the Mid-Atlantic Regional Assessment Team for the U.S. Global Change Research Program, additional research by Neff et al. (2000) and Najjar et al. (1999, 2000), and the *Water Resources Management in the Potomac River Basin under Climate Uncertainty* by Steiner et al. (1997) a cursory evaluation of potential climate change impacts on the WMA demand is provided. The adjustment is made in two parts. The first part increases historical temperature records to account for changes in local temperature that have occurred in the last 73 years. This adjustment would account for any changes in climate due to heat island effects of urbanization, or to changes that are part of a broader climate signal. The adjustment is conservative, since historical temperatures are increased to account for today's conditions. The second part examines the results of regional climate change research, and applies those results to predictions of future temperature, in order to account for potential changes in climate.

### *4.13.1 Adjusting historical temperature records*

In order to assess the impact of climate variability and change on demand, the historical temperature records are first detrended to represent the current temperatures for the WMA. For example, July temperatures in 1930 are increased by 1.48 degrees Fahrenheit. July temperatures in 2002 are not adjusted. For years in-between 1930 and 2002, the temperatures are increased by linear interpolation. The increase is determined as the average of the increases shown in Table 4-10, excluding the Baltimore Customs

House. The adjustments made to the historical record are likely due to heat island effects of urbanization but could be affected partly by changes in climate. Regardless of whether the trends are due to heat island effects, climate change, or are random, the decision to alter historical temperature is conservative in that higher temperatures translate into higher demand. These altered temperature records are further adjusted to represent future climate change scenarios as discussed below.

### *4.13.2 Adjusting temperature, precipitation, and stream flow records based on future conditions*

The climate change conditions considered for this resource analysis are based on research in the greater Mid-Atlantic Region and the neighboring basin of the Susquehanna River. Using climate change scenarios from the Canadian Climate Centre (CCC) and the British Hadley Center (Hadley), Neff et al. (2000), Najjar et al. (2000), and others assessed climate impacts of various facets of water resources during two ten-year periods: 2025-2034 and 2090-2099 (Table 4-11). The authors considered impacts on stream flow, sea-level rise, groundwater, water quality, temperature, and precipitation and how these impacts might affect various ecological communities within the region.

This research suggests a more reliable prediction of temperature change than it does a change in precipitation, and a more reliable prediction of precipitation change than it does a change in stream flow. The estimates of reliability of the predictions in Table 4-11 are somewhat subjective (Raymond Najjar, personal communication, March 29, 2005). They are primarily based on the consistency of the model results. For example, repeated model runs across multiple models reveals consistent warming in the MAR, therefore this is considered a highly reliable prediction. In contrast, stream flow results are less consistent across the models. This is because stream flow is particularly difficult to predict given it is determined by water balance equations including both temperature and precipitation (Najjar, 1999; Raymond Najjar, personal communication, March 29, 2005).

Table 4-11: Climate change impacts in the Mid-Atlantic coast region.

| **Parameter** | **2030** | | **2095** | | **Reliability of prediction according to author** |
|---|---|---|---|---|---|
| | Mean | Range | Mean | Range | |
| Temperature (ºF)[1] | +2.3 | +1.8 to +2.7 | +7.2 | +4.9 to +9.5 | High |
| Precipitation (%)[1] | +4 | -1 to +8 | +15 | +6 to +24 | Medium |
| Streamflow (%)[2] | +2 | -2 to +6 | +11 | -4 to +27 | Low |

Notes: Table partially duplicated from Najjar et al. (2000). [1]Taken from Polsky et al. (2000); change is based on 1983-1994 baseline conditions. [2]Taken from Neff et al. (2000); change is based on 1985-1994 base period, using temperature and precipitation conditions of 1900-1987.

Due to research constraints and model capabilities, climate change scenarios presented in Table 4-11 *assume average conditions.* Given the high reliability of the water resources in the Potomac River Basin under average conditions, of greater interest is how climate change might worsen drought-like conditions. Research to date has not evaluated climate change impacts under extreme conditions, such as drought. It is unclear whether or not these extreme circumstances will be affected by climate change significantly more than average conditions. Future work may evaluate these possibilities (Raymond Najjar, personal communication, March 29, 2005), however the assessment of climate change impacts in the WMA is currently limited to average conditions. Nonetheless, and with this caveat, the regional research is used to inform a climate change scenario for the Potomac as described below.

Using this regional research to derive a climate change scenario, increases were made to temperature records within the PRRISM model which are in turn used to determine (higher) water supply demand. As noted, historical temperature variables were first altered to represent current expected temperatures (Section 4.13.1). To account for a climate change scenario an average increase in temperature of 2.3 degrees Fahrenheit from Table 4-11 is assumed for the Potomac basin. This increase is distributed using a monthly distribution cited in Najjar (1999) in which changes in both temperature and precipitation were distributed over the calendar year according to the results of a study by Jenkins and Barron (1997) on climate change in the Susquehanna River Basin.

Changes were made to the historical temperature record to account for a climate change scenario per Sections 4.13.1 and Section 4.13.2. The changes have relatively modest impact on demand. Given a repeat of the historical meteorological conditions of 1930, average modeled July through October demand is approximately 654 MGD (stdev = 6.7). After implementing the changes described in Sections 4.13.1 and Section 4.13.2, average modeled July through October demand is 665 MGD (stdev = 3.1), an increase of 11 MGD. The response of the Potomac water supply system to these changes in demand is provided in the climate change scenario described in Chapter 8.

Regional research showed precipitation increases occurring in the winter, with little change to average summer precipitation. Given there is little expected increase in precipitation during the summer months, a conservative approach was assumed and no increase in precipitation was modeled.

When considering the possible increase in stream flow and precipitation alone, the mean change in Table 4-11 suggests additional resource availability. Altered stream flow under the Hadley and CCC models can be shown in Figure 4-11 below, taken from Najjar et al. (2000). According to these results, increased stream flow can be expected during cooler seasons on average, while average summer stream flow appears to be basically unaffected in the 2030 scenario. This is not the case, however, in the later decades, where stream flow appears to be decreasing during times of peak water demand. Despite secure appearances, increased stream flow by 2030 may not outweigh seasonal or episodic extreme conditions. The research looks at changes in average conditions, not at changes in extreme event conditions such as droughts. One potential impact of climate change is that even if average stream flow conditions increase, stream flow might be reduced in drought years.

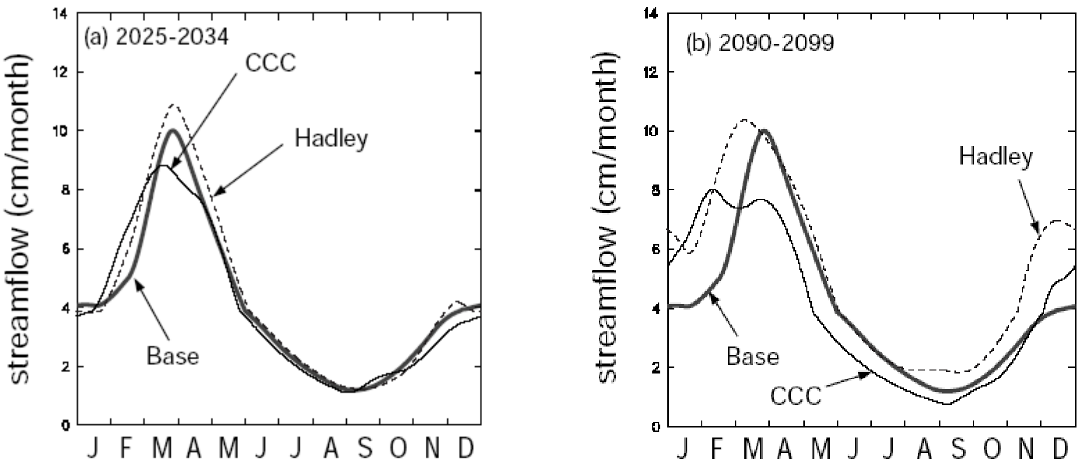



Figure 4-11: Simulated stream flow at the mouth of the Susquehanna River (1985-1994 baseline) for Hadley and CCC GCMs. Results for 2025-2034 and 2090-2099 (Neff et al., 2000). Borrowed with permissions of the author (Najjar).

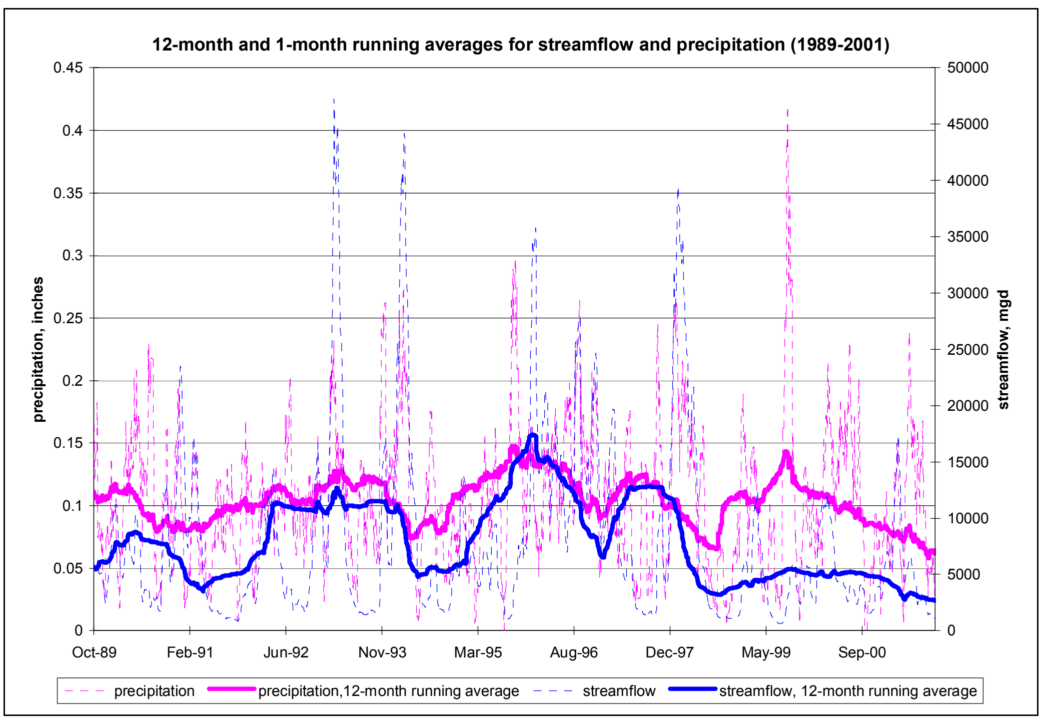



Figure 4-12: One and twelve month running averages of stream flow and precipitation. Precipitation is a composite record used for demand forecasting for the Washington Aqueduct; stream flow is adjusted USGS gage flow from Little Falls further adjusted to remove the effects of upstream regulation.

Changes in temperature and precipitation are expected to affect the timing and availability of future resources as represented by reservoir inflow and stream flow. Some regional results suggest that on average, stream flow is predicted to increase due to possible changes in climate (Table 4-11). As shown in Figure 4-11, average flow is not as affected by climate change in the 2025-2034 timeframe as it is in a more extended forecast of 2090-2099.

The work of Neff et al. (2000) and Najjar et al. (2000) reveals some of the uncertainty in climate change research especially as it relates to stream flow. The Hadley model is associated with predictions of greater, or relatively unchanged, average stream flow conditions depending on time of year, and the CCC model with lower average stream flow conditions occurring in the spring through fall period and greater average conditions in the winter. Although some regional research suggests that on average, stream flow may increase, the regional research cited above does not explore the potential changes in stream flow during extreme events such as droughts. Stream flow may decrease during extreme events, even if on average stream flow increases.

Using long-term streamflow records, the USGS has evaluated whether droughts have increased in recent decades in response to climatic conditions (Lins, 2005). The results of that study are summarized below. USGS reports that stream flow has been increasing in the United States since at least 1940, with the Mid Atlantic among those regions experiencing the most increase. Increases were most prevalent in low to moderate stream flows (seen at 40 percent of the stream flow gaging stations), with relatively few decreases (seen at 8 percent of stations). The pattern of trends is dominated by increases in the months of September through December. This pattern is consistent with observed increases in streamflow at the low to moderate percentiles, which generally occur during the late summer and autumn period. This result also is consistent with increases in reported precipitation increases in the United States, which have been greatest during the autumn season. The USGS reports that stream flow increases occurred as a sudden rather than gradual change around 1970, suggesting the climate shifted to a new regime. According to the USGS, a regime shift from one set of conditions to another suggests that the new conditions are likely to persist until the next sudden shift occurs. The rapidity of the shift suggests the changes are due to variability in climate whereas a slow, gradual trend implies a pattern that is likely to continue into the future. The USGS concludes that what this may mean for future variations and changes in U.S. stream flow will only be revealed with time but that we should expect our rivers and streams to continue to be characterized by both short- and long-term variations.

Despite the recent USGS research suggesting increases in drought year flows, a ten percent reduction in July through October stream flow is modeled in PRRISM as a sensitivity analysis to explore how the system responds to reductions in resources. The application of a 10% decrease is entirely arbitrary and serves only to gage the reliability of the system given a significant decrease in stream flow. Regional research (e.g., Neff et al., 2000) does not yield evidence of a 10% decrease. However, the regional research reflects modeled changes in *average* conditions, and does not attempt to model extreme event hydrology like droughts. What happens to stream flow during droughts under climate change scenarios is a question that has not been answered by regional research, which is why a modeled *reduction* in resources is warranted as a conservative assumption for a sensitivity analysis.

## 4.14 Recommended study approach for more detailed climate change analysis

As discussed above, General Circulation Models (GCMs) are used to forecast changes in temperature and precipitation on a global scale. These models do not have the spatial resolution needed for adequate simulation of precipitation on the regional scales of interest. The disaggregation of temperature and precipitation from broad scales to local scales requires nesting of a more detailed, regional model within the framework of the GCM.

When assessing climate change impacts on water resources, the use of GCMs represents only the first step in a multi-step evaluation process. In a report produced for the Pew Center on Global Climate Change, Frederick and Gleick (1999) propose a five step process that includes:

1. Using GCMs to simulate future climate conditions on a global scale,
2. The re-scaling of global climate data down to a river basin scale,
3. Hydrologic modeling of downscaled GCM data to simulate stream flows under altered climate conditions,
4. The use of a systems simulation model to assess the effects of altered stream flows on water resource systems, and
5. Assessment of impacts on the users of water resource systems, including potential changes in demand and demographics under climate change scenarios.

Other approaches adopt the use of a statistical empirical model to relate changes forecast by GCMs to precipitation and stream flow, although to predict changes in monthly flow for larger basins such as the Susquehanna or Potomac, this will most likely be achieved by employing models that resolve the large spatial variations of the climate and hydrology in large basins (Najjar, 1999).

# 5 Forecasts of future water demand

## 5.1 Introduction

Results of the water demand forecast are presented in this chapter. Forecasts of water demand for each service area by supplier are presented. A detailed account of the demand forecasting model and unit use methodology are presented in Sections 5.3 and 5.4, respectively. Results and validation of the daily demand model are provided in Section 5.5.

## 5.2 Most likely forecasts of water demand

Annual water demand is forecast to increase for most WMA suppliers. These results include all water sources for each listed water supplier and account for conservation savings from the 1992 Energy Policy Act and also for unmetered water. Summaries for each supplier, including conservation and other information can be found in Appendix L.

A 10 percent minimum water loss for unmetered water use was assumed, to account for aging infrastructure. Some suppliers have unmetered water use of less than 10 percent now, but these suppliers have relatively new infrastructure. Future scenarios assumed at least 10 percent loss to account for the fact that unmetered water use might increase.

Unit use for Fairfax Water and wholesale customers was increased by 2.5 percent to account for lower-than-normal demand during the billing period used to calculate the unit use values, which was basically a correction for weather effects on water use during the billing period. WSSC had higher-than-normal demand during its billing period (+ 1.9 percent) but its unit use was not lowered as this would not be conservative, and the Aqueduct's was very close to normal during the billing period in question, only slightly below normal (-0.2 percent).

Annual water demand in MGD is summarized in Table 5-1 and in Table 5-2. Current average annual water use for the WMA water suppliers during normal years is approximately 488 MGD and is projected to be 572 MGD in 2025. Demand during a hot and dry year in 2025 is projected to be approximately 587 MGD. The overall WMA water supplier and wholesale customer average annual demand is forecast to increase by nearly 84 MGD by 2025. Of this total, Fairfax Water demand is forecast to increase by approximately 35 MGD, the Aqueduct by 17 MGD, and WSSC by 32 MGD. Growth in annual average demand from 2005 to 2025 by supplier service area and water use class is shown in Table 5-2, including categories of single family, multi-family, employee, and unmetered water use.

Table 5-1: Forecast of average annual water demand for the WMA. Reported in MGD.

| Service Area | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|
| **Fairfax Water** | | | | | |
| Dulles | 1.0 | 1.3 | 1.6 | 1.8 | 2.2 |
| Ft. Belvoir | 1.7 | 2.2 | 2.6 | 3.0 | 3.2 |
| Herndon | 2.6 | 2.9 | 2.9 | 3.0 | 3.0 |
| Loudoun Co. Sanitation Authority | 14.3 | 17.5 | 20.5 | 22.7 | 24.8 |
| Prince William Co. Service Authority | 22.6 | 25.9 | 28.3 | 29.9 | 32.6 |
| Fairfax Water retail | 84.5 | 89.7 | 90.9 | 92.5 | 93.1 |
| Virginia American - Alexandria | 16.6 | 17.4 | 17.8 | 18.1 | 18.3 |
| Virginia American - Dale City | 6.7 | 7.3 | 7.5 | 7.6 | 7.8 |
| **TOTAL Fairfax Water and wholesale** | **150.1** | **164.2** | **172.0** | **178.6** | **184.9** |
| **Washington Aqueduct** | | | | | |
| Arlington Co. DPW | 25.6 | 27.2 | 28.3 | 29.6 | 30.1 |
| Falls Church DEP | 12.2 | 12.6 | 12.6 | 12.5 | 12.5 |
| Falls Church-Vienna DPW | 2.7 | 2.8 | 2.8 | 2.8 | 2.8 |
| D.C. Water and Sewer Authority | 126.4 | 129.5 | 135.1 | 136.6 | 138.2 |
| Fort Meyer | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| D.C. Soldiers Home & Howard Univ. | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 |
| **TOTAL Washington Aqueduct** | **168.4** | **173.5** | **180.3** | **183.0** | **185.1** |
| **Washington Suburban Sanitary Commission** | | | | | |
| **TOTAL WSSC retail** | **169.5** | **177.1** | **183.7** | **190.0** | **201.8** |
| | | | | | |
| **TOTAL WMA water suppliers** | **488.0** | **514.8** | **536.0** | **551.6** | **571.8** |
| City of Rockville DPW | 4.8 | 5.5 | 5.5 | 5.6 | 5.5 |

Table 5-2 shows that the growth in Fairfax Water's retail and wholesale water use is projected to be balanced between the single family residential and employment categories. Most of the Aqueduct's wholesale water use is projected to be in the employee category. WSSC's future water use is projected to be primarily a factor of growth in employee use. Overall, the main increase in WMA water supplier future water use is projected to be roughly split between employee and combined single and multi-family water use. A few jurisdictions (e.g., Falls Church, Alexandria, etc.) show a slightly lower water use in the single family category, due to relatively static growth in single family households. This may be a feature of slowed population growth and/or regional build out combined with declining unit use rates.

Table 5-2: Growth in demand by water use category from 2005 to 2025 (MGD).

| Service Area | Single Family | Multi-family | Employees | Unmetered | Total |
|---|---|---|---|---|---|
| **Fairfax Water** | | | | | |
| Dulles | 0.00 | 0.00 | 1.03 | 0.10 | **1.1** |
| Ft. Belvoir | 0.46 | 0.12 | 0.78 | 0.14 | **1.5** |
| Herndon | 0.17 | 0.04 | 0.12 | 0.03 | **0.4** |
| Loudoun Co. Sanitation Authority | 4.23 | 2.15 | 2.68 | 0.91 | **10.0** |
| Prince William Co. Service Authority | 6.15 | 0.71 | 2.74 | 0.96 | **10.6** |
| Fairfax Water retail | 2.77 | 0.14 | 4.88 | 0.78 | **8.6** |
| Virginia American - Alexandria | -0.16 | 0.33 | 1.35 | 0.16 | **1.7** |
| Virginia American - Dale City | 0.09 | 0.10 | 0.81 | 0.10 | **1.1** |
| **TOTAL Fairfax Water and wholesale** | **13.7** | **3.6** | **14.4** | **3.2** | **34.8** |
| **Washington Aqueduct** | | | | | |
| Arlington Co. DPW | -0.15 | 1.16 | 2.54 | 1.02 | **4.6** |
| Falls Church DEP | -1.66 | 1.35 | 0.55 | 0.04 | **0.3** |
| Falls Church-Vienna DPW | -0.03 | -0.01 | 0.08 | 0.01 | **0.1** |
| D.C. Water and Sewer Authority | 1.09 | 1.21 | 6.78 | 2.63 | **11.7** |
| Fort Meyer | 0.00 | 0.00 | 0.00 | 0.00 | **0.0** |
| D.C. Soldiers Home & Howard Univ. | 0.02 | 0.00 | 0.00 | 0.01 | **0.0** |
| **TOTAL Washington Aqueduct** | **-0.7** | **3.7** | **10.0** | **3.7** | **16.6** |
| **Washington Suburban Sanitary Commission** | | | | | |
| **TOTAL WSSC retail** | **6.8** | **5.8** | **14.5** | **5.2** | **32.3** |
| | | | | | |
| **TOTAL WMA water suppliers** | **19.8** | **13.1** | **38.8** | **12.1** | **83.8** |
| | | | | | |
| City of Rockville DPW | -0.04 | 0.30 | 0.37 | 0.12 | 0.63 |

Note: Assuming a minimum unmetered water use of 10 percent, the unmetered water use is forecast as 91 MGD in 2005 and 103 MGD in 2025.

## 5.3 Estimate of demand based on MWCOG growth scenarios

An additional component of the MWCOG regional forecasts includes estimates of low and high growth scenarios. These estimates reflect the range of uncertainty in long-range market and development trends inherent to the MWCOG forecasts. Low and high forecasts were not made for any of the forecasts subsequent to Round 6, so the most recently available forecast from Round 6 was used to develop a low and high forecast. Percentages associated with the difference between the published Round 6.4a forecasts and low and high estimates of regional population from Round 6 are displayed in Table 5-3 below. Because of recent high growth rates, the more current Round 6.4a forecast is tracking closely to the Round 6 high growth forecast as of 2005.

Table 5-3: Difference between Round 6.4a and Round 6 low and high forecasts.

| | MWCOG population forecast | |
|---|---|---|
| **Year** | **Round 6 Low** | **Round 6 High** |
| **2005** | -9.94% | 0.58% |
| **2010** | -10.99% | 0.32% |
| **2015** | -11.01% | 0.76% |
| **2020** | -10.36% | 2.83% |
| **2025** | -7.52% | 6.08% |

The CO-OP Water Supplier service area is a subset of the entire MWCOG forecast area (the greater WMA). The MWCOG low and high Round 6 forecast applies to the greater WMA. However, these percentages are the best available to develop low or high population growth scenarios and are used as the basis on which to predict future demand. The MWCOG high growth demographic scenario is used to determine the sensitivity of the demand to potentially higher realizations of demographic growth; a scenario is drafted for lower growth as well. The MWCOG low Round 6 forecast for 2025 is 7.52 percent less than the Round 6.4a forecast, and the MWCOG high Round 6 forecast for 2025 is 6.08 percent greater than the Round 6.4a forecast. These percentages were applied to future estimates of CO-OP demand in order to estimate a range of feasible future demand. These forecasts are plotted below (Figure 5-1).

Low, intermediate, and high forecasts are presented along with a scenario representing a high forecast during drought years in Figure 5-1. Drought year demand conditions are produced by adding a value of 16.5 MGD to the estimate of demand. (The value of 16.5 MGD is the difference between the modeled maximum and average annual demand given a repeat of historical temperature and precipitation conditions.)

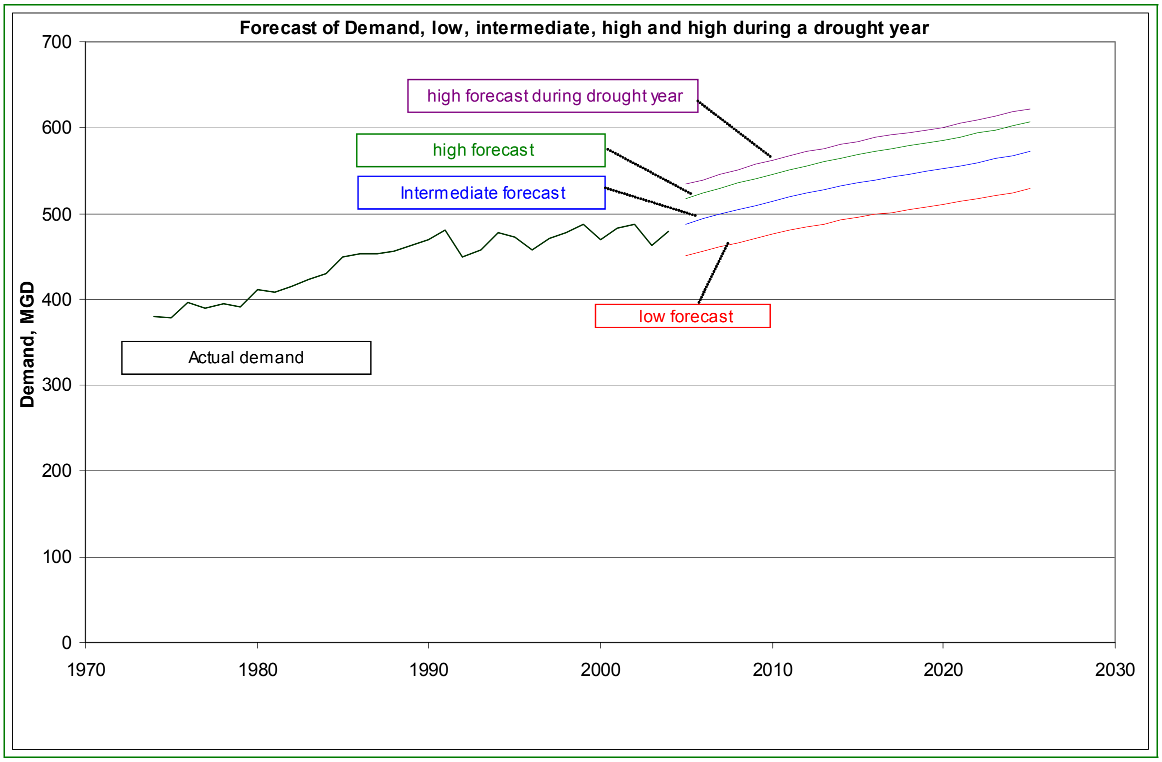



Figure 5-1: Forecast of average annual demand as based on Round 6 low and high growth scenarios and also the intermediate forecast based on the Round 6.4a scenario. Modeled demand is higher in a drought year.

## 5.4 Comparison of water demand forecast with earlier studies

A comparison of the forecast in average annual demand developed for this study was made with several earlier studies of Washington area demand including the three prior ICPRB studies including the *2000 Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Hagen and Steiner, 2000), the *1995 Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Mullusky et. al, 1996), the *20 year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area* (Holmes and Steiner, 1990). Other studies include the *Metropolitan Washington Area Water Supply Study* completed in 1983 by the Army Corps of Engineers (U.S. Army Corps of Engineers, 1983) and other studies as shown in Figure 5-2. All three ICPRB studies use the same basic method as this study, but earlier demographic data.

Current average annual water use for the WMA water suppliers during normal years is approximately 488 MGD and is projected to be 572 MGD in 2025. Demand during a hot and dry year in 2025 is projected to be approximately 587 MGD. The 2005 CO-OP forecast of annual average demand for 2020 is approximately 28 MGD less than the level forecast by the 2000 study (Figure 5-2). The lower forecast in this study is due primarily to updated demographic forecasts and lower calculated unit use rates. Population growth has increased at a faster rate than water demand in recent years.

Figure 5-2 reveals the 2005 CO-OP forecast of annual average demand for 2020 is approximately 28 MGD below the level forecast by the 2000 study and approximately 70 MGD less than the level forecast by the 1995 study. The lower forecast in this study is due to several factors, including updated demographic forecasts and lower calculated unit use rates. Actual population growth has increased at a faster rate than water demand, resulting in fairly flat growth in water demand since 1990 despite significant growth in regional population over the same interval.

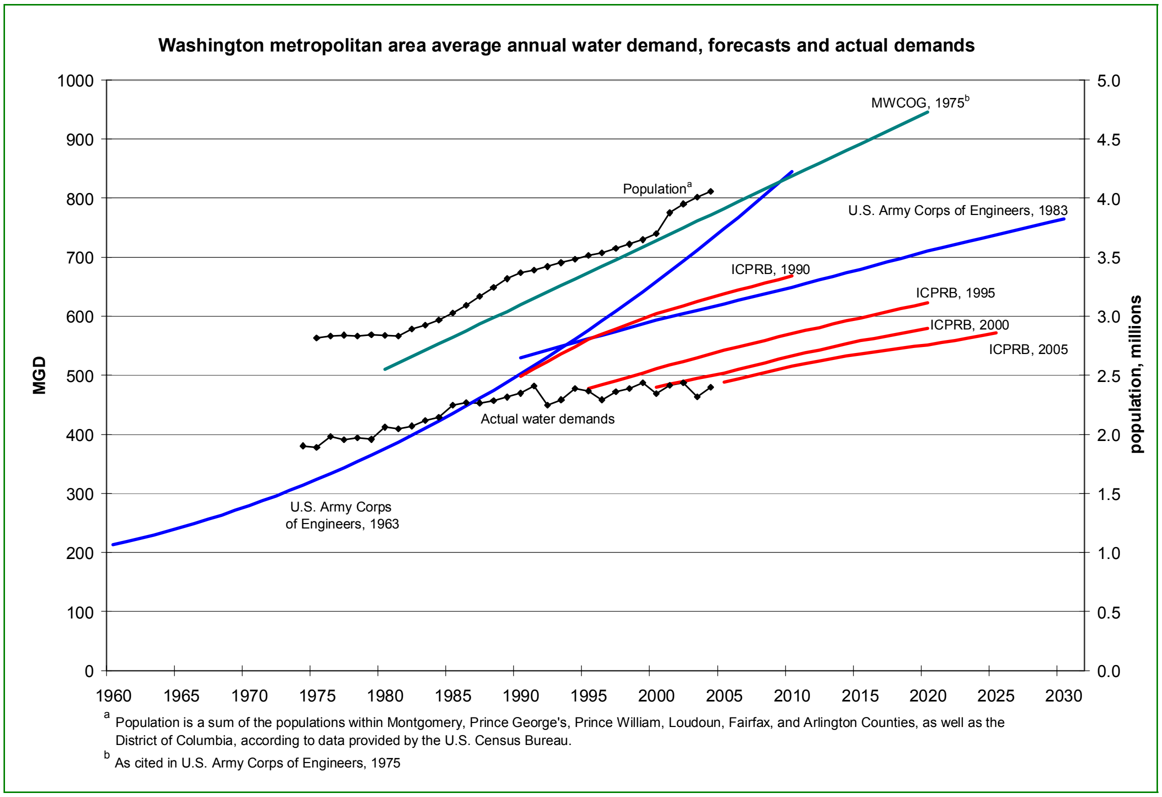



Figure 5-2: Comparison with forecasts from earlier studies for WMA water suppliers.

Note: 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.

## 5.5 Demand model validation

The calibration of the demand model was completed using the methodology and independent variables noted in Section 3 over 12 years, January 1, 1990-September 30, 2002. Figures demonstrating this calibration were displayed in Figures 3-5 through 3-8 in Chapter 3. Additional evaluation of the model was completed in the Extend modeling platform and provided additional results for the period of 2003-2004. Year 2003 and 2004 demand was estimated and compared with actual historical demand in an effort to validate the method used to forecast demand. As summer presents the highest demand and greatest stress on regional resources, validation for these two summers are shown in Figure 5-3 and Figure 5-4.

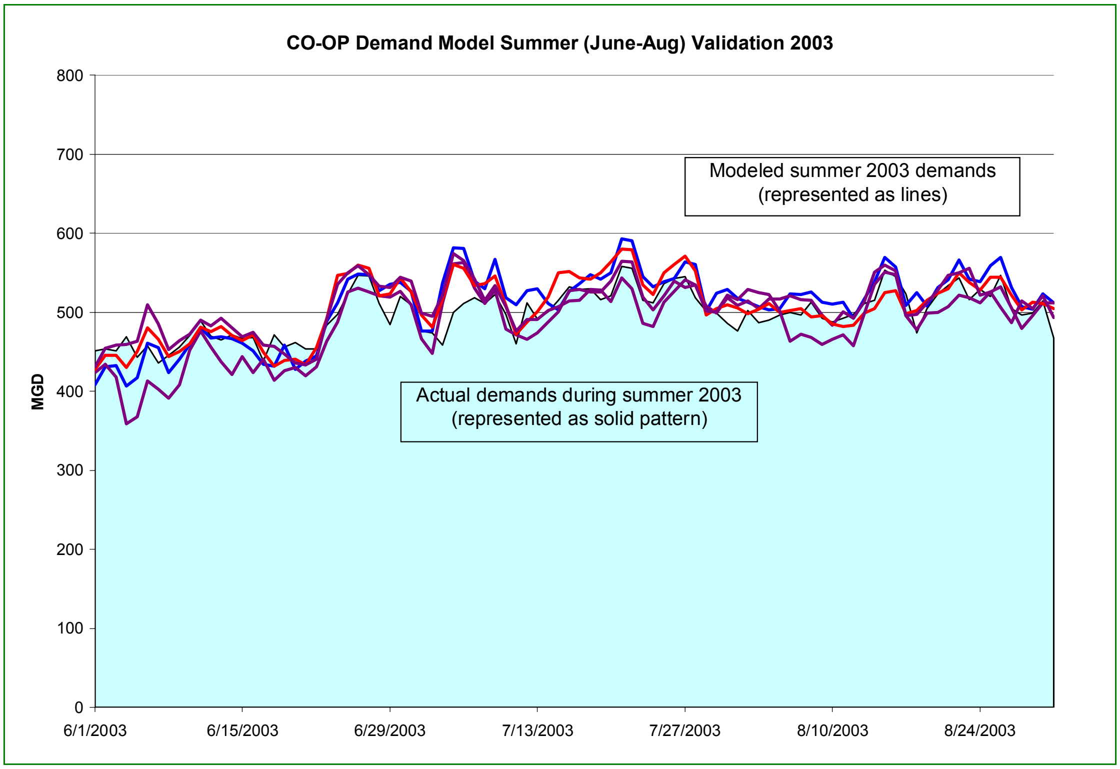



Figure 5-3: Five realizations of modeled demand during June-August, 2003.

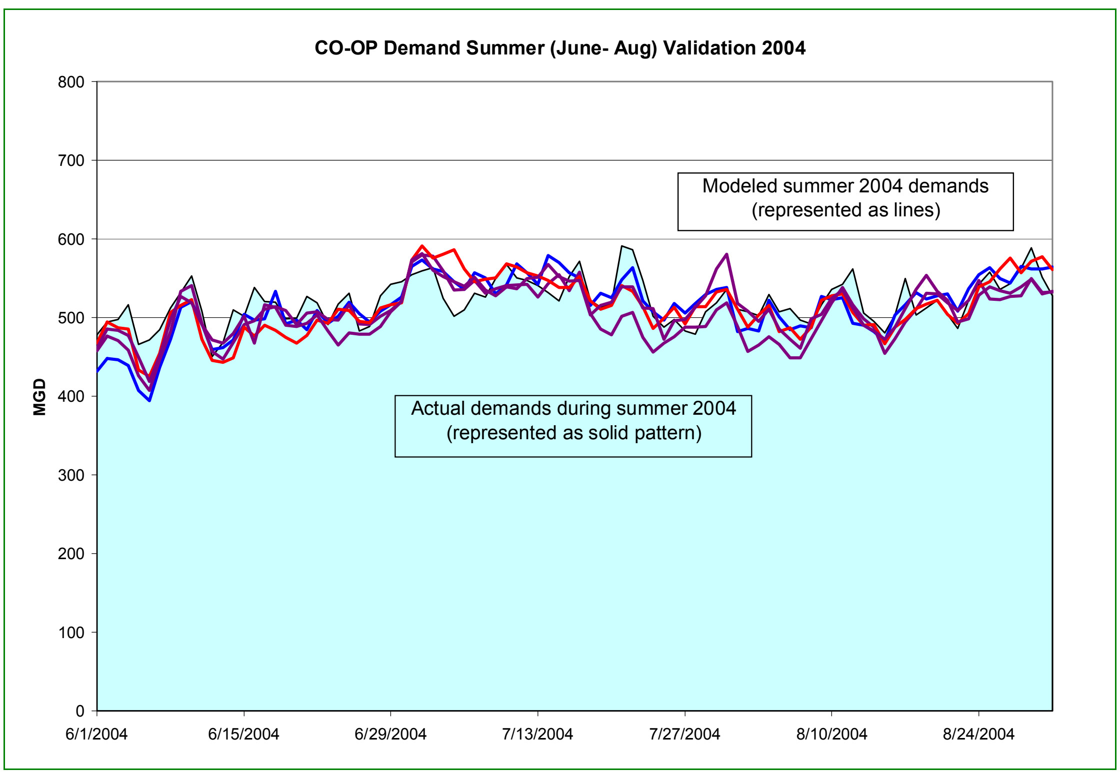



Figure 5-4: Five realizations of modeled demand during June-August, 2004.

The inherently random characteristics of WMA daily demand are modeled as shown by the differences between multiple traces in Figure 5-3 and Figure 5-4. These multiple traces represent several feasible manifestations of demand in the WMA. This random quality is captured by modeling techniques that replicate the randomness inherent in the dataset as discussed in Section 3.6 and 3.7. The random component is generated anew during each model run and represents the random component associated with actual water demand.

Though imperfect, Figure 5-3 and Figure 5-4 demonstrate the effectiveness of the demand model in modeling water demand in the WMA. The predictive strength of the climate variables in the demand regression is significant.

# 6 Resource analysis method and modeling assumptions

## 6.1 Introduction

This chapter introduces and describes the system model that is developed for the resource assessment portion of the study and documents modeling assumptions. A history and overview of the model is provided in Section 6.2. The method used to extend the historical streamflow record is described in Section 6.3. Several additional modeling assumptions are presented, including:

- System reservoir operations (Section 6.4).
- The effects of siltation on reservoir storage over time (Section 6.5).
- Increasing return flows from wastewater treatment plants upstream of the Potomac water supply intakes and Occoquan Reservoir (Section 6.6).
- Water supply alternatives in Loudoun County (Section 6.7).
- The recommended environmental flow rate for Little Falls (Section 6.8).
- Water quality releases from Jennings Randolph water quality storage (Section 6.9).
- Upstream consumptive water demand (Section 6.10).
- Savage Reservoir operations (Section 6.11)

## 6.2 Model description

The Potomac Reservoir and River Simulation Model (PRRISM) is a simulation model that incorporates the daily operating rules of the system of reservoirs for the WMA. 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 in 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 models Jennings Randolph Reservoir in the headwaters of the Potomac River basin, Little Seneca Reservoir in the WMA, and Potomac flow upstream and downstream of the WMA. PRRISM also models the Occoquan and Patuxent reservoirs, which provide about 25 percent of the total water supplied in the WMA. An outline of PRRISM's modeling components, inputs, and outputs is presented in Table 6-1.

Table 6-1: Modeled system components and inputs and outputs for PRRISM.

| **Modeled system components** | **Inputs** | **Outputs** |
|---|---|---|
| Reservoirs:<br>• Jennings Randolph water quality storage<br>• Jennings Randolph water supply storage<br>• Savage Reservoir<br>• Little Seneca Reservoir<br>• Patuxent reservoirs<br>• Occoquan Reservoir<br><br>Water withdrawals for:<br>• Washington Aqueduct<br>• Fairfax Water<br>• Washington Suburban Sanitary Commission | • Choice of historic streamflow (1929-2002) or synthetic streamflow (500 years of record)<br>• Forecast year (translated into annual demand as determined by demand study)<br>• Choice of water supply alternatives<br>• Restriction percentages<br>• Operational preferences, capacities, and constraints | • Daily reservoir volumes<br>• Daily reservoir release rates<br>• Number of days of releases<br>• Potomac River flow upstream and downstream of the water supply intakes,<br>• Potomac “natural” flow (that flow unaffected by upstream human activities)<br>• Magnitude and frequency of low flows<br>• Vulnerability and reliability |

The modeling algorithm in PRRISM can be compared to an accounting procedure, tracking inputs (reservoir inflows and Potomac streamflow) and outputs (reservoir releases, streamflow, reservoir storage, etc.). The modeler can choose inputs of either the historical record of streamflow, or an extended streamflow time series that is synthetically generated (Section 6.3). Reservoir releases are made to meet the minimum streamflow plus a safety factor, after accounting for river flow and projected withdrawals. The model tracks the reservoir releases and is able to determine daily reservoir storage and river flow throughout either the historical record or the extended synthetic record. PRRISM can thus be used to determine how the current system of reservoirs and the Potomac River would respond to current or future demand given the current reservoir operating procedures and inputs of streamflow.

PRRISM is run in a continuous mode on a daily time step. 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, and is noteworthy for lasting from the summer of 1930 through the winter of 1931.

## 6.3 Extended streamflow record

Drought planning for the Washington, D.C. metropolitan area has traditionally relied on a planning event based on the worst drought experienced in the 73-year historical streamflow record. However, while the historical record indicates what has happened, it does not tell us what could happen in the future, as the severity of future droughts is not limited to what has been observed in the historical record. Indeed, as drought conditions unfolded from fall 2001 to summer 2002, observational data showed an extended period of below normal precipitation, record low groundwater levels, and record low streamflows, raising the spectre that drought conditions could worsen to something more severe than that recorded in the historical record.

In the end, such extreme drought conditions did not manifest in 2002, but the events prompted further analysis of the ability of the water supply system to meet demand in droughts more extreme than have been observed in the historical record. While the WMA was lucky, other water suppliers including Denver and Las Vegas recently experienced droughts described as worse than that of the drought of record. Denver describes its drought as worse than that "the 300-year drought," (Gardener, 2004) and Las Vegas is described as having a "five-year drought, the worst in 100 years of record-keeping and perhaps -- tree rings suggest this -- the worst in 500 years." (Will, 2005).

The impact of a drought on the metropolitan area water supply system depends on its duration, timing, and specific streamflow characteristics. To examine the impact of a drought that is worse than that recorded in the historical streamflow record, the streamflow record must be extended. Several methods of extending the historical streamflow record exist and include:

- Synthesize longer streamflow records by using longer precipitation records (Werrick et al., 2001).
- Synthesize streamflow records by modeling streamflow response to different meteorological conditions given the same initial watershed conditions.
- Synthesize streamflow based on the statistics of the historical record (Grygier and Stedinger, 2001).

For the Washington, D.C. metropolitan area's system, daily streamflow information is necessary to accurately model the system's response to drought events. Limited daily precipitation records go back to approximately the late 1800s, but that would not extend the record much more than already exists. Furthermore, the adequacy of daily records has not been researched for application in this method by ICPRB. In addition, a fully calibrated watershed model that adequately considers the watershed state is not yet fully developed for the Potomac River basin. Thus, the most appropriate method of extending the historical record is to synthesize flow sequences using a model which is statistically characteristic of the historical record.

The SPIGOT modeling package (Grygier and Stedinger, 1990, 2001) is used to generate a stochastic streamflow series for input to PRRISM (Kiang et al., 2004). SPIGOT is used to generate synthetic daily flows at several stream locations in a stepwise fashion. First, a synthetic annual flow series is generated for Point of Rocks, the most downstream gaging location that is unaffected by metropolitan area water withdrawals. The annual average flows for this station are then temporally disaggregated to weekly flow. The resulting weekly flow series is spatially disaggregated to multiple sites throughout the basin. Synthetic weekly values are disaggregated into daily values by matching pieces of the daily historical record with similar weekly volumes. In order to keep the summer dry season as part of a continuous simulation year, the start of the simulation year is set at the beginning of June.

Figure 6-1 presents a comparison of monthly average Potomac River flow at Little Falls from the historical time series and from the synthetic time series. The synthetic flow series captures the seasonal cycle of flows well at the monthly level. Figure 6-2 shows the average flow at Little Falls from June 1 to October 31, the main part of the potential reservoir release season. The synthetic distribution mimics the historical distribution fairly well, particularly in the low flow ranges.

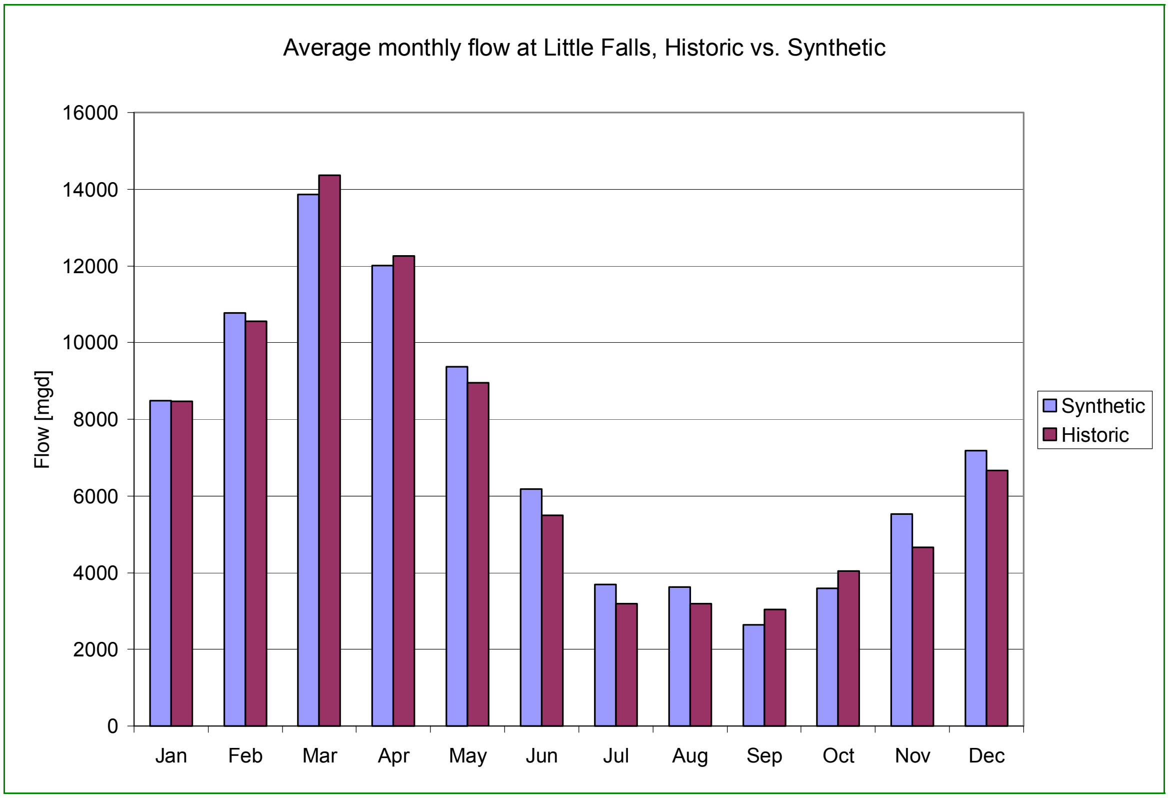



Figure 6-1: Comparison of historical and synthetic monthly average Potomac River flow at Little Falls.

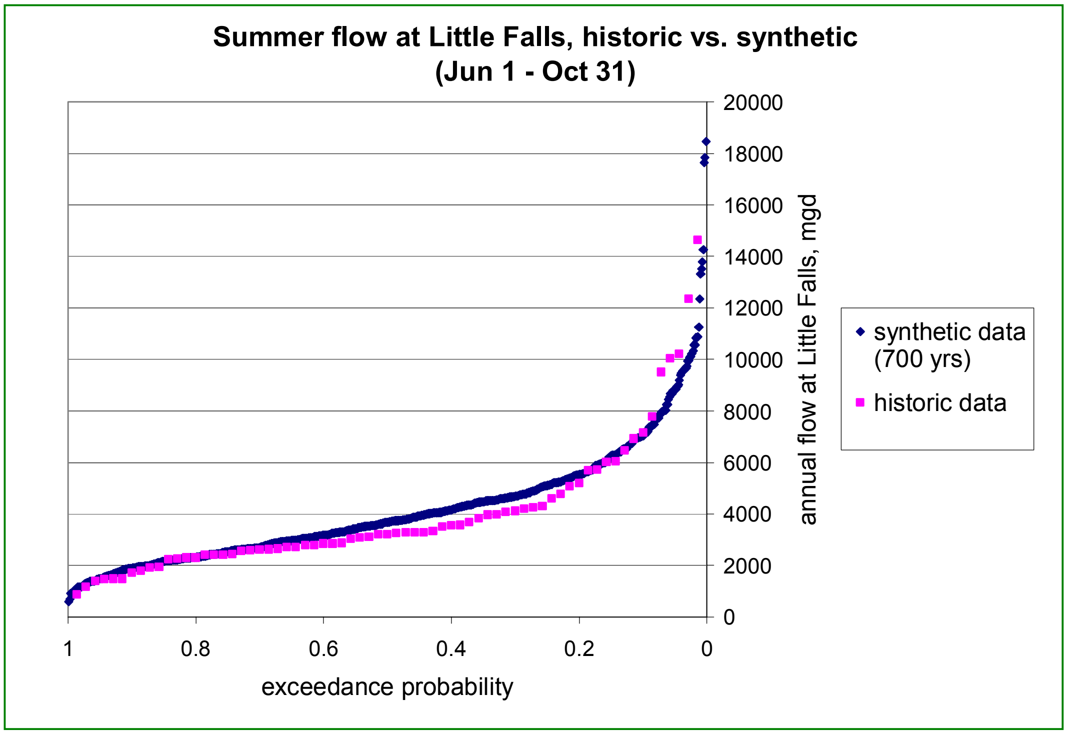



Figure 6-2: Comparison of historical and synthetic flow distributions for Potomac River flow at Little Falls, averaged from June 1 to October 31.

## 6.4 Reservoir 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 been made in only two seasons; in 1999 and in 2002. Water supply releases flow into the Potomac River and downstream to the water supply intakes. The Jennings Randolph releases take about 9-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 streamflow, etc.

During normal periods, the Patuxent and Occoquan reservoirs are used to meet water supply demand for WSSC and Fairfax Water. The amount of water withdrawn from these reservoirs 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 during drought summers 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.

### *6.4.1 Patuxent and Occoquan reservoirs*

Reservoir withdrawals from Patuxent and Occoquan 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.

When Potomac flows are low enough to require releases from Little Seneca Reservoir, the withdrawal rates from the Patuxent and Occoquan reservoirs are set higher than the rule curve withdrawal. When there are no Little Seneca releases, the withdrawal rate is lower than the rule curve withdrawal rate 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 variable. If demand is more or less than forecast, this 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 forecast, 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 forecast, this water flows past the intakes and is unavailable for future use.

### *6.4.2 Jennings Randolph and Little Seneca reservoirs*

Jennings Randolph and Little Seneca reservoirs are used to augment low flows in the Potomac River. Jennings Randolph and Little Seneca releases are made when predicted 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 from Jennings Randolph Reservoir 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 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 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 3.5). 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 streamflow recessions. In turn, these recessions are used to forecast Potomac flow 9 days beyond the current model timestep. In model runs as in real life operations, the flow downstream of Little Falls 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 9 days when the release is large (on the order of at least 100 to 200 MGD) and travels as a "wave," a condition called *unsteady flow* by hydraulic engineers. For a small release less than approximately 100 MGD, the water travels downstream as a particle, and would take approximately 20 days to arrive at DC during periods of low flow. Thus, the Jennings Randolph release in both real operations and as modeled in PRRISM calls for an initial day's release of 200 MGD whenever the forecast of demand is greater than the forecast of river flow 9 days hence. The large release is made to quickly get the water to the intakes as a "wave." Subsequent day's releases are at least 100 MGD whenever the forecast of 9-day demand is greater than the forecast of river flow 9 days hence. Little Seneca is assumed in model runs to be 100% efficient, in addition to which a safety factor of 30 MGD is released.

## 6.5 Effects of sedimentation on reservoir storage

Reservoir storage is assumed to decrease over time due to the effects of reservoir sedimentation. Table 6-1 shows the approximated current and projected reservoir storage for the system reservoirs. Sedimentation rates are determined by comparing recent bathymetric surveys to older bathymetric surveys. Various ICPRB reports (Hagen et al, 1998a, 1998b, 1999) document reservoir sedimentation for the system reservoirs. The changes in reservoir storage are incorporated into the system model as a function of forecast year. For those reservoirs without recent bathymetric survey information, current storage is calculated assuming various sedimentation rates as provided in the table.

Table 6-1: Effects of sedimentation on system reservoir storage.

| Reservoir | Usable capacity in year 2005, mg | Usable capacity in year 2025, mg | Rate of sedimentation assumed, mg per year |
|---|---|---|---|
| Occoquan Reservoir | 7,986 | 7,186 | 40 |
| Patuxent reservoirs | 10,080 | 9,600 | 24 |
| Little Seneca Reservoir | 3,785 | 3,485 | 15 |
| Jennings Randolph water supply | 13,262 | 12,870 | 44 (distributed between water supply and quality storage) |
| Jennings Randolph water quality | 16,501 | 16,013 | |
| Savage Reservoir | 6,241 | 5,881 | 18 |

## 6.6 Effects of increased treated wastewater return flow

Several waste-water treatment plants (WWTPs) serving the WMA return treated water upstream of the metro area water intakes, both in the Potomac River and upstream of Occoquan Reservoir. This treated water is released upstream of the water supply intakes (or reservoir), so the return flow is recycled—it is considered available for further use at downstream withdrawal points. These return flows are estimated for future years and incorporated into PRRISM. The facilities considered for this analysis include WSSC's Seneca WWTP, Loudoun County Sanitation Authority's planned Broad Run WWTP, and the Upper Occoquan Sewage Authority's (UOSA's) WWTP. The projected average annual return flows are listed in Table 6-2 through Table 6-4. Estimates used in prior demand studies are provided in Prelewicz et al., 2004.

Table 6-2: Projected WWTP return flow for Broad Run.

| Year | Total LCSA Flow, average annual, MGD | LCSA Flow at Broad Run WRF, MGD | Fairfax Flow at Broad Run, MGD | Total Projected WWTP return flow for Broad Run, MGD |
|---|---|---|---|---|
| 2015 | 18 | 4.2 | 1 | 5.2 |
| 2020 | 20.6 | 6.8 | 1 | 7.8 |
| 2025 | 22.4 | 8.6 | 1 | 9.6 |
| 2030 | 23.8 | 10 | 1 | 11 |

Note: Data through 2030 provided by Tim Coughlin and Tom Broderick, 9/7/2004, as based upon the information from the "BPSA Wastewater Flow Management Programs - 2003 Annual Report" that was produced by MWCOG and showed total LCSA flow. Broad Run return flow is based upon LCSA maximizing its 13.8 allocation at Blue Plains and assuming 1 MGD of treated flow originating from Fairfax County. ICPRB estimated 17 MGD total projected WWTP return flow for 2050 (linear trend of data provided and buildout capacity of 20 MGD).

Table 6-3: Projected WWTP return flow for Seneca WWTP.

| Year | Flow, MGD |
|---|---|
| 2005 | 17.1 |
| 2010 | 18.8 |
| 2015 | 20.6 |
| 2020 | 22 |
| 2025 | 22.5 |
| 2050 | 27 |

Note: Data provided by Craig Fricke, 9/2/2004. Note that WSSC does not routinely do projections beyond the date of the official demographic projections, but provided 26-28 MGD for 2050 as a rough estimate.

Table 6-4: Projected WWTP return flow for UOSA WWTP.

| Year | MGD | Year | MGD |
|---|---|---|---|
| 2005 | 29 | 2030 | 51.5 |
| 2010 | 33.5 | 2035 | 56 |
| 2015 | 38 | 2040 | 60.5 |
| 2020 | 42.5 | 2045 | 65 |
| 2025 | 47 | 2050 | 69.5 |

Note: Data provided by Traci Kammer Goldberg, Fairfax Water, as compiled by John C. (Jack) Sellman, Upper Occoquan Sewage Authority, Director, Treatment Process Division, September 2004.

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. Typically the numbers range from 0.8 to 1.2 for these treatment plants. It is important to capture the variation in production water supply releases from the Jennings Randolph and Little Seneca reservoirs since 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 Broad Run, Seneca, and UOSA WWTPs.

Table 6-5: Production factor used to estimate monthly return flow, Broad Run WWTP.

| Month | Monthly Factors | | |
|---|---|---|---|
| | Broad Run WWTP (minimum of 2001, 2002, and 2003 factors)[1] | Seneca WWTP (minimum of 2002, 2003, and 2004 factors)[2] | UOSA WWTP (compiled by UOSA)[3] |
| January | 0.93 | 0.94 | 1.08 |
| February | 0.93 | 0.96 | 1 |
| March | 0.97 | 1.02 | 1.14 |
| April | 0.96 | 0.99 | 1.01 |
| May | 0.98 | 0.84 | 1.03 |
| June | 0.97 | 1 | 0.98 |
| July | 0.92 | 0.96 | 0.92 |
| August | 0.89 | 0.92 | 0.94 |
| September | 0.99 | 0.95 | 0.93 |
| October | 0.95 | 0.93 | 0.95 |
| November | 0.98 | 0.97 | 0.96 |
| December | 1.02 | 0.99 | 1.04 |

Notes: [1]Data request to Tim Coughlin and as provided by Sherrie M. Leanord, Engineering Programs Assistant, LCSA in November of 2004.
[2] Data request to Craig Fricke, as compiled by Shari Djourshari of WSSC in January of 2005.
[3] Data provided to ICPRB by Traci Kammer Goldberg, as compiled by John C. (Jack) Sellman, Upper Occoquan Sewage Authority, Director, Treatment Process Division, September 2004.

## 6.7 Loudoun County Sanitation Authority

To meet its growing demand, the Loudoun County Sanitation Authority (LCSA) is investigating several water supply alternatives. One alternative is to expand its contract with Fairfax Water. Another option involves the conversion of existing rock quarries to water supply reservoirs, which would be used as a source of water during droughts. If quarries are brought online as a source of water for the LCSA, the net impact of LCSA's growth in water demand on MWA water supply reliability would be mitigated. Since it is impossible to know which alternative will be developed at this time, we conservatively assume that all of LCSA demand will be met by Fairfax Water and is thus included in the estimates of future demand in the MWA.

## 6.8 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 (Maryland Department of Natural Resources, 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 of 2003, the 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 methodologies 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" (Maryland Department of Natural Resources, 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 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 million gallons per day 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, especially biological information, needed to be collected and discussed 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 whom have expertise on the possibly affected species and guilds. Efforts on behalf of ICPRB, the US Army Corps of Engineers, Baltimore District, and The Nature Conservancy to secure funding for this workshop have not been successful. At this juncture ICPRB is considering a scaled down version of the workshop to address interim measures to begin collecting some of the information needs. Reports on these activities can be found at

http://esm.versar.com/pprp/potomac/

Any change in the 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.

## 6.9 Jennings Randolph water quality release

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

The goal of regulation for water quality management at Jennings Randolph is to use as much of the available water quality storage as needed every year to produce the greatest possible improvement in water quality downstream in the North Branch Potomac. Joint regulation with nearby Savage River Dam is used to assist in meeting this goal. The release rule for water quality is based on the expected inflow rate and the volume of remaining storage in the lake. The idea is to maximize the minimum flow from the reservoir without running out of water. However, when a request for a water supply release is made by ICPRB on behalf of the WMA water suppliers, the Jennings Randolph release from water quality may be reduced by the COE to the minimum release of 120 cubic feet per second (cfs; 78 MGD). In the summer of 1999, water quality releases dropped from about 160 cfs (103 MGD) to 120 cfs at the beginning of the first water supply release.

The version of PRRISM used in the 2000 study conservatively assumed the minimum release from water quality storage at all times. Since that time, substantial effort was expended to develop, verify, and calibrate a model of the COE's North Branch water quality operations. The model development and verification is available in Prelewicz, 2004, including graphs showing modeled and actual flows and reservoir storage. The North Branch operations model was incorporated into the current version of PRRISM. North Branch water quality operations usually result in higher releases from the North Branch than the minimum 77 MGD release, which offsets the timing and magnitude of reservoir releases needed from water supply storage. Including the effects of North Branch water quality operations increases historical water supply yield by approximately 29 MGD.

## 6.10 Upstream consumptive demand

An examination of cumulative consumptive demand 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 concept of consumptive use as used here is consistent with that of others in the field, including the U.S. Geological Survey (USGS): "That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment," (USGS, 1998).

The Basin Study suggests that total June through August consumptive use in the Potomac basin upstream of the metropolitan water supply intakes for 2000 is approximately 129 MGD during hot and dry years. Projected June through August consumptive use in the basin is forecast to increase by 30 MGD from 2000 to 2030 assuming hot and dry conditions—approximately 1 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 is estimated to be 42 MGD, increasing by 4 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 the computer simulation model PRRISM to account for present and forecast levels of consumptive demand. The adjustment is made in two parts. First, the streamflow 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 streamflow record is modified to represent flows prior to human consumptive use, as follows. It is assumed that actual consumptive use in 1929 is zero and that the 1929 historical streamflow record did not have to be adjusted. It is assumed that actual consumptive use in 2000 is 129 MGD and that the historical streamflow record in 2000 must be adjusted by adding 129 MGD in June, July and August. For years between 1929 and 2000, the historical streamflow 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 years between 1929 and 2000, the historical streamflow 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 streamflow in all years, prior to water supply withdrawals in summer months. When projected year 2025 demand is modeled, streamflow resources are decreased by an additional 25 MGD in the summer and 4 MGD in the other months for all years of the historical record, prior to water supply withdrawals. An additional adjustment of 1 MGD is made to account for new power plants as described below.

The Basin Study (Steiner et al., 2000) made no provision of increased consumptive use due to new power plants. Two new plants have been approved since that time, with significant new levels of consumptive use.

- Catoctin Power, LLC's plant was recently approved. It is not a net consumptive use since it plans to augment Potomac flow from a quarry to make up its consumptive use per a settlement agreement reached with the water suppliers.

- Mirant Dickerson Development, LLC's plant will reduce its consumptive use to 1 MGD per settlement agreement during periods of water supplier reservoir releases.

The demand study for 2005 assumes that there is 1 MGD of additional consumptive use to account for the planned Mirant Dickerson Development, LLC power plant, beyond that described in the Basin Study.

## 6.11 Savage Reservoir Operations

Savage Reservoir is owned by the Upper Potomac River Commission with operational guidance provided by the COE. This 6.2 BG reservoir is located in the headwaters of the basin near Jennings Randolph Reservoir. Savage Reservoir is operated primarily to maintain instream flow for industrial wastewater dilution in the North Branch Potomac. Together, Savage and Jennings Randolph reservoirs control about 3 percent of the Potomac watershed upstream of Washington D.C.

During the drought operations of 2002, a percentage of the Jennings Randolph water supply release was matched by a concurrent water quality release from Savage Reservoir. The Savage release amounted to approximately 20% of the total water supply request. The Savage matching policy is based on the COE master manuals for the North Branch system, in which a concurrent Savage release during Jennings Randolph releases is authorized for water quality purposes. The continuing implementation of this policy has been approved by the Upper Potomac River Commission (UPRC), the owners of Savage Reservoir. PRRISM operations assume that when water supply releases are requested from Jennings Randolph Reservoir, a concurrent water quality release is made from Savage Reservoir.

# 7 Uncertainty in water supply reliability forecasting

## 7.1 Introduction

This chapter provides a short description of some sources of uncertainty that may affect the likelihood of this study's forecast being realized.

As techniques in water demand forecasting evolve, so do the accuracy of those forecasts. Researchers, however, recognize the considerable uncertainty that is involved in the process of prediction. Though methodologies have evolved in the last several decades, the U.S. Senate Select Committee on National Water Resources (1968) aptly characterized the field of water demand forecasting in stating, "The number of uncertainties that intervene for a regional forecast, allowing for all foreseeable possibilities of interregional substitution … compounds the difficulties and raises the probability of error by an unknown but undoubtedly formidable factor" (Osborn et al., 1986).

Uncertainty in water demand forecasting and water supply reliability assessment can be broadly categorized. These categories include the accuracy of stream gages used to develop the inflow data set, assumptions about system management including basic system operations, assumptions developed within the demand forecast including the accuracy of demographic projections and changes in water demand behavior, and potential climate change or increased climate variability. The uncertainty associated with subsets of each category is described in Table 7-1 (Hahn and Palmer, 2002) and is described in more detail below.

### 7.1.1 Uncertainty due to stream flows

The Potomac basin is one of the most heavily gaged basins in the country and has the longest continuous running stream flow record in the country at Point of Rocks. Overall, the uncertainty level associated with the historical stream flow record is low. The Occoquan inflow record was based on an extended streamflow record, so there is moderate uncertainty associated with this reservoir's inflow record. The extended synthetic stream flow record has a moderate level of uncertainty but is best used in examining the response of the water resources to droughts worse than that of the historical stream flow record.

Table 7-1: Level of uncertainty in water supply reliability forecasting.

| Category | Factor in determining reliability | Uncertainty |
|---|---|---|
| Stream flows | Gage within basin | Low |
| | Record is extended | Moderate |
| | Record is located from adjacent basin | Moderate |
| | Short record length | High |
| Demand forecast | Forecasting skill has not been monitored | High |
| | Forecasting skill is poor | Moderate |
| | Forecasting skill is fair | Low |
| | Forecasting skill is excellent | Low |
| System model and management | Model is validated | Low |
| | Model developed by political stakeholders | Low |
| | Modeling or estimation technique is poor | High |
| Climate change | Single climate change model | High |
| | Multiple climate change model | Moderate |
| | Temperature signal impacting results | Low |
| | Precipitation signal impacting results | Moderate |

Note: As adapted from Hahn and Palmer, 2002.

### 7.1.2 Uncertainty in demand forecast

The significant change in demographics between the 2000 Demand study and the current study is evidence of how this variable can appreciably alter the expected demand regime. The changes in estimates of population and households derive from refined estimates due to the national Census 2000. That the numbers could be so far off suggests that future uncertainties may occur at both the local and national level. As planning agencies' methodologies for demographic data collection and population projections improve, the variables that primarily dictate water demand will probably improve as well but will still be subject to great uncertainty.

Regional changes in the political climate or status of the economy will also have an impact on regional growth patterns and can even affect water demand. The social and political landscape may affect the preference for management choices ranging from expansion alternatives to rate changes. In addition, economic up- or downturns may affect anticipated employment, population forecasts, or construction planning for various jurisdictions. Though we assume WMA water demand patterns will remain the same, there are unforeseen circumstances that may alter regional water demand. In addition, the interest in and publication of conservation studies by the WMA water suppliers since the 2000 demand study suggests potential for new approaches to demand management.

The historical forecasting skill for the WMA is poor to fair (Figure 5-2) with an associated uncertainty of low to moderate (Table 7-1). However, the policy of regularly updating the demand forecast recognizes and mitigates the inherent inadequacy of demographic and water use forecasts, as updated forecasts incorporate the most recent information about changing economic, demographic, and water use rates. The old adage holds true for water demand forecasting: "if you can't do it well, do it often!"

### 7.1.3 Uncertainty due to system model and management

The various components of the system model have been studied, validated, and revised on an ongoing basis, reflecting the most current understanding of the physical system and of operations management. The uncertainty level associated with the system model is low.

The simulation model allows for exploration of various operational and management alternatives. The exploration of these alternatives has been extensive and is informed by a thorough understanding of system constraints such as pumping capacities, distribution system requirements, and operational constraints as experienced during the droughts of 1999 and 2002. Indeed, an exploration of new operations made possible by higher treatment capacities at the Patuxent and Occoquan reservoirs allows for a more efficient system operation in the current study, as compared to the 2000 study (as described in more detail in Chapter 8). Ongoing work involves the development of an optimization model that can be used to further explore and inform operational and management alternatives. Thus, the uncertainty associated with the management alternatives is low to moderate.

### 7.1.4 Uncertainty due to climate change

The potential impacts of climate change and continued climate variability inevitably alter our ability to perfectly forecast regional water demand. The uncertainty associated with both climate change and variability is significant.

A review of climate change studies from the nearby Susquehanna basin allows for an extrapolation of these results to the Potomac basin, albeit with a higher degree of uncertainty. The incorporation of temperature and precipitation in the demand model (Section 3-6) allows for low to moderate uncertainty in the assessment of climate change and its effect on water supply demand. However, a high level of uncertainty must be used to describe the resource assessment, in which a simplistic sensitivity analysis is conducted to illustrate the response of the system to potential changes in resources.

# 8 Results, conclusions, and recommendations

The results, conclusions, and recommendations for future work are provided in this chapter. The model run scenarios assumptions are presented in Section 8.1. The model run outputs used to assess system performance are introduced in Section 8.2. Model run results for the intermediate and high growth estimates are provided in Section 8.3. Differences between model run results for the current study are compared to the 2000 study in Section 8.4. Additional model run results addressing a range of scenarios including no Federal Energy Policy Act, climate change, a 2045 demand scenario and a five-hundred year synthetic stream flow simulation are provided in Sections 8.5 through 8.9. The relationship between increasing demand and low flow frequency is provided in Section 8.10. Conclusions and recommendations of the report are provided in 8.11 and 8.12.

## 8.1 Scenarios

Table 8-1 details the scenarios and itemizes the major assumptions.

Table 8-1: Summary of model run scenarios and assumptions for resource analysis.

| Scenario | Demand year | Growth scenario | Stream flow simulation |
|---|---|---|---|
| *MWCOG Round 6.4a* (Section 8.3) | 2025 | Round 6.4a | 73 years (historical, 1929-2002) |
| *High growth* (Section 8.3) | 2025 | Round 6 High | 73 years (historical) (historical, 1929-2002) |
| *No Federal Energy Policy Act (Section 8.5)* | 2025 | Round 6.4a | 73 years (historical, 1929-2002) |
| *Climate Change* (Section 8.6) | 2025 | Round 6 High | 73 years (historical) (historical, 1929-2002) |
| *2045 demand* (Section 8.7) | 2045 | Round 6.4a | 73 years (historical) (historical, 1929-2002) |
| *Extended stream flow – 1* (Section 8.8) | 2025 | Round 6.4a | 500 years (synthetic) |
| *Extended stream flow – 2* (Section 8.9) | 2020 | Round 6.4a | 500 years (synthetic) |

### 8.1.1 Scenario assumptions

Although the MWCOG population forecast is valid through the year 2030, the forecast was extended to the year 2045 by assuming similar rates of growth. This extension allows for a broader analysis of when the water resource system might be stressed. It should be noted that the population forecast (and corresponding demand forecast) beyond the 2030 horizon is a rough approximation.

Unless otherwise noted, the model run results correspond to model runs conducted over the historical period of record, October 1, 1929 through September 30, 2002. The rationale for a 500-year synthetic streamflow record selection is provided in Section 8.8.

A range of demand forecasts is compared with the available resources. Unless otherwise noted, model runs assume the MWCOG Round 6.4a growth estimates as described in Section 5-3. All scenarios assume the current environmental flow recommendations, current levels of conservation (i.e., effects of *Energy Policy Act of 1992*), water pricing rates, implementation of restrictions as described in Section 4-9, upstream consumptive demand as documented in Section 6-10, and a repeat of either the drought of record or the synthetic (extended) stream flow record as described in Section 6-3. The climate change scenario assumes an estimate of drought-year temperature and precipitation effect on demand. Other miscellaneous demand and resource assumptions are documented in Chapters 4, 5, and 6.

Model runs assume that the 100 MGD environmental flow is met at all times. Shortfalls in the Potomac resource are allocated to the WMA water suppliers and reported 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, a combined reduction in demand by the three water suppliers may be necessary, 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 given set of meteorological conditions while incorporating the randomness inherent in the original demand data set. (Sections 3-7 and 3-8 provide more detail on the random component of demand.) Since demand is slightly different in each model run, the model is run several 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 8.2.

## 8.2 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.
- *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.
- *Number of Occoquan water supply shortfalls.* This metric is a measure of the vulnerability of the Occoquan Reservoir.
- *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 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.

## 8.3 Model run results for *MWCOG Round 6.4a* and *Round 6 high growth* scenarios and 2025 demand

Model run results are presented in terms of the model run metrics described in Section 8.2. The model run results presented in Table 8-2 assume year 2025 demand and the *MWCOG Round 6.4a* scenario or *MWCOG Round 6 high growth* scenario.

Table 8-2: Results for *Round 6.4a* and *Round 6 high growth* scenarios, 2025 demand.

| Results | Round 6.4a | 6.4a Std. deviation | Round 6 high | 6 Std. deviation |
|---:|---:|---:|---:|---:|
| **Reliability, Vulnerability, Resiliency** | | | | |
| Percentage of years with no Potomac deficits | 100 | 0.0 | 100 | 0.0 |
| Maximum number of days in a row of Potomac deficits | 0.0 | 0.0 | 0.0 | 0.0 |
| Number of days in which Potomac deficits must be allocated | 0.0 | 0.0 | 0.0 | 0.0 |
| Maximum amount of deficit allocated in a single day, MGD | 0.0 | 0.0 | 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 | 0.0 | 0.0 |
| Number of Occoquan water supply shortfalls | 0.0 | 0.0 | 0.0 | 0.0 |
| **Percentage of years with restrictions** | | | | |
| Voluntary restrictions | 4.1 | 0 | 5.5 | 0.0 |
| Mandatory restrictions | 0.0 | 0 | 0.3 | 0.6 |
| Emergency restrictions | 0.0 | 0 | 0.0 | 0 |
| **Minimum reservoir storage, BG, (percent full of 2005 storage)** | | | | |
| Little Seneca Reservoir | 2.7 (72) | 0.10 | 2.6 (68) | 0.11 |
| Jennings Randolph water supply account | 4.6 (35) | 0.11 | 3.3 (25) | 0.16 |
| Jennings Randolph water quality account | 1.5 (9) | 0.00 | 1.3 (8) | 0.00 |
| Patuxent Reservoir | 2 (20) | 0.05 | 1.8 (18) | 0.08 |
| Occoquan Reservoir | 1.6 (20) | 0.02 | 1.6 (20) | 0.01 |
| Savage Reservoir | 0.7 (11) | 0.00 | 0.7 (11) | 0.00 |
| Little Seneca Reservoir and Jennings Randolph water supply account, combined | 7.4 (43) | 0.21 | 6.0 (35) | 0.26 |
| Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined | 12 (23) | 0.23 | 10.3 (20) | 0.36 |
| **Miscellaneous** | | | | |
| Number of years in simulation (10/1/1929 – 9/30/2002) | 73 | NA | 73 | NA |
| Average annual demand drought year (1930, MGD) | 587 | 2 | 623 | 2 |
| **Minimum average flow** | | | | |
| Minimum average natural flow summer (1930), MGD | 1,141 | NA | 1,141 | NA |
| Minimum average natural flow fall (1930), MGD | 606 | NA | 606 | NA |
| Min. ave. summer flow downstream of intakes (1930), MGD | 567 | 5 | 550 | 5 |
| Min. average fall flow downstream of intakes (1930), MGD | 245 | 5 | 220 | 9 |

The 1930-1931 drought was the longest drought in the historical record and is the period in which modeled PRRISM reservoir storage was most depleted given 2025 demand. Table 8-2 shows that during a repeat of the worst drought of record and given intermediate estimates (Round 6.4a) of 2025 demand, the minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply is 12.0 BG with a standard deviation of 0.23 BG. The minimum combined storage in Jennings Randolph and Little Seneca reservoirs is 7.4 BG with a standard deviation of 0.21 BG. Other minimum reservoir storages are provided in the table. There are no years of mandatory or emergency restrictions, and voluntary restrictions occur in 4.1 percent of years. There are no years with Potomac deficits and system reliability is 100 percent over the 73-year simulation record.

The average modeled flow downstream of Little Falls given 1930 stream flow is 567 MGD in the summer (June, July, and August) after all water supply withdrawals and other upstream consumptive use and given 2025 levels of demand and the *MWCOG Round 6.4a* scenario. Average flow at Little Falls during the fall (September, October, and November) is 245 MGD.

The *high growth* scenario utilizes the MWCOG high estimates of population growth to develop the demand estimates, as described in Section 5-3. The model run results presented in Table 8-2 correspond to an assumption of year 2025 demand. The model run results correspond to model runs conducted over the entire period of record, October 1, 1929 through September 30, 2002. During a repeat of the worst drought of record and given estimates of 2025 demand, the minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply is 10.3 BG with a standard deviation of 0.36 BG under the *high growth* scenario (Table 8-2). The minimum combined storage in Jennings Randolph and Little Seneca reservoirs is 6.0 BG with a standard deviation of 0.26 BG. Other minimum reservoir storages are provided in the table. Voluntary restrictions occur in 5.5 percent of years and mandatory restrictions occur in 0.3 percent of years. There are no years with emergency restrictions or Potomac deficits and system reliability is 100 percent over the 73-year simulation record.

## 8.4 Differences between results in 2000 and 2005 studies

Minimum combined storage in Jennings Randolph and Little Seneca is 7.4 BG with a standard deviation of 0.21 BG in Table 8-2 given 2025 demand, which compares to a model run result of 3.1 BG in the 2000 demand study given 2020 demand (An increase of 4.3 BG). There are several reasons for this difference, including changes in unit use and the resulting demand forecast, how Jennings Randolph water quality releases are modeled, simulation of Patuxent and Occoquan reservoir operation, and how releases are made from Savage Reservoir. These changes are described in detail below and quantified in Table 8-3.

Table 8-3: Differences between 2000 and 2005 Twenty-Year Demand Forecast and Resource Analyses.

| **Difference between two studies** | | **Change in minimum storage in Jennings Randolph and Little Seneca Reservoirs** |
|---|---|---|
| Changes in demand forecast | The 2000 forecast of 2020 demand is 597 MGD, and the 2005 forecast of 2025 demand is 572 MGD. | +0.4 BG |
| Water quality releases | More sophisticated modeling of Jennings Randolph/Savage water quality operations and releases. | +2.8 BG |
| Operational efficiency | Improved system operations made possible by increases in treatment capacity at Patuxent and Occoquan reservoirs. | +1.3 BG |
| Savage operations | A percentage of the Jennings Randolph Reservoir water supply release is matched by a concurrent water quality release from Savage Reservoir. | +0.6 BG |

A significant difference between the 2000 study and the current one is the decrease in unit use. Lower unit use translates to a lower estimate of future demand. The average annual demand predicted in the 2000 study for the WMA water suppliers in 2020 is 597 MGD. The average annual demand predicted in the current study for the WMA water suppliers in 2025 is 572 MGD, with further adjustments to account for drought year demand. Given the temperature and precipitation conditions from the drought of 1930, an average annual demand of 587 MGD (standard deviation of 3 MGD) is estimated in the current study. The demand of 587 MGD estimated for 2025 in drought years is less than the average annual demand modeled in the 2000 study of 597 MGD.

Water quality operations and releases were modeled differently in the two studies, as described in detail in Section 6-9. The prior study assumed the minimum release from water quality storage whereas the current study models actual water supply operations in the North Branch.

Patuxent and Occoquan reservoir operations during extreme droughts were also modeled differently in the two studies. When a Little Seneca release was necessary in model runs for the current study, the Patuxent and Occoquan reservoir withdrawal rate was temporarily increased. When river flow was higher than needed, the release rates from Patuxent and Occoquan reservoirs were lowered accordingly, allowing their storage to recover. This change in operations is more efficient from a systems perspective and is discussed in more detail in Section 6.4.1. This change in operations is made possible due to the increase in capacity now under construction or planned at both Patuxent and Occoquan treatment plants, allowing for higher rates of treatment. (Treatment rates of 100 MGD and 120 MGD were assumed, respectively).

An additional difference in the two studies includes a change in how releases are modeled from Savage Reservoir. In the current study, the assumption is that when water supply releases are requested from Jennings Randolph Reservoir, a concurrent water quality release is made from Savage Reservoir per the documentation in Section 6-11. This change is consistent with changes in operational procedures between 2000 and the current study.

The net increase in Jennings Randolph and Little Seneca storage that can be attributed to the changes noted above is 5.1 BG, 0.8 BG more than the calculated difference in storage between the end results of the two demand studies of 4.3 BG. Other miscellaneous changes in results are due to different (lower) estimates of wastewater treatment plant return flow rates in the current study (as documented in Prelewicz et al., 2004), lower estimates of reservoir storage capacity in 2025, higher estimates of water loss at the Occoquan plant (the difference between water withdrawn and water that is produced – a rate of 12 percent is assumed in the current study), and other minor factors.

## 8.5 Results for scenario, *No Federal Energy Policy Act of 1992*

The water supply demand forecast for this study assumes that future unit use will be less as a result of water savings due to the effects of the *Federal Energy Policy Act of 1992.* These assumptions are documented in Chapter 4 and in Appendix E. An alternative demand scenario was developed to quantify how the Potomac River and reservoir resources would be affected if future demand was not reduced, i.e., future unit use was assumed to be the same as today's unit use. Assumptions for each water suppliers' unit use are provided in Appendix H. Model run results are presented in Table 8-4.

Model run results suggest that for 2025 and given no reduction in future unit use, the system can meet future demand (Table 8-4). During a repeat of the worst drought of record and given estimates of 2025 demand, the minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply is 10.5 BG with a standard deviation of 0.5 BG under the *No Federal Energy Policy Act of 1992* scenario. The minimum combined storage in Jennings Randolph and Little Seneca reservoirs is 6.3 BG with a standard deviation of 0.29 BG. Voluntary restrictions occur in 5.5 percent of years, and mandatory restrictions occur in some of the simulation runs but not all runs. There are no years with Potomac deficits and system reliability is 100 percent over the 73-year simulation record.

Table 8-4: Results for scenario, *No demand reduction due to Federal Energy Policy Act of 1992*

| | Result | Standard Deviation |
|---|---|---|
| **Reliability, Vulnerability, Resiliency** | | |
| Percentage of years with no Potomac deficits | 100% | 0.0% |
| Maximum number of days in a row of Potomac deficits | - | - |
| Number of days in which Potomac deficits must be allocated | - | - |
| Maximum amount of deficit allocated in a single day, MGD | - | - |
| Average amount of deficit allocated, MGD | - | - |
| Total amount of deficit allocated, MG | - | - |
| Number of Patuxent water supply shortfalls | - | - |
| Number of Occoquan water supply shortfalls | - | - |
| **Percentage of years with restrictions** | | |
| Voluntary restrictions | 5.5% | 0% |
| Mandatory restrictions | 0.3% | 0.6% |
| Emergency restrictions | 0.0% | 0% |
| **Minimum reservoir storage, BG, (percent full)** | | |
| Little Seneca Reservoir | 2.7 (71) | 0.12 |
| Jennings Randolph water supply account | 3.5 (26) | 0.21 |
| Jennings Randolph water quality account | 1.3 (8) | 0.00 |
| Patuxent Reservoir | 1.8 (18) | 0.13 |
| Occoquan Reservoir | 1.6 (20) | 0.02 |
| Savage Reservoir | 0.7 (11) | 0.00 |
| Little Seneca Reservoir and Jennings Randolph water supply account, combined | 6.3 (37) | 0.29 |
| Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined | 10.5 (20) | 0.50 |
| **Miscellaneous** | | |
| Number of years in simulation (10/1/1929 – 9/30/2002) | 73 | NA |
| Average annual demand drought year (1930, MGD) | 631 | 3 |
| **Minimum average flow** | | |
| Minimum average natural flow summer (1930), MGD | 1,141 | NA |
| Minimum average natural flow fall (1930), MGD | 606 | NA |
| Minimum average summer flow downstream of intakes (1930), MGD | 552 | 6 |
| Minimum average fall flow downstream of intakes (1930), MGD | 229 | 10 |

## 8.6 Results for *climate change* scenario

Climate change impacts projected for the mid-Atlantic region are modeled for the year 2025, based on the assumptions provided in Chapter 4. Adjustments are made to temperature and precipitation records within PRRISM to model the effect on regional water demand during droughts. To explore the sensitivity of the system to potential changes in resources, Potomac stream flow and reservoir inflow is reduced by 10 percent during the months of July through October, the time period in which reservoir releases are most likely to occur. The *MWCOG Round 6 high growth* scenario was assumed.

Table 8-5: PRRISM results for *climate change* scenario, 2025 demand.

| **Results** | | **Standard Deviation** |
|---|---|---|
| **Reliability, Vulnerability, Resiliency** | | |
| Percentage of years without Potomac deficits | 100 | 0.0 |
| Maximum number of days in a row of Potomac deficits | - | - |
| Number of days in which Potomac deficits must be allocated | - | - |
| Maximum amount of deficit allocated in a single day, MGD | - | - |
| Average amount of deficit allocated, MGD | - | - |
| Total amount of deficit allocated, MG | - | - |
| Number of Patuxent water supply shortfalls | - | - |
| Number of Occoquan water supply shortfalls | - | - |
| **Percentage of years with restrictions** | | |
| Voluntary restrictions | 7.0 | 0.4 |
| Mandatory restrictions | 4.1 | 0.0 |
| Emergency restrictions | 0.0 | 0.0 |
| **Minimum reservoir storage, BG, (percent full of 2005 storage)** | | |
| Little Seneca Reservoir | 1.9 (49) | 0.15 |
| Jennings Randolph water supply account | 1.5 (11) | 0.16 |
| Jennings Randolph water quality account | 1.4 (8) | 0.00 |
| Patuxent Reservoir | 1.2 (12) | 0.11 |
| Occoquan Reservoir | 1.3 (16) | 0.09 |
| Savage Reservoir | 0.7 (11) | 0.00 |
| Little Seneca Reservoir and Jennings Randolph water supply account, combined | 3.4 (20) | 0.30 |
| Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined | 6.2 (12) | 0.43 |
| **Miscellaneous** | | |
| Number of years in simulation (10/1/1929 – 9/30/2002) | 73 | NA |
| Average annual demand drought year (1930, MGD) | 626 | 3 |
| **Minimum average flow** | | |
| Minimum average natural flow summer (1930), MGD | 1,078 | NA |
| Minimum average natural flow fall (1930), MGD | 566 | NA |
| Minimum average summer flow downstream of intakes (1930), MGD | 500 | 5 |
| Minimum average fall flow downstream of intakes (1930), MGD | 207 | 4 |

Model run results suggest that for 2025 and given regional climate change scenarios, the system can meet future demand (Table 8-5). During a repeat of the worst drought of record and given high estimates of 2025 demand, the minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply is 6.2 BG with a standard deviation of 0.43 BG under the *climate change* scenario. The minimum combined storage in Jennings Randolph and Little Seneca reservoirs is 3.4 BG with a standard deviation of 0.3 BG Voluntary restrictions occur in 7.0 percent of years, and mandatory restrictions occur in 4.1 percent of years. There are no years with Potomac deficits and system reliability is 100 percent over the 73-year simulation record.

*These results must be interpreted with extreme caution.* The climate change research is of high uncertainty as applied to the Potomac basin. Regional climate research is oriented towards changes in average conditions, when precisely what is needed is an assessment of changes in extreme drought conditions. While the regional research suggests possible increases in stream flow resources *on average* it does not describe potential changes in resources during droughts. Furthermore, the reliability of the climate change research with regards to changes in stream flow resources is described as low (see Section 4-13). Therefore, a reduction in stream flow resources of ten percent was chosen as a sensitivity analysis and is entirely arbitrary.

## 8.7 Results for *2045 demand* scenario

Although the study horizon is through 2025, the forecast was extended to 2045 by assuming similar rates of growth in order to assess the response of the system to higher demand. The year 2045 was arbitrarily selected and represents a doubling of the required twenty year demand forecast. The model run results presented in Table 8-6 correspond to an assumption of year 2045 demand and *MWCOG Round 6.4a* estimates of growth.

Table 8-2 shows that the minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply is 6.7 BG with a standard deviation of 0.32 BG. The minimum combined storage in Jennings Randolph and Little Seneca reservoirs is 3.0 BG with a standard deviation of 0.28 BG Other minimum reservoir storages are provided in the table. Voluntary restrictions occur in 5.5 percent of years, mandatory restrictions in 4.1 percent of years, and emergency restrictions in no years. There are no years with Potomac deficits and system reliability is 100 percent over the 73-year simulation record.

Table 8-6: PRRISM results for *2045 demand* scenario, given MWCOG Round 6.4a forecast of growth.

| Results | | Standard Deviation |
|---|---|---|
| **Reliability, Vulnerability, Resiliency** | | |
| Percentage of years with no Potomac deficits | 100 | 0.0 |
| Maximum number of days in a row of Potomac deficits | - | - |
| Number of days in which Potomac deficits must be allocated | - | - |
| Maximum amount of deficit allocated in a single day, MGD | - | - |
| Average amount of deficit allocated, MGD | - | - |
| Total amount of deficit allocated, MG | - | - |
| Number of Patuxent water supply shortfalls | - | - |
| Number of Occoquan water supply shortfalls | - | - |
| **Percentage of years with restrictions** | | |
| Voluntary restrictions | 5.5 | 0 |
| Mandatory restrictions | 4.1 | 0 |
| Emergency restrictions | 0.0 | 0 |
| **Minimum reservoir storage, BG, (percent full of 2005 storage)** | | |
| Little Seneca Reservoir | 1.8 (48) | 0.13 |
| Jennings Randolph water supply account | 1.1 (9) | 0.16 |
| Jennings Randolph water quality account | 1.7 (11) | 0.00 |
| Patuxent Reservoir | 1.8 (18) | 0.07 |
| Occoquan Reservoir | 0.9 (12) | 0.07 |
| Savage Reservoir | 0.7 (11) | 0.00 |
| Little Seneca Reservoir and Jennings Randolph water supply account, combined | 3.0 (18) | 0.28 |
| Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined | 6.7 (13) | 0.32 |
| **Miscellaneous** | | |
| Number of years in simulation (10/1/1929 – 9/30/2002) | 73 | 0 |
| Average annual demand drought year (1930, MGD) | 658 | 2 |
| **Minimum average flow** | | |
| Minimum average natural flow summer (1930), MGD | 1,141 | 0 |
| Minimum average natural flow fall (1930), MGD | 606 | 0 |
| Minimum average summer flow downstream of intakes (1930), MGD | 520 | 7 |
| Minimum average fall flow downstream of intakes (1930), MGD | 225 | 4 |

### 8.8 Results for *extended stream flow* scenario – year 2025 demand

Recent evidence in the western United States shows that the severity of future droughts is not limited to the historical record. Therefore a 500-year synthetic stream flow record was developed in order to quantify the response of the Potomac system to droughts more severe than the historical record. The length (500 years) of the extended stream flow record was arbitrarily selected. The stream flow record developed preserves the statistical properties of the historical stream flow data set and represents a statistically feasible flow regime. The results must be interpreted with caution, as there is some uncertainty associated with the method and actual events may be worse than the simulated drought. The documentation of the development of the extended stream flow record is provided in Section 6-3. The model run results presented in correspond to an assumption of year 2025 demand and the MWCOG Round 6.4a forecast of growth.

Given a repeat of the five-hundred years of simulated stream flow, the Potomac River and reservoir system is able to meet anticipated 2025 demand in all but approximately six days. The average shortfall over the six days is 41 MGD (standard deviation of 28 MGD), a total shortfall of 0.33 bg(standard deviation of 0.34 bg), and a maximum shortfall of 90 MGD (standard deviation of 78 MGD) (Table 8-7). When the existing resources are insufficient to meet demand, the suppliers would use existing agreements to place restrictions on demand and allocate available resources.

Since temperature and precipitation records were unavailable for the extended stream flow simulation, the pattern of demand associated with the 1930 drought of record was simulated along with a randomly generated component of demand.

Section 8.9 examines the reliability of the Potomac system to slightly lower demand (2020) and a similar stream flow regime.

### 8.9 Results for *extended stream flow* scenario – year 2020 demand

Lower demand associated with 2020 was executed as a continued test of the system's reliability. Analysis illustrates the system is adequate to meet 2020 demand without any supply shortfalls, although system storage is significantly depleted and there is a 0.4 percent probability in any given year of experiencing emergency restrictions (Table 8-8). A simulation of 2020 demand over the 500 year stochastic stream flow record results in a minimum combined water supply storage in Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply account of 2.0 BG with a standard deviation of 0.16 BG. Voluntary restrictions occur in 3.4 percent of years, mandatory restrictions in 1.1 percent of years, and emergency restrictions in 0.6 percent of years. There are no years with Potomac deficits and system reliability is 100 percent over the 500-year simulation record.

Table 8-7: PRRISM results for *extended stream flow* scenario, 2025 demand.

| Results | Average | Standard Deviation |
|---|---|---|
| **Reliability, Vulnerability, Resiliency** | | |
| Percentage of years with no Potomac deficits | 99.8 | 0.1 |
| Maximum number of days in a row of Potomac deficits | 3 | 2 |
| Number of days in which Potomac deficits must be allocated | 6 | 4 |
| Maximum amount of deficit allocated in a single day, MGD | 90 | 78 |
| Average amount of deficit allocated, MGD | 41 | 28 |
| Total amount of deficit allocated, MG | 333 | 342 |
| Number of Patuxent water supply shortfalls | - | - |
| Number of Occoquan water supply shortfalls | - | - |
| **Percentage of years with restrictions** | | |
| Voluntary restrictions | 2.5 | 0.2 |
| Mandatory restrictions | 1.0 | 0.1 |
| Emergency restrictions | 0.3 | 0 |
| **Minimum reservoir storage, BG, (percent full of 2005 storage)** | | |
| Little Seneca Reservoir | 0.5 (14) | 0.19 |
| Jennings Randolph water supply account | 0 (0) | 0.01 |
| Jennings Randolph water quality account | 1.4 (8) | 0.06 |
| Patuxent Reservoir | 1.5 (15) | 0.10 |
| Occoquan Reservoir | 0.5 (6) | 0.08 |
| Savage Reservoir | 0.8 (13) | 0.00 |
| Little Seneca Reservoir and Jennings Randolph water supply account, combined | 0.8 (5) | 0.27 |
| Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined | 3.2 (6) | 0.26 |
| **Miscellaneous** | | |
| Number of years in simulation | 500 | 0 |
| Average annual demand drought year, MGD | 587 | 2 |

Table 8-8: PRRISM results for *extended stream flow* scenario, 2020 demand.

| **Results** | | **Standard Deviation** |
|---|---|---|
| **Reliability, Vulnerability, Resiliency** | | |
| Percentage of years with no Potomac deficits | 100 | 0.0 |
| Maximum number of days in a row of Potomac deficits | - | - |
| Number of days in which Potomac deficits must be allocated | - | - |
| Maximum amount of deficit allocated in a single day, MGD | - | - |
| Average amount of deficit allocated, MGD | - | - |
| Total amount of deficit allocated, MG | - | - |
| Number of Patuxent water supply shortfalls | - | - |
| Number of Occoquan water supply shortfalls | - | - |
| **Percentage of years with restrictions** | | |
| Voluntary restrictions | 3.4 | 0 |
| Mandatory restrictions | 1.1 | 0 |
| Emergency restrictions | 0.6 | 0 |
| **Minimum reservoir storage, BG, (percent full of 2005 storage)** | | |
| Little Seneca Reservoir | 0.0 (0) | 0.00 |
| Jennings Randolph water supply account | 0.0 (0) | 0.00 |
| Jennings Randolph water quality account | 1.2 (7) | 0.00 |
| Patuxent Reservoir | 1.0 (10) | 0.06 |
| Occoquan Reservoir | 0.1(1) | 0.08 |
| Savage Reservoir | 0.8 (13) | 0.00 |
| Little Seneca Reservoir and Jennings Randolph water supply account, combined | 0.0 (0) | 0.00 |
| Patuxent, Occoquan, and Little Seneca reservoirs and Jennings Randolph water supply, combined | 2.0(6) | 0.16 |
| **Miscellaneous** | | |
| Number of years in simulation (10/1/1929 – 9/30/2002) | 500 | 0 |
| Average annual demand drought year (1930, MGD) | 568 | 3 |
| **Minimum average flow** | | |
| Minimum average natural flow summer (1930), MGD | 795 | NA |
| Minimum average natural flow fall (1930), MGD | 525 | NA |
| Minimum average summer flow downstream of intakes (1930), MGD | 398 | 4 |
| Minimum average fall flow downstream of intakes (1930), MGD | 236 | 3 |

## 8.10 Low flow frequency analysis

A low flow frequency analysis was conducted to show the effect of increasing demand on low flow in the Potomac. Flow during the drought of 1930 is shown in Figure 8-1 corresponding to the *MWCOG Round 6.4a* scenario. The natural flow is the flow that would have occurred without upstream reservoir regulation, upstream consumptive use, return flows from wastewater treatment plants, or upstream reservoirs.

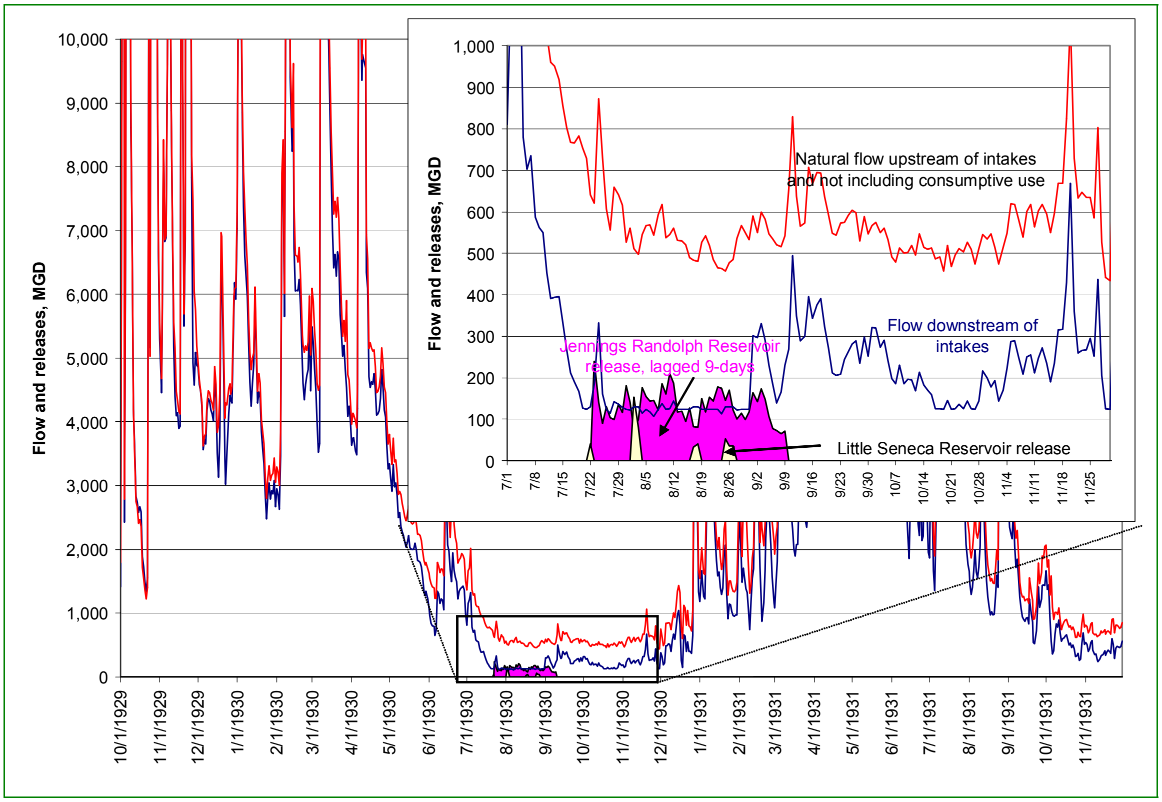



Figure 8-1: Flow at Little Falls and reservoir releases given *MWCOG Round 6.4a* scenario and a repeat of meteorological conditions from 1930.

Figure 8-2 compares the natural flow regime and the 2005 and 2025 flow regimes downstream of the Potomac intakes for fifth percentile flows. Though the difference between the natural flow regime and 2005 regime is evident, these results also illustrate the relatively small impact growing demand has on additional changes to the flow regime, as can be seen by comparing the 2025 flow regime to the 2005 flow regime.

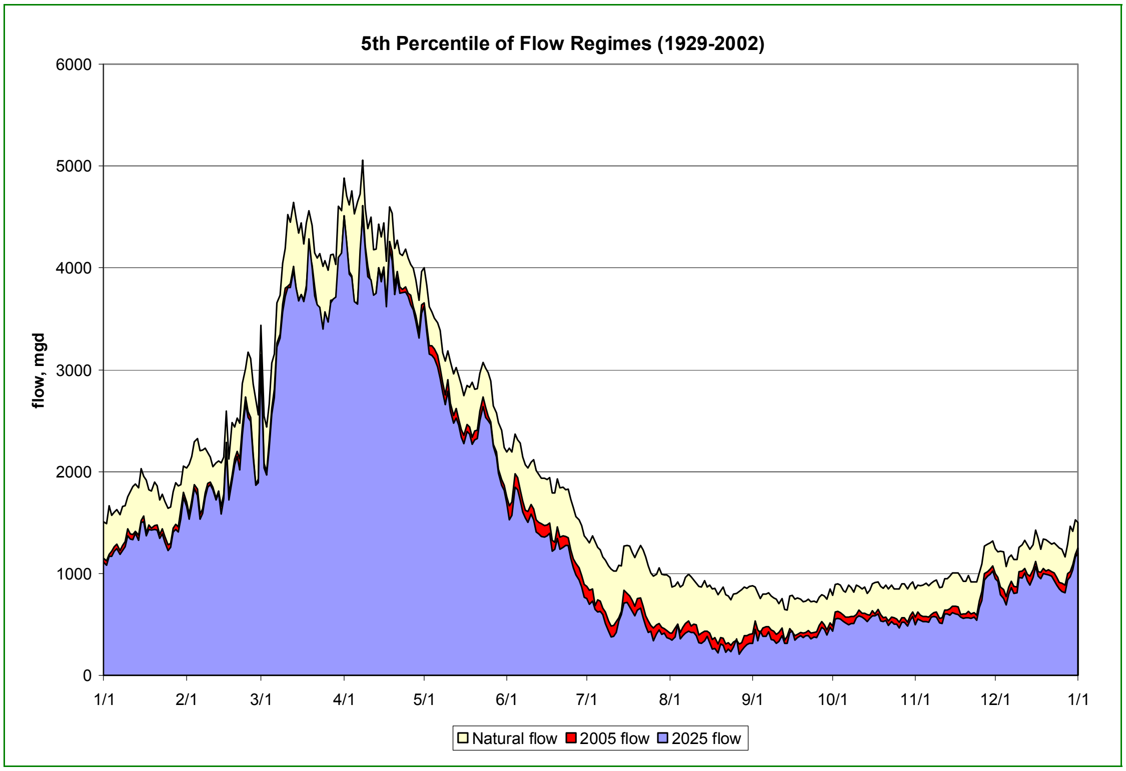



Figure 8-2: Fifth percentile of the natural, 2005, and 2025 flow regimes. (Natural flow represents flow at Little Falls without water withdrawals, reservoir regulation or other human alteration of flow. 2005 and 2025 flow regimes represent flows near Little Falls downstream of the intakes after upstream consumptive use, withdrawals, and other human alteration of flow.)

During the months of peak water demand, June through August, a similar trend is observed. Flows are significantly lower during 2005, as compared to the natural flow regime but show minimal, decrease from 2005 to 2025. The difference appears greatest during the month of July, and smallest during the month of June. Figures Figure 8-3, Figure 8-4, and Figure 8-5 display average monthly flows for summer months for natural, 2005, and 2025 flow regimes downstream of Little Falls.

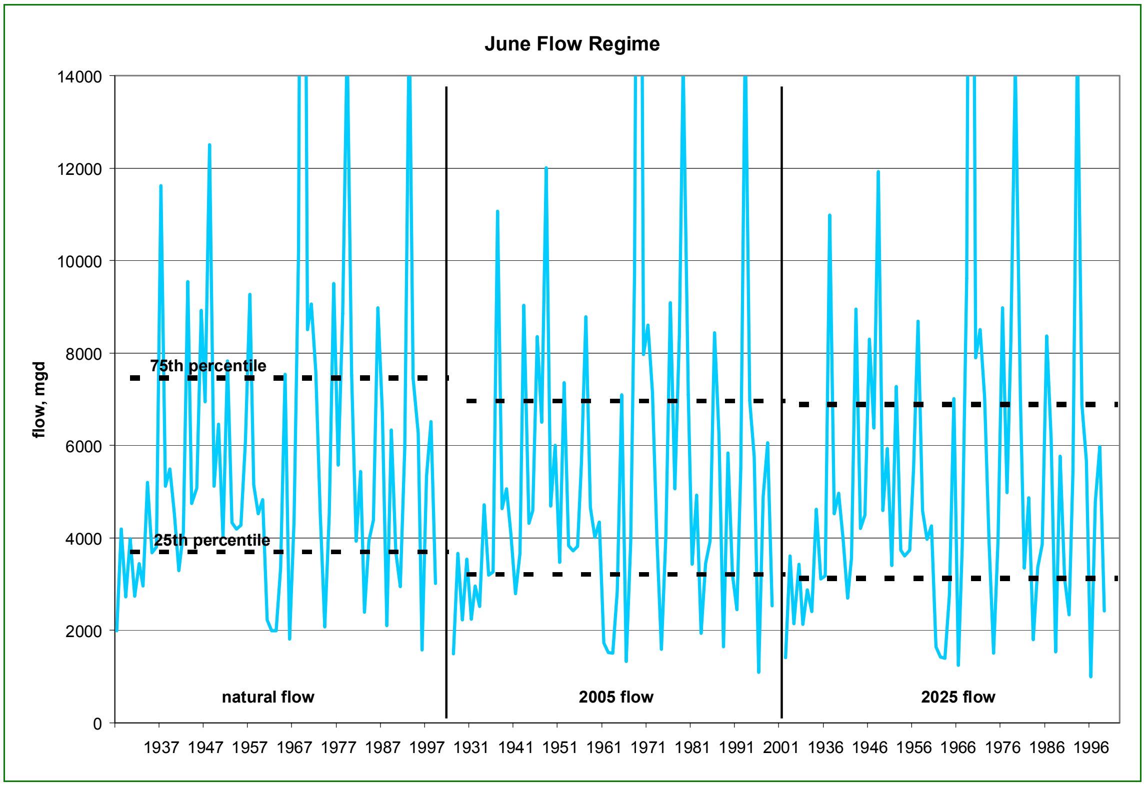



Figure 8-3: June stream flow for natural, 2005, and 2025 flow downstream of Little Falls.

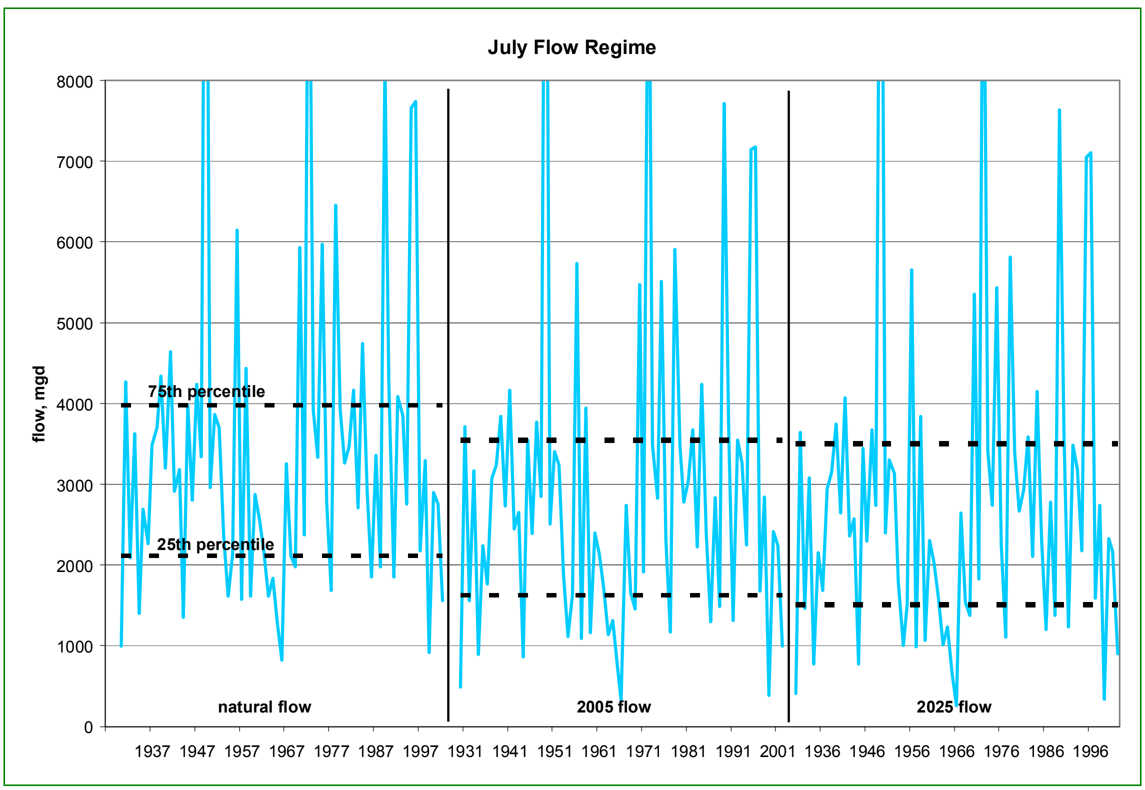



Figure 8-4: July stream flow for natural, 2005, and 2025 flow downstream of Little Falls.

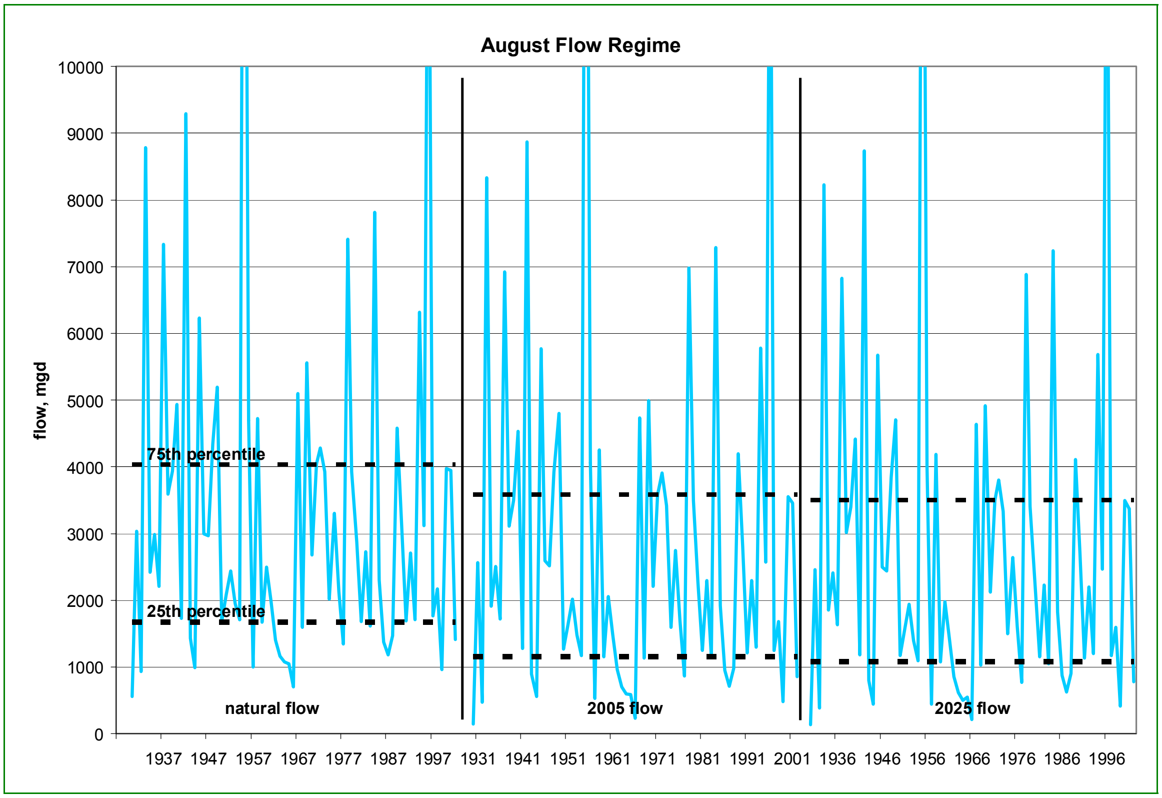



Figure 8-5: August stream flow for natural, 2005, and 2025 flow downstream of Little Falls.

Of note is the scale of decrease between the historic natural flows and the flow regimes of 2005 and 2025. The difference between the 25$^{th}$ percentile of the natural flows and 2005 flow for the month of July is approximately 489 mgd. Over the 20-year period between 2005 and 2025, the 25$^{th}$ percentile of the flow drops about 116 mgd from 2005 to 2025.

Also of interest is that the frequency of low flows in does not increase from 2000 to 2025. Average Potomac withdrawals are approximately 0.35 billion gallons per day (350 MGD), which compares to a much higher median flow of approximately 7 billion gallons per day. Relatively small increases in withdrawals do not increase the frequency of low flows significantly as shown in Figures Figure 8-3, Figure 8-4, and Figure 8-5.

Reservoir releases increase flow in the 200-mile stretch of the Potomac River upstream of the water supply intakes during low flow periods as compared to natural stream flow.

## 8.11 Conclusions

*The current assessment of future water demand and water supply reliability for the metropolitan Washington area demonstrates that even with a high growth (MWCOG Round 6 high growth scenario), the water supply system developed twenty-five years ago is adequate to meet 2025 demand under a repeat of the worst meteorological and stream flow conditions on record. Furthermore, the system is able to meet estimated future water supply demand in 2045 given a repeat of the same drought conditions.*

*Results of the current resource analysis show more storage remaining in system reservoirs under a repeat of the drought of record than those of the demand and resource study conducted five years ago.*

*Estimates of future water demand are reduced in this study to account for water savings due to the Federal Energy Policy Act of 1992. An alternative scenario was developed to explore how resources would be affected if there was no such reduction in future unit use. Results showed that the water supply system is adequate to meet 2025 demand under a repeat of the worst meteorological and stream flow conditions on record.*

*Results of a simulation over a drought worse than the drought of record (i.e., over a 500-hundred year stream flow simulation) show that the system would be unable to meet all demand for approximately six days during one year of the 500-year simulation. The average shortfall over the six days was 41 MGD with an average total shortfall of 0.3 billion gallons and an average maximum shortfall of 90 MGD. Lower demand associated with 2020 was examined. In that case, the system was adequate to meet 2020 demand without any supply shortfalls, although system storage was significantly depleted and emergency restrictions were required.* All demand cannot be met with available stream flow when Little Seneca Reservoir and Jennings Randolph reservoirs are empty. When the existing resources are insufficient to meet demand, the suppliers would use existing agreements to place restrictions on demand and allocate available resources. The length (500 years) of the extended stream flow record was arbitrarily selected. The stream flow record developed preserves the statistical properties of the historical stream flow data set and represents a statistically feasible flow regime. The results must be interpreted with caution, as there is some uncertainty associated with the method and actual events may be worse than the simulated drought.

*An assessment of potential impacts of climate change included the effects of potential changes to water demand due to temperature changes, and a sensitivity analysis which reduced stream flow. The results suggest that the water supply system maintains a high degree of reliability over the 20-year forecast horizon of this study. It should be noted that the degree of uncertainty associated with the climate change analysis conducted for this study is high.* While climate change research for the mid-Atlantic basin suggests that the long-term trend is towards warmer and wetter conditions, these conclusions must be interpreted with caution from the perspective of water supply management. An increase in average annual precipitation does not mean that every year will be wetter than normal—during dry years, it may be drier than historical droughts.

*Flows are lower in the Potomac downstream of Little Falls as compared to natural conditions. Growth in demand over the next 20 years will not significantly change the frequency of low flows but will lower the magnitude of those flows that are already low. Reservoir releases increase flow in the 200-mile stretch of the Potomac River upstream of the water supply intakes during low flows as compared to natural conditions.* Low flow statistics were examined. The median flow in the river is approximately 7 billion gallons per day. This flow rate is much higher than average Potomac withdrawals of approximately 0.35 billion gallons per day so relatively small increases in withdrawals do not increase the frequency of low flows significantly. Reservoir releases increase flow in the 200-mile stretch of the Potomac River upstream of the water supply intakes during low flow periods as compared to natural stream flow.

*Per-household water use rates have changed significantly over the past 15 years, declining approximately 20 percent across single-family households from 1990 to 2000, and another 15 percent from 2000 to 2005.* These declining water use rates may be due to several factors. A poll by a MWCOG study shows the region's residents support conservation, with 80-90 percent of respondents describing conservation as "very" or "somewhat important." Each of the suppliers has programs in place to encourage moderation in water use. For example, WSSC's rate structure and plumbing code are both credited with reducing recent growth in demand. In the near term, the WMA water suppliers are addressing demand management through participation in the regional Wise Water Use Campaign to encourage year-round conservation. How much of the change in water use is due to these conservation programs is unknown. Some changes may also be due to changes in plumbing codes, social attitudes towards water use, availability of low energy and water use appliances, the *Energy Policy Act of 1992*, or other factors.

*Water use rates and regional growth projections in the WMA may continue to change rapidly, suggesting that conducting the study regularly is of considerable value.* The selection of the five-year interval for the current study provides multiple additional benefits. It allows regular updates and incorporation of recent demographic forecasts, and increases visibility and understanding of the adequacy of the region's water resources. It provides adequate time to conduct research on the physical system and incorporate modifications in subsequent studies. It allows for improvements in system operation to be explored and implemented as low-cost alternatives to construction of future resources.

*The current study results suggest that there is time available to assess future water supply alternatives, although droughts worse than the historical drought of record could result in emergency restrictions and/or shortages in the 2020 to 2025 time frame. The need for additional supplies may not materialize as quickly if further operational improvements are made and/or declines in unit use continue.* For the longer term, structural and non-structural methods can be explored to meet future increases in demand. Operational improvements show promise, and can continue to be refined through annual drought exercises. Potential structural enhancements to supply include the use of large rock quarries that may be available in future years for water storage. While analysis of the structural measures has received some recent attention, the non-structural ideas are the main focus of ongoing and recent efforts.

## 8.12 Recommendations

The following recommendations are suggested for future research:

- *The high degree of uncertainty associated with climate change research in the Potomac basin can be addressed through more focused study, which attempts to clarify the potential impact of climate change on extreme hydrologic events such as drought.* The existing regional climate research is oriented towards changes in average conditions, when precisely what is needed is an assessment of changes in extreme conditions. For these reasons, additional study is warranted to establish potential changes in stream flow during extreme conditions (drought) under potential climate-change scenarios.

- *The model used to predict demand that is based on weather and other variables can be further improved for operational and planning applications.* In addition to the demand model, it is important to continue to maintain and refine the existing PRRISM model as knowledge and understanding of the Potomac system improves.

- *Continue to refine operational procedures in order to maximize water supply reliability.* This will result in two benefits. One, operational drought readiness will be improved. Second, operational improvements can offset growth in demand, perhaps delaying the time that new resources are needed.

- *Refine estimates of consumptive use in the basin.* Estimates of upstream consumptive use are highly uncertain, so additional study is warranted to check the accuracy of these estimates.

- *Explore the effects of changing historical land use on hydrology.* The Potomac basin is significantly more forested now than it was during the drought of 1930. Additional study can explore how land use changes affect low flow hydrology.

# 9 LITERATURE CITED

102D Congress, 2d session. 1992. Energy Policy Act of 1992. Conference Report. US House of Representatives. Report 102-1018. U.S. Government Printing Office, Washington, DC, October 5, 1992.

Aly, A.H., N.W. Wanakule, 2004. Short-Term Forecasting for Urban Water Consumption. Journal of Water Resources Planning and Management, September/October: 405-410.

Boland, J., 1997. Assessing Urban Water Use and the Role of Water Conservation Measures Under Climate Uncertainty. Climatic Change, 37: 157-176.

The City of Frederick Water Conservation and Drought Response Plan, 2002. Appendix D. April 4, 2002.

Crane, R.G., Hewitson, B.C., 1998. Doubled CO2 precipitation changes for the Susquehanna Basin: downscaling from the Genesis General Circulation Model. Int. J. Climatology, 18: 65-76.

DeOreo, W.B., A. Dieteman, T. Skeel, P. Mayer, et. al., 2001. Retrofit Realities. Journal American Water Works Association, March.

DeOreo, W.B., J.O. Lander and P.W. Mayer, Evaluating Conservation Retrofit Savings with Precise End Use Data. In *Proceedings of the 1996 Annual Conference,* American Water Works Association, Heatherwood, Colorado, June 1996

DeOreo, W.B., J.P. Heaney, and P.W. Mayer. 1996. Flow Trace Analysis to Assess Water Use. *Journal American Water Works Association.* 88(1):79-90.

Dziegielewski, B, W.Y. Davis, P.W. Mayer, Existing Efficiencies in Residential Indoor Water Use. In *Proceedings of the Conserv99 Annual Conference*, American Water Works Association, Monterey, California, January 31- February 3, 1999

Franklin, S.L., D.R. Maidment, 1897. An Evaluation of Weekly and Monthly time Series Forecasts of Municipal Water Use, 22 (4): 611-621.

Frederick, K.D., and P.H. Gleick, 1999: Water and Global Climate Change: Potential Impacts on U.S. Water Resources. Pew Center on Global Climate Change, Arlington, VA.

Gardener, E.V., 2004. Denver: Surviving the Worst Drought in 300 Years. Presentation at *2004 Water Sources Conference*, American Water Works Association and Water Environment Federation, Austin, Texas. Jan 11-14, 2004.

Grygier, Jan C. and Jery R. Stedinger, SPIGOT: A Synthetic Streamflow Generation Software Package Technical Description, Version 2.6, Cornell University, December 1990.

Grygier, Jan C. and Jery R. Stedinger, SPIGOT: A Synthetic Streamflow Generation Software Package User's Manual, Version 2.7, Cornell Univesity, February 2001.

Hagen, E.R., R.C. Steiner, 2000. Year 2000 Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area, Interstate Commission on the Potomac River Basin, ICPRB 00-6, Rockville, Maryland.

Hagen, E. R., and R.C. Steiner, 1999. *Little Seneca Reservoir "Natural" Daily Inflow Development*. Interstate Commission on the Potomac River Basin. ICPRB report 99-3. Rockville, MD.

Hagen, E. R., and R.C. Steiner, 1998a. *Occoquan Reservoir Watershed: "Natural" Daily Inflow Development.* Interstate Commission on the Potomac River Basin. ICPRB report 98-3. Rockville, MD.

Hagen, E.R., R.C. Steiner, and J.L. Ducnuigeen, 1998b. *Jennings Randolph Reservoir Watershed: "Natural" Daily Inflow Development.* Interstate Commission on the Potomac River Basin. ICPRB report 98-5. Rockville, MD.

Hahn, M.A., R.N. Palmer, 2002. Climate Change Impacts on Municipal Supplies: When Are Capital Investments Justified? In *EWRI Proceedings, 2002 Conference on Water Resources Planning and Management*, Roanoake, Virginia. May 19-22, 2002.

Hashimoto, T., J.R. Stedinger, and D.P. Loucks, 1982. Reliability, Resiliency, and Vulnerability Criteria for Water Resources System Performance Evaluation, Water Resources Research, Vol. 18, No. 1, 1982.

Holmes, K.J., R.C. Steiner, 1990. Twenty-Year Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area, Interstate Commission on the Potomac River Basin, ICPRB 90-5, Rockville, Maryland.

Hurd, B.H., N. Leary, R. Jones, and J.B. Smith. 1999. "Relative regional vulnerability of water resources to climate change." Journal of the American Water Resources Association 35(6): 1399-1410.

Imagine That!, 2005. Object oriented software. San Jose, CA. www.imaginethatinc.com.

Jenkins, G.S., Barron, E.J., 1997. Global climate model and coupled regional climate model simulations over the eastern United States: GENESIS and RegCM2 simulations. Global and Planetary Change 15, 3–32.

Kiang, J. E., E.R. Hagen, 2004. In *Proceedings of the World Water and Environmental Resources Congress, Critical Transitions in Water and Environmental Resources Management*, American Society of Civil Engineers, Salt Lake City, Utah. June 27-July 1, 2004.

Lins, H.F. 2005. Stream flow Trends in the United States, U.S. Department of the Interior, United States Geological Survey. Fact Sheet 2005-3017. March, 2005.

Low Flow Allocation Agreement, 1978. Signatories include: the Secretary of the Army for the United States of America, the Governor for the State of Maryland, the Governor for the Commonwealth of Virginia, the Mayor for the District of Columbia, the Chairman of the Washington Suburban Sanitary Commission, and the Chairman of the Fairfax County Water Authority.

Loucks, D. P., J.R. Stedinger, D.A. Haith, 1981. Water Resources Planning and Analysis, Prentice Hall, Englewood Cliffs, New Jersey, 278 pp.

Madrikas, S, S.C. Wheelwright, R.J. Hyndman, 2001. Forecasting, Methods and Applications, 3rd ed. John Wiley & Sons, Inc. New York.

Maidment, D.R., S.P. Miaou, 1986. Daily Water Use in Nine Cities. Water Resources Research, 22(6):845-851.

Maidment, D.R., S.P. Miaou, M.M. Crawford, 1985. Transfer Function Models of Daily Urban Water Use. Water Resources Research, 21 (4): 425-432.

Maryland Department of Natural Resources, 1981. Potomac River Environmental Flow-By Study. Maryland Department of Natural Resources. Annapolis, MD.

Maryland Department of Natural Resources, 2003. Habitat Assessment of the Potomac River from Little Falls to Seneca Pool. Maryland Power Plant Research Program, Final Document # PPAD-03-1. Annapolis, Maryland.

Mathsoft, 2000. S-Plus®2000 statistics and graphics software package. Seattle, Washington.

Mayer, P.W., W.B. DeOreo, E.M. Opitz, J.C. Kiefer, W.Y. Davis, B. Dziegielewski, J.O. Nelson, 1999. Residential End Uses of Water. AWWA Research Foundation. Denver, Colorado. 310 p.

Metropolitan Washington Council of Governments, 2004. Round 6.4A Cooperative Forecasting: Employment, Population, and Household Forecasts to 2030 by Traffic Analysis Zone. Metropolitan Washington Council of Governments, Publication number 20048202. Washington, D.C.

Metropolitan Washington Council of Governments, 2003. Growth Trends to 2030: Cooperative Forecasting in the Washington Region. Metropolitan Council of Governments, Publication number 23810. Washington, D.C.

Metropolitan Washington Council of Governments, NuStats. May, 2002. *Water Conservation Market Survey Final Report*. NuStats publication, Alexandria, Virginia.

Metropolitan Washington Council of Governments, 1998. Round 6a Cooperative Forecasting: Population, Employment and Household Forecasts to 2020 by COG Analysis Zone. Metropolitan Washington Council of Governments, Publication number 98823. Washington, D.C.

Metropolitan Washington Council of Governments, 1994. Cooperative Forecasting: Round V Technical Report –1994. Metropolitan Washington Council of Governments, Publication number 96809. Washington, D.C.

Metropolitan Washington Council of Governments, 1988. Cooperative Forecasting: Round IV Technical Report – 1988. Metropolitan Washington Council of Governments, Washington, D.C.

MWCOG Board Task Force on Regional Water Supply Issues, 2000. Metropolitan Washington Water Supply and Drought Awareness Response Plan: Potomac River System. Metropolitan Washington Council of Governments, Publication number 20703. Washington, D.C.

MWCOG, NuStats (Zmud, M., Research Director), 2002. Water Conservation Market Survey Final Report. Nustats publication for MWCOG.

Mid-Atlantic Regional Assessment Team, 2000. Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change. Penn State University publication for the U.S. Global Change Research Program.

Mullusky, M.G., Schwartz, S.S., Steiner, R.C., 1996. 1995 Water Demand Forecast and Resource Availability Analysis for the Washington Metropolitan Area, Interstate Commission on the Potomac River Basin, ICPRB 95-6, Rockville, Maryland.

Najjar, R. G., 1999. The water balance of the Susquehanna River Basin and its response to climate change. Journal of Hydrology, 219: 7-19.

Najjar, R.G., H.A. Walker, P.J. Anderson, E.J. Barron, R. Bord, J. Gibson, V.S. Kennedy, C.G. Knight, P. Megonigal, R. O'Connor, C.D. Polsky, N.P. Psuty, B. Richards, L.G. Sorenson, E. Steele, and R.S. Swanson, 2000. The potential impacts of climate change on the Mid-Atlantic Coastal Region. Climate Research, 14: 219-233.

National Research Council, 1984. Water for the Future of the Nation's Capital Area 1984: A Review of the U.S. Army Corps of Engineers Metropolitan Washington Area Water Supply Study. Water Science and Technology Board, National Academy Press, Washington D.C.

Neff R., H. Chang, C.G. Knight, R.G. Najjar, B. Yarnal and H.A. Walker, 2000. Impact of climate variation and change on Mid-Atlantic Region hydrology and water resources. Climate Research, 14: 207-218.

Osborn, C.T., J.E. Schefter, and L. Shabman, 1986. The Accuracy of Water Use Forecasts: Evaluation and Implications, 22 (1): 101-109.

Palmer, R.N., J.R. Wright, J.A. Smith, J.L. Cohon, and C.S. ReVelle, 1979. Policy Analysis of Reservoir Operations in the Potomac River Basin. Volume I. Executive Summary. Water Resources Series Technical Report No. 59, University of Maryland, College Park, Maryland.

Palmer, R.N., J.A. Smith, J.L. Cohon, and C.S. ReVelle, 1982. Reservoir management in the Potomac River Basin. Journal of Water Resources Planning and Management, 108(1):47-66.

Prelewicz, G. J., E.R. Hagen, A. Kame'enui, 2004. The Potomac Reservoir and River System Model (PRRISM): A User's Guide and Model Documentation. Interstate Commission on the Potomac River Basin, ICPRB 04-03, Rockville, Maryland.

Potomac Basin Reporter, 1982. Interstate Commission on the Potomac River Basin, Vol. 38, No. 4, April-May, 1982.

Sheer, D.P., 1977. A Perspective on the Washington Metropolitan Area Water Supply Problem, Interstate Commission on the Potomac River Basin, ICPRB M-6, Rockville, Maryland.

Sheer, D.P., P.W. Eastman, 1980. Interstate Commission on the Potomac River Basin and Washington Metro Water Management, Journal of Water Resources Planning and Management, 106, 303-317.

Sheer, D.P, 1983. Assured Water Supply for the Washington Metropolitan Area, Interstate Commission on the Potomac River Basin, ICPRB M-14, Rockville, Maryland.

Smith, J. A., 1988. A Model of Daily Municipal Water Use for Short-Term Forecasting, Water Resources Research, 24(2), 201 – 206.

Smith, J. A., 1989. Yield analysis for the Washington D. C. Metropolitan Area water supply system, Journal of Water Resources Planning and Management, 115(2), 230 - 242.

Steiner, R.C., 1984. Short-Term Forecasting of Municipal Water Use, PhD Dissertation. The Johns Hopkins University, Baltimore, Maryland.

Steiner, R.C. and Boland, J.J., N.N. Ehrlich, G.S. Choudhury, W. Teitz, S. McCusker, A. Yamamoto, 1997. Water Resources Management in the Potomac River Basin under Climate Uncertainty. Interstate Commission on the Potomac River Basin, ICPRB 94-3, Rockville, Maryland.

Steiner, R.C., E.H. Hagen, J.Ducnuigeen, 2000. Water Supply Demands and Resources Analysis in the Potomac River Basin, Interstate Commission on the Potomac River Basin, ICPRB 00-5, Rockville, Maryland.

Werrick, William J. et al., An Evaluation of the Risk of Water Shortages in the Lower Peninsula, Virginia, IWR Special Study, June 25, 2001.

Will, G. 2005, February 27. A city that bets on water. The Washington Post, p. B7.

Wurbs, Ralph A. 1996. Modeling and Analysis of Reservoir System Operations. Prentice Hall PTR, Upper Saddle River, NJ.

United States Census Bureau, 2004. http://www.census.gov. Population Division, Information & Research Services Internet Staff. Last updated August 13, 2004.

United States Geological Survey, 2001. Water Resources Data Maryland and Delaware, 2000. Volume 1. Surface Water Data. MD-DE-2000-1. Baltimore, Maryland.

United States General Accounting Office. 2000. *Report to Congressional Requesters: Water Infrastructure, Water-Efficient Plumbing Fixtures and Reduce Water Consumption and Wastewater* flows. Report GAO/RCED-00-232. U.S. GAO, Washington, DC.

U.S. Army Corps of Engineers, 1963. Potomac River Basin Report. Dept. of the Army, U.S. Army Engineer Division, North Atlantic, Baltimore Basin Studies Branch. Baltimore, Md.

U.S. Army Corps of Engineers, 1975. Washington Metropolitan Area Water Supply Study Report; Northeastern Unites States Water Supply (NEWS) Study. Department of the Army, North Atlantic Division. Baltimore, Maryland.

U.S. Army Corps of Engineers, 1983. Metropolitan Washington Area Water Supply Study. Department of the Army, North Atlantic Division. Baltimore, Maryland.

Vickers, A., 2001. Water Use and Conservation. Water Plow Press, Amherts, Massachusettes, 446 pp.

Ways, H.C., 1993. The Washington Aqueduct 1852-1992. Washington Aqueduct Division, U.S. Army Corps of Engineers. Washington, D.C.

Water Supply Coordination Agreement, 1982. Signatories include: The District Engineer Baltimore District COE for the United States of America, the Chairman of the Fairfax County Water Authority, the General Manager of the Washington Suburban Sanitary Commission, The Mayor of the District of Columbia, General Counsel for the Interstate Commission on the Potomac River Basin.

**Appendix A - Production data for Washington Aqueduct**

| | 2000 | 2001 | 2002 | 2003 | 2004 | Average |
|---|---|---|---|---|---|---|
| Average annual production, mgd | 176 | 179 | 178 | 164 | 172 | 174 |
| | | | | | | |
| Monthly average production, mgd | | | | | | |
| January | 166 | 163 | 168 | 159 | 168 | 165 |
| February | 168 | 157 | 167 | 156 | 167 | 163 |
| March | 163 | 160 | 168 | 152 | 161 | 161 |
| April | 167 | 168 | 170 | 155 | 163 | 165 |
| May | 177 | 192 | 170 | 155 | 172 | 173 |
| June | 186 | 195 | 192 | 165 | 178 | 183 |
| July | 193 | 197 | 208 | 180 | 192 | 194 |
| August | 195 | 198 | 217 | 179 | 192 | 196 |
| September | 186 | 190 | 192 | 171 | 187 | 185 |
| October | 182 | 179 | 174 | 166 | 173 | 175 |
| November | 168 | 179 | 158 | 164 | 156 | 165 |
| December | 165 | 164 | 154 | 159 | 155 | 159 |
| | | | | | | |
| Peak 1-day production, mgd | | | | | | |
| January | 186 | 201 | 183 | 202 | 206 | 196 |
| February | 189 | 180 | 181 | 181 | 200 | 186 |
| March | 188 | 180 | 190 | 172 | 199 | 186 |
| April | 199 | 204 | 197 | 187 | 198 | 197 |
| May | 224 | 214 | 187 | 173 | 190 | 198 |
| June | 213 | 238 | 228 | 205 | 200 | 217 |
| July | 214 | 232 | 238 | 197 | 225 | 221 |
| August | 219 | 246 | 251 | 197 | 235 | 230 |
| September | 202 | 244 | 212 | 240 | 215 | 222 |
| October | 199 | 203 | 201 | 195 | 192 | 198 |
| November | 189 | 203 | 180 | 188 | 182 | 188 |
| December | 195 | 178 | 201 | 200 | 200 | 195 |
| | | | | | | |
| Maximum 1-day demand | 224 | 246 | 251 | 240 | 235 | 239 |

**Appendix B - Production data for Fairfax Water**

| | 2000 | 2001 | 2002 | 2003 | 2004 | Average |
|---|---|---|---|---|---|---|
| Average annual production, mgd | 131 | 137 | 144 | 135 | 140 | 137 |
| | | | | | | |
| Monthly average production, mgd | | | | | | |
| January | 117 | 120 | 121 | 129 | 125 | 122 |
| February | 119 | 115 | 120 | 126 | 125 | 121 |
| March | 118 | 117 | 118 | 126 | 126 | 121 |
| April | 122 | 128 | 132 | 132 | 133 | 129 |
| May | 140 | 153 | 141 | 132 | 151 | 144 |
| June | 145 | 149 | 165 | 140 | 153 | 150 |
| July | 146 | 156 | 183 | 157 | 162 | 161 |
| August | 138 | 155 | 191 | 153 | 154 | 158 |
| September | 136 | 150 | 160 | 139 | 148 | 147 |
| October | 137 | 141 | 141 | 136 | 139 | 139 |
| November | 128 | 136 | 129 | 128 | 130 | 130 |
| December | 123 | 121 | 130 | 126 | 127 | 125 |
| | | | | | | |
| Peak 1-day production, mgd | | | | | | |
| January | 126 | 128 | 131 | 144 | 141 | 134 |
| February | 128 | 129 | 127 | 133 | 134 | 130 |
| March | 129 | 133 | 127 | 134 | 138 | 132 |
| April | 131 | 157 | 160 | 143 | 153 | 149 |
| May | 165 | 179 | 163 | 143 | 176 | 165 |
| June | 177 | 183 | 194 | 161 | 174 | 178 |
| July | 176 | 194 | 212 | 183 | 188 | 190 |
| August | 160 | 198 | 223 | 181 | 181 | 188 |
| September | 152 | 183 | 183 | 152 | 177 | 169 |
| October | 149 | 154 | 174 | 153 | 159 | 158 |
| November | 145 | 159 | 143 | 138 | 139 | 145 |
| December | 134 | 129 | 140 | 136 | 136 | 135 |
| | | | | | | |
| Maximum 1-day demand | 177 | 198 | 223 | 183 | 188 | 193 |

**Appendix C - Production data for Washington Suburban Sanitary Commission**

| | 2000 | 2001 | 2002 | 2003 | 2004 | Average |
|---|---|---|---|---|---|---|
| Average annual production, mgd | 162 | 167 | 165 | 164 | 168 | 165 |
| | | | | | | |
| Monthly average production, mgd | | | | | | |
| January | 157 | 159 | 153 | 162 | 167 | 160 |
| February | 158 | 154 | 148 | 159 | 167 | 157 |
| March | 153 | 160 | 148 | 159 | 157 | 155 |
| April | 152 | 168 | 156 | 161 | 162 | 160 |
| May | 167 | 180 | 164 | 163 | 175 | 170 |
| June | 173 | 181 | 182 | 168 | 176 | 176 |
| July | 172 | 177 | 192 | 174 | 179 | 179 |
| August | 169 | 177 | 192 | 176 | 176 | 178 |
| September | 164 | 178 | 170 | 168 | 176 | 171 |
| October | 160 | 165 | 159 | 161 | 163 | 162 |
| November | 155 | 159 | 153 | 160 | 161 | 158 |
| December | 158 | 151 | 158 | 159 | 159 | 157 |
| | | | | | | |
| Peak 1-day production, mgd | | | | | | |
| January | 183 | 182 | 171 | 206 | 187 | 186 |
| February | 180 | 175 | 162 | 172 | 182 | 174 |
| March | 166 | 175 | 162 | 173 | 178 | 171 |
| April | 161 | 189 | 175 | 173 | 180 | 176 |
| May | 195 | 211 | 197 | 176 | 195 | 195 |
| June | 201 | 205 | 219 | 184 | 193 | 201 |
| July | 191 | 209 | 217 | 193 | 198 | 202 |
| August | 191 | 217 | 222 | 191 | 210 | 206 |
| September | 183 | 253 | 185 | 182 | 206 | 202 |
| October | 167 | 187 | 177 | 182 | 175 | 177 |
| November | 170 | 183 | 167 | 182 | 178 | 176 |
| December | 176 | 160 | 177 | 175 | 180 | 173 |
| | | | | | | |
| Maximum 1-day demand | 201 | 253 | 222 | 206 | 210 | 219 |

**Appendix D - Production data for CO-OP Suppliers total**

| | 2000 | 2001 | 2002 | 2003 | 2004 | Average |
|---|---|---|---|---|---|---|
| Average annual production, mgd | 469 | 483 | 487 | 463 | 480 | 476 |
| | | | | | | |
| Monthly average production, mgd | | | | | | |
| January | 440 | 441 | 442 | 450 | 460 | 447 |
| February | 445 | 426 | 436 | 441 | 459 | 441 |
| March | 435 | 437 | 435 | 437 | 444 | 437 |
| April | 441 | 465 | 458 | 447 | 457 | 454 |
| May | 485 | 525 | 475 | 450 | 499 | 487 |
| June | 504 | 526 | 539 | 474 | 507 | 510 |
| July | 510 | 529 | 582 | 511 | 532 | 533 |
| August | 502 | 530 | 600 | 508 | 523 | 532 |
| September | 487 | 518 | 522 | 479 | 510 | 503 |
| October | 478 | 485 | 474 | 463 | 476 | 475 |
| November | 451 | 474 | 441 | 453 | 447 | 453 |
| December | 445 | 435 | 443 | 444 | 441 | 442 |
| | | | | | | |
| Peak 1-day production, mgd | | | | | | |
| January | 486 | 488 | 468 | 509 | 510 | 492 |
| February | 469 | 463 | 459 | 471 | 512 | 475 |
| March | 456 | 461 | 468 | 463 | 465 | 463 |
| April | 471 | 532 | 531 | 479 | 502 | 503 |
| May | 577 | 596 | 528 | 479 | 545 | 545 |
| June | 570 | 607 | 637 | 546 | 553 | 583 |
| July | 555 | 614 | 645 | 558 | 592 | 593 |
| August | 556 | 623 | 670 | 553 | 589 | 598 |
| September | 526 | 645 | 575 | 541 | 592 | 576 |
| October | 510 | 522 | 531 | 486 | 508 | 511 |
| November | 487 | 510 | 470 | 480 | 480 | 485 |
| December | 484 | 461 | 505 | 488 | 484 | 484 |
| | | | | | | |
| Maximum 1-day demand | 577 | 645 | 670 | 558 | 592 | 608 |

# Appendix E. Detailed notes on calculation of unit use factor

## Introduction

This section provides a detailed documentation of data sources and billing records, as well as the method used for calculating unmetered water use, determination of single family and multi-family unit use factors, and determination of employee unit use factors. In addition, other relevant notes are included as appropriate.

Note that 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.

## Data Sources

The study authors give their hearty thanks 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.

*Water data*

The following employees of the water providers were invaluable to the data collection process by which the unit use factors were calculated. From Fairfax Water: Dave Guerra and Greg Prelewicz; LCSA: Tim Coughlin, Mohammed Shammet, Nick Jackson, and Ben Shoemaker; PWCSA: Beau Caire; Virginia American: Bill Walsh and Tonni Monk; the Aqueduct: Tom Jacobus and Lloyd Stowe; DC WASA: John Dunn and Charles Kiely; Arlington DPW: Dave Hundelt, Leigh Sue, and Molly Oberst; Falls Church DEP: Mary Ann Burke and Matthew Jacobi; Vienna DPW: Marion Serfass; Rockville DPW: Susan Strauss and Bill Sizemore; WSSC: Roland Steiner, Tim Hirrel, Rizwan Elahi, Sigi Sharp, and Karen Wright.

*Demographic and service area mapping data*

Similarly, the following county employees provided critical data for the calculation of dwelling unit ratios and mapping of service area perimeters. From MWCOG: Paul DesJardin; Fairfax County: Fatima Khaja and Mubarika Shah; Loudoun County: Tricia Hankinson; Prince William County: Jill Almon; City of Alexandria: Ralph Rosenbaum; District of Columbia: Bob Beasley; Arlington County: Lisa Fowler; City of Falls Church: Gary Fuller; City of Rockville: Mayra Bayonet; Montgomery County: Wayne Koempel, Apollo Teng, and Alan Soukup; Prince George's County: Joseph Valenza, Donna Wilson, and Michael Bashore; Maryland National Capital Park and Planning Commission (MNCPPC): Asfaw Fanta, Martin Howes, and Mike Shean.

## Fairfax Water

*Unmetered water use*

According to recent Fairfax Water billing records, the net water billed in Fairfax Water's direct service area in 2004 was approximately 73.3 MGD (Dave Guerra, personal communication, January, 2005). The amount of water sold to all wholesale customers was documented in 2004 at 59.7 MGD on average, for a total of 133 MGD of water billed directly in its service area or sold to wholesale customers in 2004. The total water produced at the Occoquan and Potomac treatment plants was 137.98 MGD in 2004. The difference between water produced and billed water consumption is unmetered or unaccounted/non-revenue water use. For 2004 this difference was 4.98 MGD or 6.36% for Fairfax Water's direct retail service area. This unmetered water use compares to an unmetered water use of 11.4% in the 2000 study (ICPRB 00-6). The smaller number is primarily due to meter replacement and Fairfax Water's new calibration program. New meters allow the utility to measure the entire range of flows from both wholesale and retail customers (Dave Guerra, Fairfax Water, personal communication, February 18, 2005).

*Billing records*

Fairfax Water uses several service classifications including single family houses, townhouses, apartments, commercial, and municipal categories. Therefore the dissagregation of demands into single family, multi-family and employment categories is simple.

*Determination of single and multi-family unit use factors*

During 2004 Fairfax Water billed approximately 32.13 MGD to the single family household water use category, 11.26 MGD to the townhouse water use category, and 13.06 MGD to the multi-family category. The single family and townhouse water use categories were combined into the single family residence category. The number of 2004 households in the Fairfax Water's direct service area is 292,437 as based on the ICPRB analysis using a GIS overlay of Fairfax Water's direct service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the dwelling unit ratio of 2.56 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in the Fairfax Water service area yields 210,228 single family households and 82,209 multi-family households. The Fairfax Water unit use for 2004 for single-family residences is 206.4 gallons per day per household, as based on 43.39 MGD over 210,228 households. The Fairfax Water unit use for multi-family households for 2004 is 158.9 gallons per household per day as based on 13.06 MGD used by 82,209 multi-family households in 2004.

According to a Fairfax Water analysis, the per household consumption for single family dwellings was 200 GPD (gallons per day) and for townhouses 169 GPD in 2004 based on retail sales and the number of connections. Combining the volume of water sold in 2004 to both single family dwellings and townhouses and dividing by the Fairfax Water estimate of the number of total single family and townhouse connections yields an average per household water use of 190.8 gallons per day. This result is within 7.6% of the 206.4 gallon per household per day estimate derived by ICPRB using traffic analysis zones and dwelling unit ratios.

*Determination of employee unit use factors*

Fairfax Water reports that there was 14.4 MGD of water used in the commercial category and 2.4 MGD used in the municipal category in 2004. The Fairfax Water commercial and municipal categories were combined into a single commercial category. The number of 2004 employees in the Fairfax Water service area is 373,084 as based on the ICPRB analysis using a GIS overlay of Fairfax Water's service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. The per employee daily water use is thus calculated as 45.0 gallons per day.

*Notes*

Fairfax Water notes an industrial water use of 0.24 MGD of untreated water sold to Vulcan and 0.024 MGD to Prince William County Park Authority in 2004. Fairfax Water has shut down many of its wells as only one well system remains in operation. Well production at Riverside Manor in 2004 averaged .02 MGD (Dave Guerra et al., Fairfax Water, personal communication, March 16, 2005). A direct accounting of well production and untreated water sold to Vulcan and Prince William County Parks was not conducted, as the total water use and production for these categories is insignificant.

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

*Unmetered water use*

PWCSA relies on several sources of water (R.B. Caire, PWCSA, personal communication, December, 2004, January, 2005). Purchasing records available through Fairfax Water indicate that in 2004 PWSCA purchased on average 16 MGD from Fairfax Water. Though no exact account has been made for 2004 by PWCSA, PWCSA reports an average bill is typically between 15 and 18 MGD from Fairfax Water, with 17-18.5 MGD in summer months and 15-16 in winter months (insert data source). Using the data provided by Fairfax water, an average of 16 MGD for 2004 is assumed purchased from Fairfax Water. PWSCA purchases water from the City of Manassas, averaging about 5 MGD annually. PWCSA has a 5 MGD capacity with the City of Manassas, however they have a recent agreement, with the installation of a new transmission line that allows for a swap of capacity of 2 MGD, assuming PWCSA gives Manassas some of the water sold to them by Fairfax Water. At the present time however, the 5 MGD average is standard and was assumed for 2004. Past well production in the western area of their service area has been approximately 2 MGD, however no wells are used for the area served by water from the City of Manassas or Fairfax Water (Beau Caire, PWCSA, personal communication, February 3, 2005). The net water produced from wells or net water bought from Manassas and FCWA totaled 21 MGD on average in 2004. Therefore the unaccounted for water calculated for PWCSA is approximately (21MGD production minus 19.3 MGD (both west and east ends) billed equals 1.7 MGD) or 8.1 %.

*Billing records*

Typically PWCSA uses residential, commercial, and unaccounted for water use categories, however during the 2004-2005 study period, PWCSA underwent a major software change. As a result, categorical breakdown of water use was not possible and annual totals were provided. Actual water use data was provided for January through November, 2004, an estimate for December was used based on 2003 data. Due to the software change, disaggregating demands into single and multi-family residential and commercial uses requires several assumptions about water use in these categories. R.B. Caire at PWCSA did indicate, however, that the ratio of residential to commercial is expected to have remained relatively the same since 2000. Residential water use makes up approximately 75% of total demands, with commercial consuming about the remaining 25% (Personal communication, December 20, 2004).

*Determination of employee unit use factors*

Because PWCSA does not break down water demand data into customer categories, ICPRB assumed that the unit use factor for PWCSA'a commercial category is equal to Fairfax Water's direct retail service area's employee unit use. The number of 2004 employees in the PWSCA service area is 77,329 as based on the ICPRB analysis using a GIS overlay of PWCSA's service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. Assuming per employee daily water use is 45.0 gallons, the daily demand for PWCSA employees in 2004 is 3.48 MGD (45.0 GPD multiplied by 77,329 employees, divided by 1,000,000).

*Determination of single and multi-family unit use factors*

As with the determination of employee unit use for 2004, the unit use factor for PWCSA's multi-family was assumed to be equal to Fairfax Water's direct retail service area's multi-family 2004 unit use figure. The number of 2004 households in the PWSCA service area is 80,146, as based on the ICPRB analysis using a GIS overlay of PWCSA's service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the dwelling unit ratio of 3.69 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in the PWCSA's service area yields 63,046 single family households and 17,101 multi-family households.

The multi-family unit use factor developed for Fairfax Water's direct service area of 158.9 gallons per day per household was assumed for PWCSA's multi-family residences. Applying Fairfax Water's multi-family unit use factor to the 17,101 multi-family households yields a total water use of 2.72 MGD. Subtracting the assumed total annual use in the multi-family (2.72 MGD) and employee (3.48 MGD) categories from PWCSA's total water billed in 2004 (19.3 MGD) yields a total single family water use of 13.1 MGD, or 207.8 gallons per household per day (assuming the value of 63,046 single family households in the PWSCA service area).

## Fairfax Water - Virginia American – Alexandria City

*Unmetered water use*

Virginia American relies on water purchased from Fairfax Water (Tonni Monk and Bill Walsh, Virginia American, personal communication, November, 2004). In 2004, Virginia American records an average of 14.4 MGD billed to the Alexandria City service area. This figure is based on actual data provided for January through October, 2004 and estimates for November and December based on data from 2003. Fairfax Water records show a sale of 16.9 MGD to Virginia American's Alexandria City jurisdiction for the entire calendar year. The result is an unaccounted for water total of 2.5 MGD or approximately 14.8%. Virginia American reports that the unmetered water may be a result of the difference in the accounting years between Fairfax Water and Virginia American. This difference is recognized in the unit use calculations and should have a limited affect on the water unaccounted for in 2004 (Tonni Monk, Virginia American, personal communication, January 27, 2004).

*Billing records*

Virginia American uses residential, commercial, industrial, and other water use categories. Virginia American's residential water use category includes only single family dwellings. Virginia American's commercial category includes multi-family dwellings, office and other commercial water uses. Virginia American's "other" category includes water sold to local, state, or Federal government offices. Billing records were available for January through October, 2004.

*Determination of single family unit use factor*

During 2004, 3.41 MGD were billed to the residential water use category (single family households). The number of 2004 households in the Virginia American Alexandria service area is 65,370 as based on the ICPRB analysis using a GIS overlay of Virginia American's Alexandria service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the dwelling unit ratio of 0.53 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in the Virginia American service area yields 22,746 single family households and 42,624 multi-family households. The single-family water use factor was thus 149.9 gallons per household per day.

*Determination of multi-family and employee unit use factor*

Virginia American's commercial category includes multi-family dwellings, office and other commercial water uses. A total of 11.0 MGD was billed to the commercial, industrial, and "other" categories in 2004. The per-employee unit use factor developed for Fairfax Water's direct service area of 45.0 gallons per day per employee was assumed for the Alexandria service area. The number of 2004 employees in the Alexandria service area is 103,150 as based on the ICPRB analysis using a GIS overlay of Alexandria's service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. Applying the Fairfax Water per-employee-unit use factor yields a total water use of 4.6 MGD. Subtracting this assumed employee water use from Alexandria's total annual commercial, industrial and "other" use yields

6.4 MGD as the net water use assumed for the multi-family category. Given 42,624 multi-family households in the Virginia American service area as calculated above, a multi family unit use was derived as 150.2 gallons per household per day (6.4 MGD over 42,624 households).

## Fairfax Water - Virginia American- Dale City

*Unmetered water use*

Virginia American relies on water purchased from Fairfax Water (Bill Walsh and Tonni Monk, Virginia American, personal communication, November, 2004). In 2004, Virginia American records reports an average of 5.85 MGD billed to the Dale City service area during2004. This is calculated based on actual data from January though September, 2004 and estimates from October through December, 2002. Fairfax Water records show a sale of 5.93 MGD to Virginia American's Dale City jurisdiction for the entire calendar. The result is an unmetered water total of .09 MGD or 1.5%.

*Billing records*

Virginia American uses residential, commercial, industrial, other, non-revenue, and unaccounted for water use categories. Virginia American's residential water use category includes only single family dwellings. Virginia American's commercial category includes multi-family dwellings, office and other commercial water uses. Virginia American's "other" category includes water sold to local, state, or Federal government offices.

*Determination of single family unit use factor*

During 2004, 3.9 MGD were billed to residential water use category (single family households). The number of 2004 households in the Virginia American service area in Dale City is 19,215 as based on the ICPRB analysis using a GIS overlay of Virginia American's Dale City service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the dwelling unit ratio of 13.1 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in the Virginia American service area yields 17,852 single family households and 1,363 multi-family households. The single-family water use factor was 218.5 gallons per household per day (assuming 3.9 MGD billed to 17,852 single family households).

*Determination of multi-family and employee unit use factor*

Virginia American's commercial category combines multi-family dwellings, office and other commercial water uses. In 2004 the water use in the combined categories of commercial, industrial, and "other" is 1.96 MGD, divided between .61 MGD in commercial and 1.35 MGD in "other." There is no industrial water use in Dale City. The multi-family unit use factor of 158.9 gallons per household per day developed for Dale City's neighbor, PWCSA was assumed for the Dale City service area. The number of 2004 multi-family households in the Virginia American service area is 1,363. Applying the PWCSA multi-family unit use factor to these households yields a total water use of nearly 0.22 MGD. Subtracting this assumed multi-family water use from Dale City's commercial and "other" categories yields 1.74 MGD (1.96 - .22) for the employee category. The number of 2004 employees in the Virginia American service area is 8,936 as based on a GIS overlay of Virginia American's service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. The per employee unit use is calculated to be just over 194.7 gallons per employee per day.

Regionally, 192.5 gallons per employee per day is obviously quite high. One possible explanation provided by Virginia American included the high water use of the Virginia Department of Transportation rest area on Interstate 95. Transit customers may, in fact, be increasing the unit use figure beyond what is typical for Dale City employees (Bill Walsh, Virginia American, personal communication, February 22, 2005).

## Fairfax Water - Loudoun County Sanitation Authority

*Unmetered water use*

LCSA purchases water from Fairfax Water and the City of Fairfax. The net water bought from the City of Fairfax and Fairfax Water in 2004 totaled 15.8 MGD on average. (The total average water purchased from Fairfax was 10.1 MGD and from City of Fairfax 5.7 MGD.) According to LCSA records, a total of 12.2 MGD was billed in 2004. The unaccounted for difference between water purchased and water sold is 3.55 MGD (15.8-12.25), or 22%. These data are abnormally high for LCSA, therefore the 2003 unmetered water was also calculated. Net water purchases from the City of Fairfax and Fairfax Water in 2003 was 13.0 MGD on average. LCSA reports approximately 12.07 MGD billed to customers, leaving the unmetered water at .83 MGD or 6.4% for 2003. During 2004 LCSA reported that cleaning of the fire hydrant flushing system was extended beyond the typical period of flushing. The flushing water is not necessarily accounted for in the billed data and may contribute significantly to the unusually high unmetered water total during 2004 (Mohammed Shammet, LCSA, personal communication, February 3, 2005). Therefore, the unmetered water percentage was assumed to be 6.4% for the current demand study.

*Billing records*

LCSA identifies several water use categories, including: residential, apartments, commercial/industrial, and construction/fire hydrant use. LCSA's residential water use category combines both single family dwellings and townhouses.

*Determination of single and multi-family unit use factors*

In 2004, 8.15 MGD was billed to the residential category (single family and townhouses). The number of 2004 households in the LCSA service area is 51,699, as based on the ICPRB analysis using a GIS overlay of LCSA's service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the dwelling unit ratio of 3.31 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in the LCSA service area yields 39,717 single family households and 11,983 multi-family households. Given the recent rapid growth and development as well as the changes in how Loudoun County's planners designate sub-planning areas, Loudoun's dwelling unit ratio estimate was difficult to calculate for the LCSA's service area, however it is our best estimate at this time.

Using the aforementioned dwelling unit ratio and the GIS overlay to determine the number of households in the LCSA service area, the following water use figures were calculated. During 2004, 8.15 MGD were billed to the single family residential water category. Over 39,717 single family households this yields 205.2 gallons per household per day. LCSA reports the multi-family water use category as having billed 1.19 MGD in 2004. This results in 99.3 MGD per multi-family household per day (1.19 MGD divided by 11,983 households.)

Note that LCSA itself reports that the individual household numbers are 47,378 single family dwellings (connections) and 6,809 apartments in 2004). Using the data provided by LCSA for 2004 for single and multi-family users, a separate set of calculations determined the following usage rates. LCSA billing records report 2,976 mg in 2004 over 47,378 single family households. This results in 172.1 gallons per household per day. For multi-family households or apartments, according to LCSA documentation, the total amount of water billed in 2004 is 435 mg (1.19 MGD). Over 649 connections or 6,809 users, this is equal to 175 gallons per day per household. According to LCSA figures, usage in single versus multi-family dwellings is relatively similar. Regionally, however, trends demonstrate that multi-family households tend to use less water than single family households. Therefore, the calculations associated with the dwelling units and GIS overlay will be used for the purposes of this study.

*Determination of employee unit use factors*

The number of 2004 employees in the LCSA service area is 69,014 as based on the ICPRB analysis using a GIS overlay of LCSA's service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. The commercial/industrial consumption reported by LCSA in 2004 is 2.605 MGD. Therefore the per employee daily water use is calculated at 37.8 gallons per day.

*Notes*

LCSA has independent contracts with both the City of Fairfax and Fairfax Water. As in 2000, LCSA reports that an agreement with the City of Fairfax typically limits average water consumption to 7 MGD, which means that all future water demands above 7 MGD can be assumed to come from Fairfax Water (Timothy Coughlin, LCSA, personal communication, January 28, 2005).

## Fairfax Water - Herndon

*Unmetered water use and billing records*

The Town of Herndon purchases water from Fairfax Water. The net water bought from Fairfax Water in 2004 totaled 2.36 MGD on average. No billing records were obtained for the Town of Herndon, therefore unaccounted/unmetered water use could not be directly calculated. Instead, the percentage of unaccounted/unmetered was calculated based on the wholesale data provided by Fairfax Water. Given 137.98 MGD in production and 73.3 MGD in retail, production for wholesale alone is 64.68 MGD. Unmetered water for Fairfax Water wholesale customers is calculated as the difference between 64.68 MGD and 59.7 MGD billed to wholesale customers. This difference equals 7.7% of 64.68 MGD.

*Determination of single and multi-family and employee unit use factors*

Unit use figures for the multi-family and single family categories are assumed to be the same as for that of Fairfax Water's direct service area in 2004 (206.4 gallons per single family household per day and 158.9 gallons per multi-family household per day). In 2004, 2.36 MGD was sold to the Town of Herndon. Assuming 7.7% unmetered water use, 2.28 MGD remained available for consumption across all water-use categories. The number of 2004 households in the Town of Herndon's service area is 7,180 and the number of employees is 23,691 as based on the ICPRB analysis using a GIS overlay of the Town of Herndon's service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the county dwelling unit ratio of nearly 2.56 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in the Town of Herndon's service area yields approximately 5,162 single family households and 2,019 multi-family households. The total water use for single family households was estimated to be 1.07 MGD (206.4 gallons per household per day multiplied by 5,162 households). The total water use for multi-family households was estimated to be 0.32 MGD (158.9 gallons per household per day multiplied by 2,019 households). In 2004, the Town of Herndon had 2.18 MGD available, less the unmetered water. Given 1.07 MGD for single families and 0.32 MGD for multi-families, the remaining water available for employee use was 0.89 MGD in 2004.

The per employee water use factor was thus calculated to be 37.6 gallons per employee per day (assuming 0.89 MGD used by 23,692 employees).

## Fairfax Water – Fort Belvoir

*Unmetered water use and billing records*

Fort Belvoir purchases water from Fairfax Water. The net water bought from the Fairfax Water in 2004 totaled 1.53 MGD on average. No billing records were obtained for Fort Belvoir, therefore unaccounted/unmetered water use could not be directly calculated. Instead, the percentage of unaccounted/unmetered was assumed to be the same as for that of Fairfax Water wholesale supply service area in 2004 at 7.7%.

*Determination of single and multi-family and employee unit use factors*

Fort Belvoir's single and multi-family unit use rates are assumed to be the same as Fairfax Water's direct service area in 2004 (206.4 gallons per single family household per day and 158.9 gallons per multi-family household per day). In 2004, 1.53 MGD was sold to Fort Belvoir. Assuming 7.7% unmetered water use, 1.47 MGD remained available for consumption across all water-use categories. A refined look at the number of households in Fort Belvoir's service area yielded fewer households than in 1998. Regional mapping indicates approximately 488 households and 26,031 employees as based on the ICPRB analysis using a GIS overlay of Fort Belvoir's service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the county dwelling unit ratio of nearly 2.56 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in Fort Belvoir service area yields 351 single family households and 137 multi-family households. The total water use for households was estimated to be 0.072 MGD for single family and 0.022 MGD for multi-family. The employee unit use rate was calculated by subtracting unmetered and single and multi-family water uses from the total amount sold to Fort Belvoir and dividing by the number of employees (1.38 MGD over 26,031 employees). Therefore the per employee unit use in 2004 was calculated as 53.0 gallons per person per day.

### Fairfax Water – D.C. Department of Corrections (Lorton)

The last year of Fairfax Water record for the D.C. Department of Corrections (DCDC) was 2002. Since this time DCDC's Lorton facilities have been close and the site has been returned to Fairfax County. This site is currently under redevelopment for residential, commercial, and municipal uses. All water services for these uses will be provided by Fairfax Water. In future demand studies, this water use will be accounted for in Faifax Water's retail demands, as this wholesale customer category no longer exists (Dave Guerra et al., Fairfax Water, personal communication, March 16, 2005).

### Fairfax Water – MWAA Dulles International Airport

*Unmetered water use and billing records*

Dulles purchases water from Faifax Water. The net water bought from the Fairfax Water in 2004 totaled 0.91 MGD on average. No billing records were obtained from Dulles, so unaccounted/unmetered water use could not be directly calculated. Instead, the percentage of unaccounted/unmetered was assumed to be the same as for that of Fairfax Water wholesale supply service area in 2004 at 7.7%. Billing records for the Dulles were not obtained.

*Determination of single and multi-family and employee unit use factors*

Dulles' single and multi-family unit use rates are assumed to be the same as Fairfax Water's direct service area in 2004 (206.4 gallons per single family household per day and 158.9 gallons per multi-family household per day). In 2004, .91 MGD was sold to the Dulles service area. Assuming 7.7% unmetered water use, .87 MGD remained available for consumption across all water-use categories. The number of 2004 households in the Dulles service area was approximately 26: 19 single family and 7 multi-family households using the county dwelling unit ratio (2.56). The number of employees is 14,532 as based on the ICPRB analysis using a GIS overlay of the Dulles service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. After subtracting the water use of single and multi-family households (.004 MGD and .001 MGD respectively), the remaining .865 MGD is attributed to the employee category. The per employee water use rate was calculated as 0.865 MGD divided by 14,532, resulting in a per-employee water use of 59.5 gallons per person per day.

Washington Metropolitan Council of Governments planning reports reveal that residential housing will be entirely eliminated from the Dulles service area by 2015, therefore water use will be entirely employee based.

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

*Unmetered water use*

WASA relies on water purchased from the Washington Aqueduct. During WASA's Fiscal Year 2004, October through September, WASA purchased on average 128 MGD from the Aqueduct. The water billed in FY 2004 was 86 MGD. A total of 128 MGD was assumed sold from the Aqueduct to DC WASA, net the filter backwash water returned to the McMillan plant. According to DC WASA officials, the ratio of sold (to customers) to pumped (from the Aqueduct) during the FY 2004 was 67.7%. This does not account for water use for hydrant flushing, cleaning and lining, street operations, etc. Water consumption for these purposes is estimated at 12.85 MGD (Charles Kiely, DC WASA, personal communication, March 2, 2005). Therefore, the unaccounted for water is total pumped minus sales and operational uses or 29.15 MGD, or 23%.

*Billing records*

All billing records received from WASA reported water use in terms of the WASA fiscal year, October through September. Due to the annual, rather than monthly, totals for each water use category, it was not possible to alter the figures to represent the actual calendar year. Therefore unit use figures for 2004 actually represent October, 2003 - September, 2004.

WASA uses residential, multi-family, municipal, commercial, DC Housing Authority, Federal, Blue Plains Treatment Plant, and Soldier's Home and Howard Univeristy for its water use categories. WASA's residential water use category includes primarily single family dwellings, condos, and townhouses; the multi-family category refers to dwellings with four or more units, typically large apartment buildings in the urban center. WASA's commercial category includes multi-family dwellings and industrial water uses. WASA's DC Government category includes schools, and the Federal category includes water sold to Federal government offices.

During the 2000 study period, WASA provided limited user categories, including residential, commercial, D.C. Government, and Federal buildings. The lack of distinction between single and multi-family water use resulted in assumptions on behalf of ICPRB and a unit use calculated based on a combined categories. Subsequently, unit use was significantly higher in 2000 than described below.

*Determination of multi-family and single family unit use factors*

The number of 2004 households in the WASA service area is 259,714 households as based on the ICPRB analysis using a GIS overlay of WASA's service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Using a dwelling unit ratio of .75 (single family/multi-family households), there are 111,305 single and 148,409 multi-family households in the District. During 2004 18.9 MGD were consumed by single family households and 23.7 MGD by multi-family households. The DC Housing Authority water use category was added to multi-family water use category. It is reasonably assumed that the majority, if not all, DC Housing Authority clients are in multi-family dwellings. Over the aforementioned number of households, this results in unit use rates of 169.8 gallons per single family household per day (18.9 MGD over 111,305 households) and 159.7 gallons per multi-family household her day (23.7 MGD over 148,409 households).

As noted, WASA separates the water use by Soldiers Home and Howard University. In 2004 a GIS overlay of this service area revealed 1628 dwellings. Given the nature of the service area, dwelling identity is both difficult and unnecessary to determine. It is likely that these dwellings are large facilities and dormitories. Therefore, a total unit use number was calculated for the Soldiers Home and Howard University category. WASA records report approximately .55 MGD in 2004 to Soldiers Home and Howard University, this reflects the total water billed to this category minus the Soldiers Home and Howard University employee use (assumed to be the same as the DC employee unit use, see below). Over 1628 dwellings, this is a unit use factor of 337.8 gallons per dwelling per day.

*Determination of employee unit use factor*

WASA's DC Government, Federal, municipal buildings water use categories were combined. In 2004, 41.7 MGD was billed to all categories. The number of 2004 employees in the WASA service area is 733,301 as based on the ICPRB analysis using a GIS overlay of WASA's service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. The employee unit use was derived as 56.9 gallons per employee per day. The number of employees in the Soldiers Home and Howard University is 3225 and unit use is assumed to be the same as the DC area employees (56.9 gallons per employee per day).

## Aqueduct – WASA – Reagan National, Pentagon, Arlington cemetery, Fort Myer

*Unmetered water use and billing records*

Reagan National, Pentagon, Arlington cemetery and Fort Myer also rely on water purchased from the Aqueduct. Independent billing records were retrieved for Fort Myer only, by way of Arlington DPW. DC WASA included Reagan National Airport, the Pentagon, and Arlington Cemetary water use in DC WASA water demand totals. Therefore, unit use numbers are not calculated for each one of the aforementioned regions independently. An unaccounted water use of 22% was assumed for Fort Myer, based on data gathered from Arlington DPW.

*Determination of multi-family and single family unit use factors*

According to the ICPRB analysis using a GIS overlay of the Fort Myer service area with traffic analysis zones, extracting the 2000 and 2005 housing and employment data and interpolating for 2004, there are 305 houses and 6032 employees in the area. Fort Myer single and multi-family households were assumed to have the same unit use as Arlington DPW's service area at 146.5 and 123.6 gallons per household per day respectively. Subtracting the total household use (.018 MGD single families and .023

for multi-families) and the unmetered water (.12 MGD) from the total billed (.53 MGD) to Fort Myer leaves .37 MGD for the employee water use category. Over 6032 employees, the unit use factor is calculated as 61.3 gallons per employee per day for 2004.

Households and employees in the Reagan National, Pentagon, and Arlington Cemetery service areas are part of the household and employee totals for DC WASA and assume DC WASA unit use for all customer categories.

## Aqueduct - Falls Church DES and Vienna DPW

*Billing records*

Monthly billing information for both Falls Church and Vienna's combined water use categories was obtained. Though both service areas use residential and commercial categories to separate its users, a breakout of water use for each of these categories was unavailable during the demand study research period. Therefore the appropriate assumptions regarding household unit use figures were made for both the Falls Church and Vienna service areas. Also, both Falls Church and Vienna provided data according to fiscal rather than calendar year, therefore unit use figures represent July, 2003 through June, 2004.

*Unmetered water use*

The City of Falls Church Department of Environmental Services/Public Utilities Division (Falls Church DES) relies on water purchased from the Aqueduct and Fairfax Water. In turn, Falls Church DES wholesales a small amount of this water to Vienna DPW, who also receives water directly from Fairfax Water. During the last period of full record from Falls Church DES, the 2003-2004 fiscal year (July-June), Falls Church DES purchased on average 8.25 MGD from the Aqueduct and 5.68 MGD from Fairfax Water. The amount of unaccounted for water for Falls Church DES is equal to 13.9 MGD (total purchasing) minus the water consumed by Falls Church customers, 10.38 MGD, minus water sold to Vienna DPW, 1.53 MGD. This comes to 2.0 MGD or 14.3% of the annual total.

Calculating unmetered water for Vienna is difficult, as the months of record differ between the water providers of Vienna DPW: Falls Church DES and Fairfax Water. According to Falls Church DES and Fairfax Water records, Vienna purchased 1.53 MGD of water from Falls Church during FY 2003-2004, and .67 MGD from Fairfax Water during 2004. Vienna billed 2.28 MGD in FY 2003-2004. Because a reliable account of the Vienna DPW's water cannot be calculated, 14.3% is assumed for Vienna's unmetered water.

*Determination of multi-family and single family unit use factors*

According to the ICPRB analysis using the GIS overlay of the Falls Church service area with traffic analysis zones, extracting the 2000 and 2005 housing data and interpolating for 2004, there are 48,506 households in the area. Using a dwelling unit ratio of 1.8, there are 31,178 single family households and 17,328 multi-family households in 2004 in Falls Church. According to similar GIS overlay of the Vienna service area, there are 7,157 single family households and 1,276 multi-family households.

Assuming Falls Church and Vienna service areas both have the same single and multi-family unit use figures as Arlington DPW, the remaining water reported by Falls Church and Vienna was attributed to the employee water use category. Falls Church and Vienna single family households have an assumed unit use of 149.9 gallons per household per day; multi-family households have an assumed unit use of 126 gallons per day per household. Total single and multi-family annual water use was calculated by multiplying these unit use figures by each of the service areas' total single or multi-family households. This results in 6.86 MGD for Falls Church households and 1.22 MGD for Vienna households.

*Determination of employee unit use factor*

The number of 2004 employees in the Falls Church service area is 121,083, as based on the ICPRB analysis using a GIS overlay of the Falls Church service areas with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. The water use for the employee category was estimated by subtracting the 2004 residential water uses from the total water billed. This results in a net employee water use of 3.52 MGD in 2004. Given 121,083 employees in the combined service areas, a per employee unit use was derived of 29.1 gallons per employee per day.

The number of 2004 employees in the Vienna service area is 13,732, as based on the ICPRB analysis using a GIS overlay of the Falls Church service areas with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. The water use for the employee category was estimated by subtracting the 2004 residential water uses from the total water. This results in a net employee water use of nearly 1.06 MGD in 2004. Given 13,732 employees in the combined service areas, a per employee unit use was derived of 77.1 gallons per employee per day during the 2003-2004 fiscal year.

## Aqueduct - Arlington County DPW

*Unmetered water use*

Arlington County DPW relies on water purchased from the Aqueduct. Based on their fiscal year (July-June), records for 2004 Arlington County DPW show a purchase average of 25.9 MGD from the Aqueduct. The total water billed for the same period at Arlington County DPW and Fort Meyer was 19.6 MGD plus .53 MGD. The unmetered/non-revenue water is the difference in the two figures, 5.77 MGD or 22% (Molly Oberst, Arlington County DPW, personal communication, January 28, 2005). Arlington County DPW has not yet determined the source of the higher than usual unmetered water during 2004. Unit use figures are based on the last entire year of record for Arlington DPW, fiscal year 2004.

*Billing records*

Arlington County DPW uses residential, commercial, apartment, and county agencies categories to describe its customer water use. Monthly billing information for each category was obtained from the Arlington County DPW Utilities Services Office.

*Determination of multi-family and single family unit use factors*

The number of 2004 households in the Arlington County DPW's direct service area is 91,692 as based on the ICPRB analysis using a GIS overlay of Arlington County DPW's direct service area with traffic analysis zones, extracting the 2000 and 2005 household data and interpolating for 2004. Applying the dwelling unit ratio of 0.67 (number of single family residences divided by number of multi-family residences) to the number of 2004 households in the Arlington service area yields 36,688 single family households and 54,758 multi-family households. The Arlington County DPW unit use for single-family residences is 149.9 gallons per day per household, as based on 5.5 MGD over 36,688 households. The Arlington County DPW unit use for multi-family households is 126 gallons per household per day as based on 6.9 MGD used by 54,758 multi-family households.

*Determination of employee unit use factor*

The total employee water use for Arlington County DPW service area combined commercial and county agencies categories for a total of 7.2 MGD in 2004. The number of 2004 employees in the Arlington County DPW service area is 162,813 as based on the ICPRB analysis using a GIS overlay of Arlington County DPW service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. Given 162,813 employees in Arlington County DPW service area as calculated above, a per employee unit use was derived of 44.2 gallons per employee per day.

## Washington Suburban Sanitary Commission (WSSC)

*Unmetered water use*

During 2004 WSSC produced an average of 168.0 MGD for its customers in Montgomery and Prince George's Counties. The billed consumption across all user categories for the same period during 2004 was 140.7 MGD. The difference, or unmetered/unaccounted water, is 27.3 MGD or 16.3%.

*Billing records*

Billing records for WSSC's single family, multi-family, employment, and wholesale categories were obtained for years 2000 through 2004. Production and total consumption data was also provided. The dissaggregation of WSSC's customers into diverse user categories makes the calculation of unit use straightforward.

*Determination of multi-family and single family unit use factors*

During 2004 WSSC billed 71.7 MGD to the single family household water use category and 33.1 MGD to multi-families. The number of 2004 households in the combined Montgomery and Prince George's County WSSC service area is 589,460 as based on the ICPRB analysis using a GIS overlay of WSSC's service area with traffic analysis zones in both Montgomery and Prince George's Counties. Household data from

2000 and 2005 were extracted and interpolated for 2004. Dwelling unit ratios were developed for each county. An average dwelling unit ratio of 2.12 in 2004 was used for the combined service area. Therefore WSSC's service area contains 400,571 single family and 188,889 multi-family households. The unit use calculated for single families is 71.7 MGD over 400,571 households which equals 178.9 gallons per household per day in 2004. Multi-family households used 175.2 gallons per household per day, as calculated by 33.1 MGD over 188,889 households.

*Determination of employee unit use factor*

During 2004, 35.5 MGD was billed to the employment category in WSSC's service area. The number of 2004 employees in the combined Montgomery and Prince George's County WSSC service area is 761,201 - as based on the ICPRB analysis using a GIS overlay of WSSC's service area with traffic analysis zones for both counties. Employment data from 2000 and 2005 were extracted and interpolated for 2004. Unit use for employees in the WSSC service area is calculated as 35.5 MGD over 761,201 employees, which equals 46.6 gallons per day per person.

## City of Rockville DPW

*Unmetered water use*

Rockville DPW relies on water withdrawn from the Potomac River. Potomac diversions to the Rockville Water Treatment Plant for calendar year 2004 were obtained from Rockville DPW (Bill Sizemore). During the first part of 2004, the treatment facility underwent significant renovation work. Without service, Rockville purchased water from Washington Suburban Sanitary Commission (WSSC). Over three months the total water purchased from WSSC was approximately 175 million gallons. The average production during 2004 comes to 4.68 MGD. The total water billed for the same period was 4.11 MGD. According to the ICPRB calculation, the difference between the produced and billed water, or the unmetered/non-revenue water, was approximately 12.2%, or 0.57 MGD.

Upon discussion with Rockville DPW, it is evident that the unmetered water use calculated by ICPRB does not distinguish between different types of unmetered water. Rockville DPW serves several city facilities with unmetered water and therefore this water should not be interpreted as "lost" water. Only a small portion of the .57 MGD is actually lost or unaccounted for water. However, because Rockville DPW has not yet completed a water audit for the 2004 calendar year, these losses have not been specified. A recent water audit (2002) found a net total of lost or unmeasured water of 10.4% (Susan Strauss and Edwin Woos, Rockville, DPW, personal communication, March 24, 2005). The audit was able to provide categories of lost or unmeasured water, including unbilled service to city office buildings, community centers, swim centers, and other facilities. Actual losses were attributed to main breaks and other undetermined causes (9.5%) Therefore, based on evidence from the 2002 audit, only a portion of the 2004 MGD of unmetered water is actually water lost within the system.

*Billing records*

Billed water totals were received from Rockville DPW. A total of 1,439 million gallons were billed during 2004 (average 3.94 MGD) across all water use categories. A break out of water use category by type was not available.

*Determination of multi-family and single family unit use factors*

The number of 2004 households in the Rockville DPW's direct service area is 15,791 as based on the ICPRB analysis using a GIS overlay of Rockville DPW's direct service area with traffic analysis zones, extracting 2000 and 2005 household data and interpolating for 2004. Applying the dwelling unit ratio (single family residences divided by multi-family residences) of 2.38 to the number of 2004 households in the Rockville DPW service area yields 11,123 single family households and 4,668 multi-family households. Due to the lack of water use categories provided by Rockville DPW, an estimate of the total annual water demand was made by ICPRB. Rockville's unit water use values were assumed to be the same as those in the WSSC service area. Single and multi-family water use is assumed to be at 178.9 MGD and 175.2 MGD, respectively.

*Determination of employee unit use factor*

The number of 2004 employees in the Rockville DPW's service area is 68,228 as based on the ICPRB analysis using a GIS overlay of Rockville DPW's service area with traffic analysis zones, extracting the 2000 and 2005 employment data and interpolating for 2004. The water use for the commercial category is estimated as the total water billed minus the assumed demand of residential customers. In 2004, this is equal to 1.3 MGD (4.11 MGD minus 1.99 MGD for single families and .82 MGD for multi-families). Given 68,228 employees in Rockville DPW's service area, a per employee unit use was derived of 19.05 gallons per employee per day.

# Appendix F. Continued effects of the *Energy Policy Act of 1992* on WMA water use.

## Typical water use inside the home

In 1999 a comprehensive water use study revealed that while residential water demands are highly influenced by weather and location, the identification of residential end uses may be critical to our ability to improve customer accountability and target conservation efforts within the home. The American Water Works Association Research Foundation's (AWWARF) *Residential End Uses of Water* study is a comprehensive source of information to determine the effects of the *Energy Policy Act of 1992* (102D Congress, 2d session, 1992). This study provides specific data on the end uses of water in the home from a representative sample of residential homes and remains the most comprehensive study for the assessment of indoor water uses (Mayer et al., 1999). Flow measurements from 1,188 homes in North America were taken from 12 study sites and 14 utilities around the country during the period May, 1996 through March, 1998. The homes were chosen using random sampling of billing databases. Two weeks of data was collected during each of the summer and winter periods. Water meter readings were recorded in 10-second intervals using electronic data loggers. The recorded timing and flow rates of all water-using events were analyzed in detail, so as to permit identification and classification of water using events (Mayer et al., 1999). Over 1.9 million end use events were identified and segregated. In addition, about 6,000 households were surveyed by mail and billing records were provided for approximately 12,000 residences.

The American Water Works Association (AWWA) manages the self proclaimed "Water Efficiency Clearinghouse" through the resourceful *WaterWiser* website. *WaterWiser* is a source of a vast array of water efficiency references, books, surveys, and other information. *WaterWiser* also provides access to the *Water Saver Home* or *H2OUSE* website. Developed by the California Urban Water Conservation Council with the U.S. Environmental Protection Agency website, visitors are able access information about typical water use inside and outside of the home. In addition, these websites sites provide dozens of water saving recommendations. Using the "home tour" component of the *Water Saver Home* website, the breakdown of indoor water use is revealed and shown in Figure 1 below. According to the *Water Saver Home* website, these data were retrieved from the aforementioned *Residential End Uses of Water* (Mayer et. al, 1999) and remain the most reliable and comprehensive resource for national residential water end use averages (Beth Ernsberger, California Urban Water Conservation Council, personal communication, December 6, 2004).

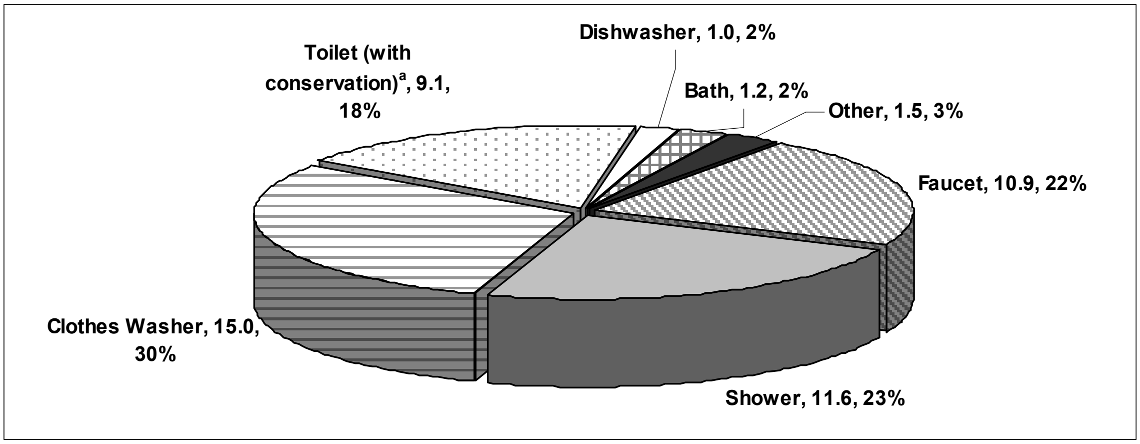



**Figure 1: Average per capita water use inside the single family home (Water Saver Home; DeOreo et al., 2001; Mayer et al., 1999). Units are in gallons per customer per day and percent of overall use. Notes: a Toilet (with conservation) refers to low flush toilets using 1.6 gallons per flush, resulting in an average 9.1 gallons per person per day.**

In addition to the *Residential End Uses of Water*, more recent studies have been developed, including, among others, the "Water Infrastructure: Water Efficient Plumbing Fixtures Reduce Water Consumption and Wastewater Flows" Report to Congressional Requesters by the General Accounting Office (2000) and Amy Vickers' *Water Use and Conservation*. These texts contribute to our growing knowledge about per capita water use and consequently, our ability to consider conservation campaigns and improved water saving techniques.

Regional water conservation has also been considered in recent years. Water conservation market surveys in the Washington Metropolitan Area (WMA) were completed by NuStats for MWCOG's "Water Use It Wisely" Campaign and the DCWASA region. A subsequent report was completed specifically for WSSC. NuStats' final report for WSSC during the summer 2002 reported the statistics of over 400 users from each of the following areas: Montgomery County, Prince George's County, Virginia, and Washington, D.C. A total of 1685 households were randomly selected and surveyed to establish a baseline attitude and gage the effectiveness of the COG conservation campaign.

The COG Water Conservation Market Survey (2002) records the level of importance for water conservation in the home (Figure 2), as well as their motivations for conserving water, fixture replacement rates, and other conservation considerations for both in and outdoor water use. MWCOG is currently working on a follow-up study to these baseline surveys to estimate any progress that has been made by the water wise campaign.

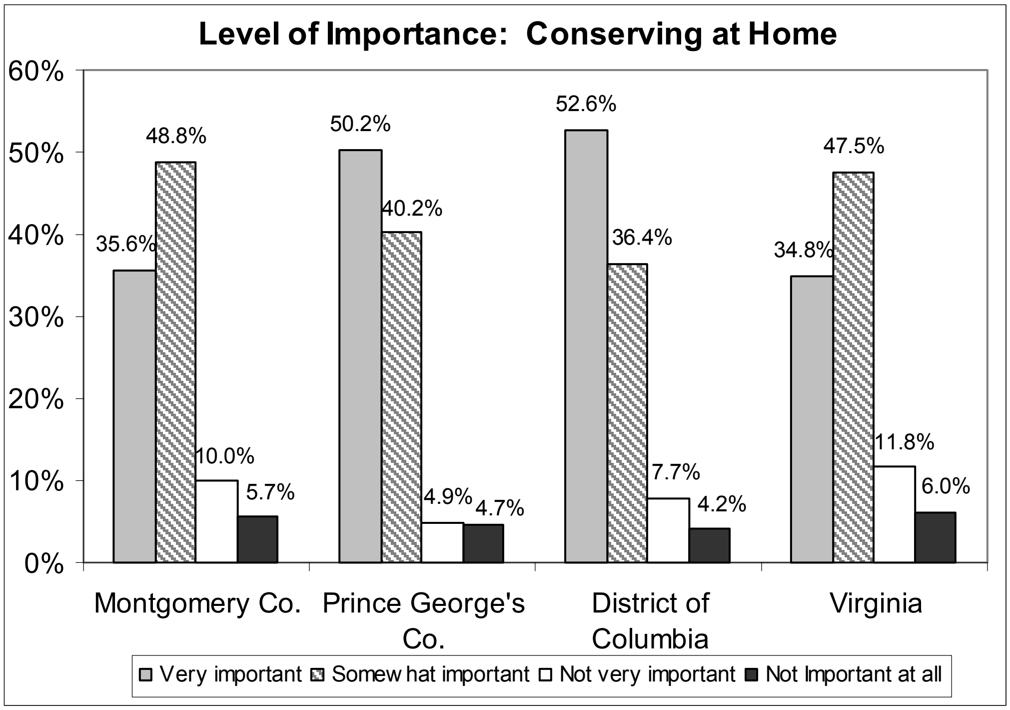



**Figure 2: Varying levels of importance of water conservation within the home in each of the Metropolitan area regions (WSSC, NuStats, 2002).**

## Reassessing the effects of the *Energy Policy Act of 1992*

The *Energy Policy Act of 1992* requires that all showerheads and toilets manufactured in the US after January 1, 1994 conform to specified flow efficiency standards. Assessing the impact of these standards on future per household water use is vital for assessing 2025 demands. The 2000 study examined the effect of the *Energy Policy Act of 1992* on regional water use (Hagen, et al., 2000). The effect of the *Energy Policy Act of 1992* on regional water use is re-examined in light of the most recently available information.

### *Low Flow Toilets*

The water savings from installation of ultra low flush (ULF) toilets due to remodeling and from new construction for the period 2000 through 2020 is estimated for the WMA based on the results of the AWWARF study and the GAO Report. It is assumed that the toilet replacement rate and flushing rates in multi-family homes in the WMA follow the same model as that for the single family homes. Effective in April of 1992, water efficiency standards for Maryland and the District of Columbia are shown in the table below (GAO, 2000). Virginia was added to the list, with the bulk of the United States, in 1994.

**Table 1: Water efficiency standards for the *Energy Policy Act of 1992***

| Locality | Ultra-low-flush toilets (gal/flush) | Low-flow showerhead (gal/min) | Kitchen faucets (gal/min) | Lavatory faucets (gal/min) | Urinals (gal/flush) |
|---|---|---|---|---|---|
| Maryland and District of Columbia | 1.6 | 2.5 | 1.2 | 2.0 | 1.0 |

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

The AWWARF study determined that the average number of flush counts per household per day is 12.4. The WMA household average size is smaller than the average household size of the 12 study sites in the AWWARF study, which means the WMA average number of flush counts per household differs from the average determined in the AWWARF study. The average number of residents per household for the AWWARF study group is 2.71. In 2005, the WMA CO-OP utilities are estimated to serve a population of 4,193,752 people living in 1,598,373 single family and multi-family households, for a total of 2.62 people per household. The average number of toilet flushes per household in the WMA is assumed to be the ratio of 2.62 over 2.71 times 12.4, or 11.99 flushes per household per day.

The net toilet use is calculated as average number of flush counts times the mean toilet flush volume. The water demand for toilet flushing in pre-1994 housing stock in the WMA is assumed to be 11.99 flushes times 3.78 gpf, for a total water use of 45.32 gallons per household. The water demand for toilet flushing in houses with remodeled bathrooms and in housing stock built after 1994 is assumed to be 11.99 flushes times 1.63 gpf, for a total water use of 19.5 gallons per household.

The hypothesis that low flush toilets are susceptible to double flushing (and lower water savings) was debunked in the AWWARF study. The average number of flushes per capita per day for the ULF homes and non-ULF homes in the study are not statistically different, indicating that residents of homes which exclusively use ULF toilets are not flushing more frequently than residents of homes without any ULF toilets (Mayer et al., 1999). A more legitimate concern, however, are toilet leaks. Approximately 25% of toilets in the U.S. are leaky, with a range of water losses (Vickers, 2001).

The current estimate of the number of WMA households in the CO-OP service area that have low flush toilets already in place is based on two key assumptions: 1) that all houses built after 1994 incorporate ULF toilets, and 2) that 2% of the original 1994 housing stock in the WMA CO-OP service area is remodeled each year with ULF toilets.[1] Figure 3 shows the percentage of people in the MWCOG NuStats survey who have recently installed a low flow toilet in the WMA. Table 2 shows the calculation of the percentage of housing with low flow toilets in the CO-OP service area. The percentage of housing stock in the WMA with low flush toilets was estimated to be 36% at the end of 2005 and 76% at the end of 2025. The 2005 estimate is consistent with the percentages shown in Figure 3.

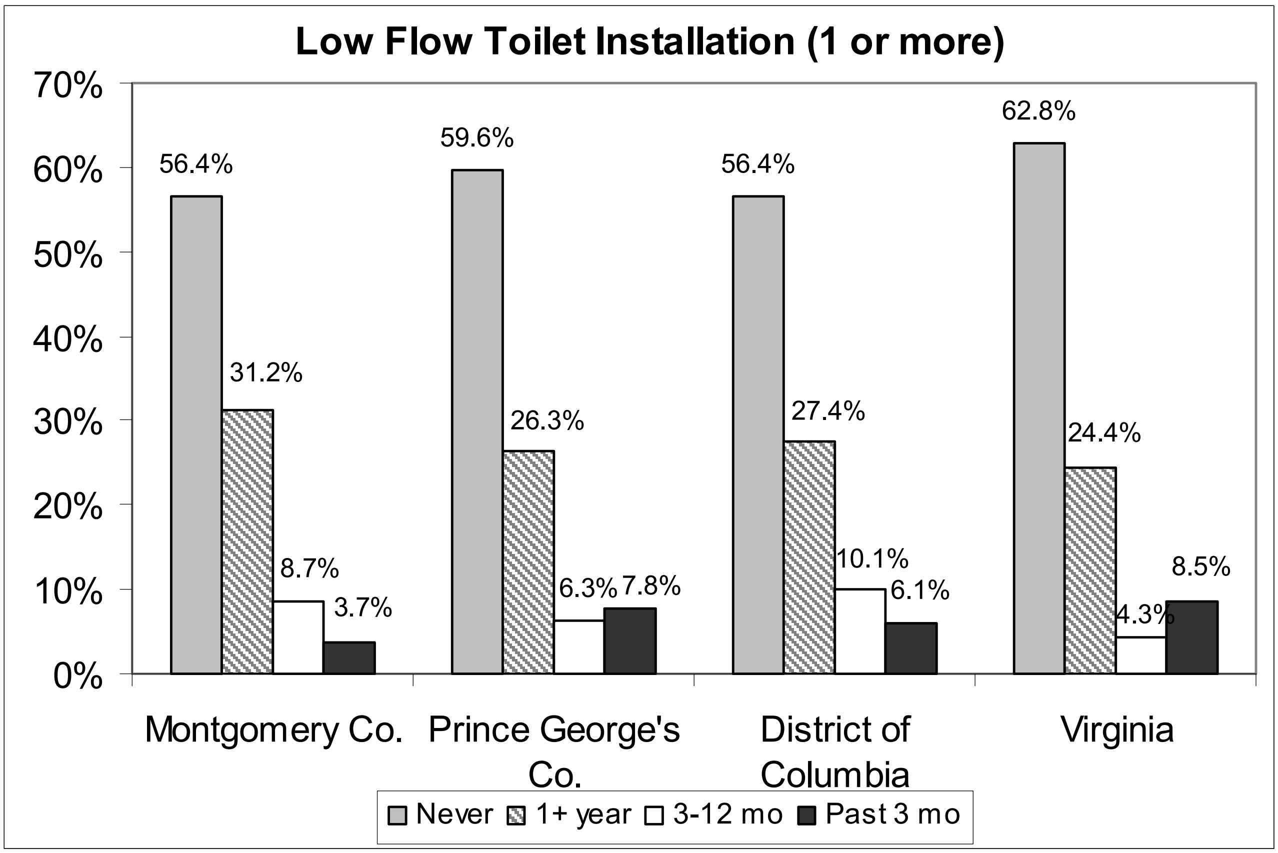



**Figure 3: Percentage of surveyed who have recently installed low flow toilets (WSSC, NuStats, 2002).**

[1] The assumption regarding the rate of toilet replacement in existing housing stock was 2 percent per year. This replacement rate is an estimate. Precise data documenting replacement rates of toilets in existing housing stock is unavailable for a this region. Presumably, the replacement rate would be a function of the age of existing housing stock and type (e.g. neighborhoods versus government housing apartments). However, Bill Davis, a professional in the conservation field, suggests that this value is a conservative, safe estimate for replacement. Davis also reports that higher rates of replacement were used in previous studies and significantly overestimated the number of facilities replaced (Bill Davis, Planning and Management Consultants, personal communication, December 13, 2004).

**Table 2: Percentage of housing with low-flow toilets in the CO-OP service area**

| Year | Portion of original 1994 housing stock with remodeled toilets at begin of year | Portion of original 1994 housing stock remodeled with low flush toilets during the year | Total number of 1994 original housing stock with low flush toilets at end of year | New households with low flush toilets installed[a] | Total number of households with low flush toilets at end of year | Total housing stock in CO-OP service area. | Percentage of total housing stock with low flush toilets at end of year |
|---|---|---|---|---|---|---|---|
| 1990 | 0 | 0 | 0 | 0 | 0 | 1,260,800 | -- |
| 1991 | 0 | 0 | 0 | 0 | 0 | 1,281,152 | -- |
| 1992 | 0 | 0 | 0 | 0 | 0 | 1,301,505 | -- |
| 1993 | 0 | 0 | 0 | 0 | 0 | 1,321,857 | 0% |
| 1994 | 0 | 26,844 | 26,844 | 20,352 | 47,197 | 1,342,210 | 4% |
| 1995 | 26,844 | 26,844 | 53,688 | 20,352 | 94,393 | 1,362,562 | 7% |
| 2000 | 161,065 | 26,844 | 187,909 | 18,806 | 328,830 | 1,464,324 | 22% |
| 2005 | 295,286 | 26,844 | 322,130 | 18,806 | 557,081 | 1,558,354 | 36% |
| 2010 | 429,507 | 26,844 | 456,351 | 18,806 | 785,332 | 1,652,384 | 48% |
| 2015 | 563,728 | 26,844 | 590,572 | 18,806 | 1,013,583 | 1,746,414 | 58% |
| 2020 | 697,949 | 26,844 | 724,793 | 18,806 | 1,241,834 | 1,840,444 | 67% |
| 2025 | 832,170 | 26,844 | 859,014 | 18,806 | 1,470,084 | 1,934,474 | 76% |

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

Using the information provided in Table 2, the average water demand per household for toilet flushing of all housing stock in the WMA can be calculated assuming a rate of 45.32 gallons per household without low flush toilets and 19.5 gallons per household for those households with low-flush toilets. The overall average WMA water demand per household for toilet flushing in the year 2005 is thus calculated to be 36.5 gallons per household. The overall average per household water demand for toilet flushing of all housing stock in the WMA in the year 2025 is calculated to be 26.0 gallons per household. Table 3 summarizes the expected overall per household average water demand in the WMA for toilet flushing for the period 2000 to 2025.

**Table 3: Per household WMA water use for flushing, 2000-2025**

| Year | Number of households with low flush toilets in use, mid-year | Total households | Percentage | Per household WMA water use for flushing, gallons |
|---|---|---|---|---|
| 2000 | 306,005 | 1,464,324 | 21% | 40 |
| 2005 | 534,255 | 1,558,354 | 34% | 36 |
| 2010 | 762,506 | 1,652,384 | 46% | 33 |
| 2015 | 990,757 | 1,746,414 | 57% | 31 |
| 2020 | 1,219,008 | 1,840,444 | 66% | 28 |
| 2025 | 1,447,259 | 1,934,474 | 75% | 26 |

### *Low flow showerheads*

According to the MWCOG NuStats report, in 2002 approximately three in ten homeowners in the WMA have installed low flow fixtures, such as showerheads or faucets a year or more prior to the survey period. Most respondents expressed concerns regarding water conservation as their primary motivation for installing the new fixtures. The best calculation of potential water savings from converting showerheads in existing housing stock to low-flow showerheads can also be calculated based on the AWWARF study. Average daily use for showering was measured at 30.8 gallons per household (Dziegielewski et al., 1999). The average daily frequency of showering was 1.98 showers per household per day. Average duration of showers was 8.2 minutes, with an average flow of 2.1 gallons per minute. Nearly three-fourths of the study's showering events were already at rates less than the standard of 2.5 gpm established by the *Energy Policy Act of 1992*. The authors conclude that the saturation of low-flow showerheads is relatively high and that often showers are throttled below their maximum rated flows (Dziegielewski et al., 1999; Mayer et al., 1999).

The WMA is assumed to have the same distribution of showerhead flow rates as the cities in the AWWARF study. Table 4 shows the potential savings by replacing all non-compliant showerheads with 2.5 gpm showerheads by the year 2025. (A 100% rate of retrofit and remodeling is assumed for non-compliant, older showerheads.) The resulting calculation shows that the current average daily use for showering is about 35.3 gallons per household per day, as compared to a predicted 2020 use of 31.3 gallons per household per day.

**Table 4: Calculation of current and future water use for showering**

| | Current scenario | | | 2025 scenario: all 2005 showers with flow greater than 2.5 gpm converted to 2.5 gpm flows | | |
|---|---|---|---|---|---|---|
| Modal shower flow (gallons per minute) | Shower flow used for calculation purposes (gallons per minute) | Percent of all showering events (Dziegielewski et al., 1999) | Water used normalized, household (gallons) | Shower flow used for calculation purposes (gallons per minute) | Percent of all showering events | Water used normalized to household (gallons) |
| 0.5 or less | 0.5 | 0.9 | 0.1 | 0.5 | 0.9 | 0.1 |
| 0.5 to 1 | 0.75 | 4.8 | 0.6 | 0.75 | 4.8 | 0.6 |
| 1 to 1.5 | 1.25 | 16.2 | 3.3 | 1.25 | 16.2 | 3.3 |
| 1.5 to 2 | 1.75 | 28.7 | 8.2 | 1.75 | 28.7 | 8.2 |
| 2 to 2.5 | 2.25 | 22 | 8.0 | 2.25 | 22 | 8.0 |
| 2.5 to 3 | 2.75 | 11.2 | 5.0 | 2.5 | 27.4 | 11.1 |
| 3 to 3.5 | 3.25 | 6.4 | 3.4 | 0 | 0 | 0.0 |
| 3.5 to 4 | 3.75 | 4.3 | 2.6 | 0 | 0 | 0.0 |
| 4 to 4.5 | 4.25 | 2.4 | 1.7 | 0 | 0 | 0.0 |
| 4.5 to 5 | 4.75 | 1.5 | 1.2 | 0 | 0 | 0.0 |
| More than 5.0 | 5.25 | 1.6 | 1.4 | 0 | 0 | 0.0 |
| Total per household ave. shower water use | | | 35.3 | | | 31.3 |

### Total water savings in the WMA

To summarize, the effects of the *Energy Policy Act of 1992* are estimated as follows for application in the 2025 WMA and are based on AWWARF's *Residential End Uses of Water* study. The current average daily use for toilet flushing (across all households and toilet-types) was calculated as 36.5 gallons per household per day, as compared to a predicted 2025 use of 26.0 gallons per household per day for a net reduction of 10.5 gallons per household per day. The current average daily use for showering was calculated as 35.3 gallons per household per day, as compared to a predicted 2025 use of 31.3 gallons per household per day for a net reduction of 2.0 gallons per household per day. **The total per household reduction in demand due to showerhead and toilet retrofitting is thus expected to drop by 10.5 + 4.0 = 14.5 gallons per household per day.** This does not, however, take into account possible savings in the WMA from low-flow faucets or more efficient clothes or dish washer units. Though the AWWARF study reports that a majority of water use is outdoors (58%), the NuStats report suggests that water users in the WMA prioritize domestic water needs over outdoor water use. Therefore, indoor savings may be of particular importance in this region. This may be a feature of the more urban nature of the WMA in contrast to some of the AWWARF study sites.

## Appendix G: Household and employee water use for each supplier

Data included in this appendix is based on actual water use, with modifications as follows.

1) The minimum unmetered water use rate is set at 10 percent of billed water, overriding smaller values of unmetered water use. This was done as a conservative assumption to account for aging infrastructure and potentially larger unmetered water use rates in the future.
2) Fairfax Water retail and wholesale customer demand increased by 2.5% to account for below normal demand during billing period.
3) No adjustment to Aqueduct or WSSC water use since billing period water use was above normal or near-normal (detrended) demand.

**Forecast of average annual water demand for the WMA, MGD**

| **Service Area** | **2005** | **2010** | **2015** | **2020** | **2025** |
|---|---|---|---|---|---|
| Fairfax Water - Dulles | 1.0 | 1.3 | 1.6 | 1.8 | 2.2 |
| Fairfax Water - Ft. Belvoir | 1.7 | 2.2 | 2.6 | 3.0 | 3.2 |
| Fairfax Water - Herndon | 2.6 | 2.9 | 2.9 | 3.0 | 3.0 |
| Fairfax Water - Loudon Co. Sanitation Authority | 14.3 | 17.5 | 20.5 | 22.7 | 24.8 |
| Fairfax Water - Prince William Co. Service Authority | 22.6 | 25.9 | 28.3 | 29.9 | 32.6 |
| Fairfax Water - Retail Service Area | 84.5 | 89.7 | 90.9 | 92.5 | 93.1 |
| Fairfax Water/Virginia American - Alexandria | 16.6 | 17.4 | 17.8 | 18.1 | 18.3 |
| Fairfax Water/Virginia American - Dale City | 6.7 | 7.3 | 7.5 | 7.6 | 7.8 |
| **TOTAL Fairfax Water** | **150.1** | **164.2** | **172.0** | **178.6** | **184.9** |
| | | | | | |
| Aqueduct - Arlington Co. DPW | 25.6 | 27.2 | 28.3 | 29.6 | 30.1 |
| Aqueduct - Falls Church DEP | 12.2 | 12.6 | 12.6 | 12.5 | 12.5 |
| Aqueduct - Falls Church-Vienna DPW | 2.7 | 2.8 | 2.8 | 2.8 | 2.8 |
| Aqueduct - District of Columbia WASA | 126.4 | 129.5 | 135.1 | 136.6 | 138.2 |
| Aqueduct - Fort Meyer | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Aqueduct - Soldiers Home & Howard Univ. | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 |
| **TOTAL Washington Aqueduct** | **168.4** | **173.5** | **180.3** | **183.0** | **185.1** |
| | | | | | |
| **WSSC** | **169.5** | **177.1** | **183.7** | **190.0** | **201.8** |
| | | | | | |
| **Subtotal** | **488.0** | **514.8** | **536.0** | **551.6** | **571.8** |
| City of Rockville DPW | 4.8 | 5.5 | 5.5 | 5.6 | 5.5 |
| | | | | | |
| **TOTAL plus Rockville** | **492.8** | **520.3** | **541.6** | **557.2** | **577.3** |

# Appendix G: Household and employee water use for each supplier

## Fairfax Water - Dulles

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 23 | 26 | 16 | 0 | 0 | 0 |
| Dwelling unit ratio | 2.63 | 2.89 | 2.86 | 2.94 | 2.96 | 2.96 |
| Single family | 17 | 19 | 12 | 0 | 0 | 0 |
| Multi-family | 6 | 7 | 4 | 0 | 0 | 0 |
| | | | | | | |
| **Employment** | 12,004 | 15,229 | 19,099 | 23,343 | 27,348 | 32,144 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 216.1 | 211.6 | 207.5 | 203.8 | 200.3 | 197.1 |
| Multi-family | 167.4 | 162.9 | 158.8 | 155.1 | 151.6 | 148.4 |
| Employee | 61.0 | 61.0 | 61.0 | 61.0 | 61.0 | 61.0 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 0.004 | 0.004 | 0.002 | 0.000 | 0.000 | 0.000 |
| Multi-family | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 |
| Employee | 0.732 | 0.929 | 1.165 | 1.424 | 1.668 | 1.960 |
| Unaccounted | 0.074 | 0.093 | 0.117 | 0.142 | 0.167 | 0.196 |
| | | | | | | |
| Total water use | 0.81 | 1.03 | 1.28 | 1.57 | 1.83 | 2.16 |

# Appendix G: Household and employee water use for each supplier

## Fairfax Water - Fort Belvoir

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Househol** | 484 | 489 | 1,531 | 2,674 | 3,652 | 3,659 |
| Dwelling u | 2.63 | 2.89 | 2.86 | 2.94 | 2.96 | 2.96 |
| Single fami | 351 | 363 | 1,134 | 1,995 | 2,729 | 2,735 |
| Multi-family | 133 | 126 | 397 | 679 | 923 | 924 |
| | | | | | | |
| **Employme** | 24,744 | 26,567 | 30,522 | 34,113 | 38,184 | 40,943 |
| | | | | | | |
| **% Unmete** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single fami | 216.1 | 211.6 | 207.5 | 203.8 | 200.3 | 197.1 |
| Multi-family | 167.3 | 162.8 | 158.7 | 155.0 | 151.5 | 148.3 |
| Employee | 54.3 | 54.3 | 54.3 | 54.3 | 54.3 | 54.3 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single fami | 0.1 | 0.1 | 0.2 | 0.4 | 0.5 | 0.5 |
| Multi-family | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 |
| Employee | 1.3 | 1.4 | 1.7 | 1.9 | 2.1 | 2.2 |
| Unaccount | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 |
| | | | | | | |
| Total water | 1.6 | 1.7 | 2.2 | 2.6 | 3.0 | 3.2 |

## Fairfax Water - Herndon

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Househol** | 6,891 | 7,309 | 8,291 | 8,671 | 8,874 | 8,987 |
| Dwelling u | 2.63 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Single fami | 4,992 | 5,482 | 6,218 | 6,503 | 6,656 | 6,740 |
| Multi-family | 1,899 | 1,827 | 2,073 | 2,168 | 2,219 | 2,247 |
| | | | | | | |
| **Employme** | 21,870 | 24,093 | 25,772 | 26,393 | 26,882 | 27,188 |
| | | | | | | |
| **% Unmete** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single fami | 216.1 | 211.6 | 207.5 | 203.8 | 200.3 | 197.1 |
| Multi-family | 167.3 | 162.8 | 158.7 | 155.0 | 151.5 | 148.3 |
| Employee | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single fami | 1.1 | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 |
| Multi-family | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Employee | 0.8 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 |
| Unaccount | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| | | | | | | |
| Total water | 2.5 | 2.6 | 2.9 | 2.9 | 3.0 | 3.0 |

# Appendix G: Household and employee water use for each supplier

## Loudoun County Sanitation Authority

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 37,455 | 54,932 | 69,129 | 81,862 | 91,132 | 99,766 |
| Dwelling unit ratio | 3.62 | 3.29 | 3.29 | 3.31 | 3.32 | 3.32 |
| Single family | 29,347 | 42,140 | 52,998 | 62,863 | 70,047 | 76,670 |
| Multi-family | 8,109 | 12,792 | 16,131 | 18,998 | 21,085 | 23,096 |
| | | | | | | |
| **Employment** | 55,003 | 72,425 | 88,928 | 105,889 | 123,529 | 143,227 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 214.8 | 210.3 | 206.3 | 202.5 | 199.1 | 195.8 |
| Multi-family | 106.3 | 101.8 | 97.7 | 94.0 | 90.5 | 87.3 |
| Employee | 38.7 | 38.7 | 38.7 | 38.7 | 38.7 | 38.7 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 6.3 | 8.9 | 10.9 | 12.7 | 13.9 | 15.0 |
| Multi-family | 0.9 | 1.3 | 1.6 | 1.8 | 1.9 | 2.0 |
| Employee | 2.1 | 2.8 | 3.4 | 4.1 | 4.8 | 5.5 |
| Unaccounted | 0.9 | 1.3 | 1.6 | 1.9 | 2.1 | 2.3 |
| | | | | | | |
| Total water use | 10.2 | 14.3 | 17.5 | 20.5 | 22.7 | 24.8 |

## Prince William County Service Authority

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 64,868 | 83,468 | 97,091 | 107,517 | 114,449 | 125,782 |
| Dwelling unit ratio | 3.67 | 3.69 | 3.65 | 3.17 | 2.84 | 2.70 |
| Single family | 50,985 | 65,653 | 76,194 | 81,740 | 84,632 | 91,761 |
| Multi-family | 13,883 | 17,815 | 20,897 | 25,777 | 29,817 | 34,021 |
| | | | | | | |
| **Employment** | 66,958 | 80,032 | 94,202 | 107,880 | 122,027 | 138,141 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 217.5 | 213.0 | 208.9 | 205.2 | 201.7 | 198.5 |
| Multi-family | 167.4 | 162.9 | 158.8 | 155.1 | 151.6 | 148.4 |
| Employee | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 11.1 | 14.0 | 15.9 | 16.8 | 17.1 | 18.2 |
| Multi-family | 2.3 | 2.9 | 3.3 | 4.0 | 4.5 | 5.0 |
| Employee | 3.1 | 3.7 | 4.3 | 5.0 | 5.6 | 6.4 |
| Unaccounted | 1.6 | 2.1 | 2.4 | 2.6 | 2.7 | 3.0 |
| | | | | | | |
| Total water use | 18.1 | 22.6 | 25.9 | 28.3 | 29.9 | 32.6 |

# Appendix G: Household and employee water use for each supplier

## Fairfax Water - retail

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 268,742 | 297,462 | 317,190 | 324,615 | 332,775 | 336,173 |
| Dwelling unit ratio | 2.63 | 2.89 | 2.86 | 2.94 | 2.96 | 2.96 |
| Single family | 194,672 | 221,006 | 234,948 | 242,190 | 248,667 | 251,301 |
| Multi-family | 74,070 | 76,456 | 82,242 | 82,424 | 84,109 | 84,872 |
| | | | | | | |
| **Employment** | 338,782 | 381,953 | 428,065 | 444,300 | 466,728 | 487,665 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 216.1 | 211.6 | 207.5 | 203.8 | 200.3 | 197.1 |
| Multi-family | 167.4 | 162.9 | 158.8 | 155.1 | 151.6 | 148.4 |
| Employee | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 42.1 | 46.8 | 48.8 | 49.4 | 49.8 | 49.5 |
| Multi-family | 12.4 | 12.5 | 13.1 | 12.8 | 12.8 | 12.6 |
| Employee | 15.6 | 17.6 | 19.7 | 20.5 | 21.5 | 22.5 |
| Unaccounted | 7.0 | 7.7 | 8.2 | 8.3 | 8.4 | 8.5 |
| | | | | | | |
| Total water use | 77.1 | 84.5 | 89.7 | 90.9 | 92.5 | 93.1 |

## Faifax Water - Virginia American (City of Alexandria)

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 61,889 | 66,194 | 70,027 | 71,804 | 72,957 | 74,296 |
| Dwelling unit ratio | 0.56 | 0.53 | 0.53 | 0.52 | 0.50 | 0.49 |
| Single family | 22,333 | 23,015 | 24,342 | 24,563 | 24,165 | 24,298 |
| Multi-family | 39,556 | 43,179 | 45,685 | 47,241 | 48,792 | 49,998 |
| | | | | | | |
| **Employment** | 91,277 | 105,612 | 114,881 | 122,138 | 129,803 | 134,774 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.2% | 10.2% | 10.2% | 10.2% | 10.2% | 10.2% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 158.1 | 153.6 | 149.5 | 145.8 | 142.3 | 139.1 |
| Multi-family | 158.5 | 154.0 | 149.9 | 146.2 | 142.7 | 139.5 |
| Employee | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 3.5 | 3.5 | 3.6 | 3.6 | 3.4 | 3.4 |
| Multi-family | 6.3 | 6.6 | 6.8 | 6.9 | 7.0 | 7.0 |
| Employee | 4.2 | 4.9 | 5.3 | 5.6 | 6.0 | 6.2 |
| Unaccounted | 1.4 | 1.5 | 1.6 | 1.7 | 1.7 | 1.7 |
| | | | | | | |
| Total water use | 15.4 | 16.6 | 17.4 | 17.8 | 18.1 | 18.3 |

# Appendix G: Household and employee water use for each supplier

## Faifax Water - Virginia American (Dale City)

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 17,653 | 19,574 | 21,179 | 21,479 | 21,479 | 22,065 |
| Dwelling unit ratio | 13.95 | 12.71 | 9.73 | 8.66 | 8.66 | 8.92 |
| Single family | 16,472 | 18,147 | 19,206 | 19,256 | 19,256 | 19,841 |
| Multi-family | 1,180 | 1,427 | 1,973 | 2,223 | 2,223 | 2,223 |
| | | | | | | |
| **Employment** | 8,403 | 9,132 | 10,493 | 11,433 | 12,292 | 13,215 |
| | | | | | | |
| **% Unmetered (of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 228.5 | 224.0 | 219.9 | 216.2 | 212.7 | 209.5 |
| Multi-family | 167.4 | 162.9 | 158.8 | 155.1 | 151.6 | 148.4 |
| Employee | 199.6 | 199.6 | 199.6 | 199.6 | 199.6 | 199.6 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 3.8 | 4.1 | 4.2 | 4.2 | 4.1 | 4.2 |
| Multi-family | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| Employee | 1.7 | 1.8 | 2.1 | 2.3 | 2.5 | 2.6 |
| Unaccounted | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 |
| | | | | | | |
| Total water use | 6.2 | 6.7 | 7.3 | 7.5 | 7.6 | 7.8 |

## Washington Aqueduct - Arlington Co. DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 86,596 | 92,643 | 98,534 | 104,506 | 109,974 | 113,138 |
| Dwelling unit ratio | 0.73 | 0.66 | 0.62 | 0.59 | 0.56 | 0.54 |
| Single family | 36,671 | 36,834 | 37,711 | 38,779 | 39,478 | 39,672 |
| Multi-family | 49,925 | 55,809 | 60,823 | 65,727 | 70,496 | 73,466 |
| | | | | | | |
| **Employment** | 157,623 | 165,329 | 185,218 | 197,668 | 213,656 | 222,819 |
| | | | | | | |
| **% Unmetered (% of billed)** | 28.7% | 28.7% | 28.7% | 28.7% | 28.7% | 28.7% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 154.4 | 149.9 | 145.8 | 142.1 | 138.6 | 135.4 |
| Multi-family | 130.5 | 126.0 | 121.9 | 118.2 | 114.7 | 111.5 |
| Employee | 44.2 | 44.2 | 44.2 | 44.2 | 44.2 | 44.2 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 5.7 | 5.5 | 5.5 | 5.5 | 5.5 | 5.4 |
| Multi-family | 6.5 | 7.0 | 7.4 | 7.8 | 8.1 | 8.2 |
| Employee | 7.0 | 7.3 | 8.2 | 8.7 | 9.4 | 9.8 |
| Unaccounted | 5.5 | 5.7 | 6.1 | 6.3 | 6.6 | 6.7 |
| | | | | | | |
| Total water use | 24.6 | 25.6 | 27.2 | 28.3 | 29.6 | 30.1 |

# Appendix G: Household and employee water use for each supplier

## Washington Aqueduct - Falls Church DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 47,248 | 48,962 | 52,092 | 53,166 | 53,930 | 54,515 |
| Dwelling unit ratio | 1.82 | 1.74 | 1.10 | 0.83 | 0.72 | 0.69 |
| Single family | 30,477 | 31,087 | 27,328 | 24,058 | 22,529 | 22,184 |
| Multi-family | 16,771 | 17,876 | 24,763 | 29,108 | 31,401 | 32,331 |
| **Employment** | 113,054 | 122,939 | 131,313 | 134,136 | 137,857 | 141,686 |
| **% Unmetered (% of billed)** | 16.7% | 16.7% | 16.7% | 16.7% | 16.7% | 16.7% |
| **Unit use (gpd)** | | | | | | |
| Single family | 154.4 | 149.9 | 145.8 | 142.1 | 138.6 | 135.4 |
| Multi-family | 130.5 | 126.0 | 121.9 | 118.2 | 114.7 | 111.5 |
| Employee | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 |
| **Water use (mgd)** | | | | | | |
| Single family | 4.7 | 4.7 | 4.0 | 3.4 | 3.1 | 3.0 |
| Multi-family | 2.2 | 2.3 | 3.0 | 3.4 | 3.6 | 3.6 |
| Employee | 3.3 | 3.6 | 3.8 | 3.9 | 4.0 | 4.1 |
| Unaccounted | 1.7 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| Total water use | 11.9 | 12.2 | 12.6 | 12.6 | 12.5 | 12.5 |

## Washington Aqueduct - Vienna DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 8,350 | 8,463 | 8,671 | 8,829 | 8,985 | 9,101 |
| Dwelling unit ratio | 6.74 | 6.38 | 6.31 | 6.49 | 6.53 | 6.54 |
| Single family | 7,271 | 7,317 | 7,485 | 7,650 | 7,792 | 7,894 |
| Multi-family | 1,079 | 1,146 | 1,186 | 1,179 | 1,193 | 1,207 |
| **Employment** | 13,404 | 13,827 | 14,382 | 14,578 | 14,781 | 14,870 |
| **% Unmetered (of billed)** | 17.4% | 17.4% | 17.4% | 17.4% | 17.4% | 17.4% |
| **Unit use (gpd)** | | | | | | |
| Single family | 154.4 | 149.9 | 145.8 | 142.1 | 138.6 | 135.4 |
| Multi-family | 130.5 | 126.0 | 121.9 | 118.2 | 114.7 | 111.5 |
| Employee | 29.1 | 77.1 | 77.1 | 77.1 | 77.1 | 77.1 |
| **Water use (mgd)** | | | | | | |
| Single family | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Multi-family | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Employee | 0.4 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Unaccounted | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Total water use | 2.1 | 2.7 | 2.8 | 2.8 | 2.8 | 2.8 |

# Appendix G: Household and employee water use for each supplier

## Washington Aqueduct - DC WASA

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 246,710 | 262,309 | 271,347 | 292,128 | 297,705 | 303,137 |
| Dwelling unit ratio | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Single family | 105,732 | 112,417 | 116,291 | 125,197 | 127,587 | 129,915 |
| Multi-family | 140,978 | 149,892 | 155,056 | 166,931 | 170,118 | 173,222 |
| | | | | | | |
| **Employment** | 699,513 | 741,026 | 775,318 | 813,730 | 836,953 | 860,242 |
| | | | | | | |
| **% Unmetered (% of billed)** | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 174.3 | 169.8 | 165.7 | 162.0 | 158.5 | 155.3 |
| Multi-family | 164.2 | 159.7 | 155.6 | 151.9 | 148.4 | 145.2 |
| Employee | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 18.4 | 19.1 | 19.3 | 20.3 | 20.2 | 20.2 |
| Multi-family | 23.1 | 23.9 | 24.1 | 25.4 | 25.3 | 25.2 |
| Employee | 39.8 | 42.2 | 44.1 | 46.3 | 47.6 | 48.9 |
| Flushing | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 |
| Unaccounted | 27.3 | 28.4 | 29.1 | 30.4 | 30.7 | 31.0 |
| | | | | | | |
| Total water use | 121.5 | 126.4 | 129.5 | 135.1 | 136.6 | 138.2 |

## Washington Aqueduct - Fort Meyer

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 305 | 305 | 305 | 305 | 305 | 305 |
| Dwelling unit ratio | 0.73 | 0.66 | 0.62 | 0.59 | 0.56 | 0.54 |
| Single family | 129 | 121 | 117 | 113 | 109 | 107 |
| Multi-family | 176 | 184 | 188 | 192 | 196 | 198 |
| | | | | | | |
| **Employment** | 6,032 | 6,032 | 6,032 | 6,032 | 6,032 | 6,032 |
| | | | | | | |
| **% Unmetered (% of billed)** | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 151.0 | 146.5 | 142.4 | 138.7 | 135.2 | 132.0 |
| Multi-family | 128.1 | 123.6 | 119.5 | 115.8 | 112.3 | 109.1 |
| Employee | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Multi-family | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Employee | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Unaccounted | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | | | | | | |
| Total water use | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

# Appendix G: Household and employee water use for each supplier

## Washington Aqueduct - Soldiers Home & Howard University

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 1,628 | 1,628 | 1,628 | 1,681 | 1,715 | 1,750 |
| Dwelling unit ratio | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Single family | N/A | N/A | N/A | N/A | N/A | N/A |
| Multi-family | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | | | | |
| **Employment** | 3,225 | 3,225 | 3,282 | 3,282 | 3,282 | 3,282 |
| | | | | | | |
| **% Unmetered (% of billed)** | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 342.3 | 337.8 | 333.7 | 330.0 | 326.5 | 323.3 |
| Multi-family | | | | | | |
| Employee | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 0.6 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 |
| Multi-family | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Employee | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Unaccounted | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | | | | | | |
| Total water use | 1.0 | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 |

## Washington Suburban Sanitary Commission

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 563,765 | 595,778 | 626,730 | 656,935 | 681,702 | 726,167 |
| Dwelling unit ratio | 2.02 | 2.01 | 1.97 | 1.94 | 1.92 | 1.88 |
| Single family | 376,921 | 398,035 | 415,809 | 433,443 | 447,946 | 474,447 |
| Multi-family | 186,844 | 197,743 | 210,921 | 223,492 | 233,756 | 251,720 |
| | | | | | | |
| **Employment** | 715,822 | 774,194 | 849,046 | 907,637 | 980,515 | 1,084,568 |
| | | | | | | |
| **% Unmetered (% of billed)** | 19.4% | 19.4% | 19.4% | 19.4% | 19.4% | 19.4% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 183.4 | 178.9 | 174.8 | 171.1 | 167.6 | 164.4 |
| Multi-family | 179.7 | 175.2 | 171.1 | 167.4 | 163.9 | 160.7 |
| Employee | 46.6 | 46.6 | 46.6 | 46.6 | 46.6 | 46.6 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 69.1 | 71.2 | 72.7 | 74.2 | 75.1 | 78.0 |
| Multi-family | 33.6 | 34.6 | 36.1 | 37.4 | 38.3 | 40.5 |
| Employee | 33.4 | 36.1 | 39.6 | 42.3 | 45.7 | 50.5 |
| Unaccounted | 26.4 | 27.5 | 28.8 | 29.8 | 30.9 | 32.8 |
| | | | | | | |
| Total water use | 162.4 | 169.5 | 177.1 | 183.7 | 190.0 | 201.8 |

# Appendix G: Household and employee water use for each supplier

## Rockville DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 14,696 | 16,186 | 18,886 | 19,027 | 19,183 | 19,248 |
| Dwelling unit ratio | 3.16 | 2.23 | 1.68 | 1.66 | 1.64 | 1.63 |
| Single family | 11,163 | 11,170 | 11,826 | 11,887 | 11,915 | 11,923 |
| Multi-family | 3,533 | 5,016 | 7,060 | 7,140 | 7,268 | 7,325 |
| | | | | | | |
| **Employment** | 61,992 | 69,787 | 80,401 | 86,494 | 89,866 | 91,834 |
| | | | | | | |
| **% Unmetered (% of billed)** | 18.6% | 18.6% | 18.6% | 18.6% | 18.6% | 18.6% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 183.4 | 178.9 | 174.8 | 171.1 | 167.6 | 164.4 |
| Multi-family | 179.7 | 175.2 | 171.1 | 167.4 | 163.9 | 160.7 |
| Employee | 16.63 | 16.63 | 16.63 | 16.63 | 16.63 | 16.63 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 2.05 | 2.00 | 2.07 | 2.03 | 2.00 | 1.96 |
| Multi-family | 0.63 | 0.88 | 1.21 | 1.20 | 1.19 | 1.18 |
| Employee | 1.03 | 1.16 | 1.34 | 1.44 | 1.49 | 1.53 |
| Unaccounted | 0.69 | 0.75 | 0.86 | 0.87 | 0.87 | 0.87 |
| | | | | | | |
| Total water use | 4.40 | 4.79 | 5.47 | 5.54 | 5.55 | 5.53 |

# Appendix H: Household and employee water use for each supplier assuming no reduction in demand due to effects of the Energy Policy Act of 1992.

Notes: Data included in this appendix is based on Appendix G, with modifications as follows.

1) There is no reduction in unit use to account for the effects of the 1992 *Federal Energy Policy Act.*

**Alternative forecast of average annual water demand for the WMA, MGD**

| Service Area | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|
| Fairfax Water - Dulles | 1.0 | 1.3 | 1.6 | 1.8 | 2.2 |
| Fairfax Water - Ft. Belvoir | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fairfax Water - Herndon | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Fairfax Water - Loudon Co. Sanitation Authority | 14.3 | 17.9 | 21.2 | 23.8 | 26.4 |
| Fairfax Water - Prince William Co. Service Authority | 22.6 | 26.4 | 29.2 | 31.4 | 34.6 |
| Fairfax Water - Retail Service Area | 84.5 | 91.1 | 93.7 | 96.6 | 98.4 |
| Fairfax Water/Virginia American - Alexandria | 16.6 | 17.7 | 18.4 | 19.0 | 19.5 |
| Fairfax Water/Virginia American - Dale City | 6.7 | 7.4 | 7.7 | 7.8 | 8.2 |
| **TOTAL Fairfax Water** | **145.8** | **161.8** | **171.7** | **180.5** | **189.3** |
| | | | | | |
| Aqueduct - Arlington Co. DPW | 25.6 | 27.7 | 29.4 | 31.2 | 32.3 |
| Aqueduct - Falls Church DEP | 12.2 | 12.9 | 13.0 | 13.2 | 13.4 |
| Aqueduct - Falls Church-Vienna DPW | 2.7 | 2.8 | 2.8 | 2.9 | 2.9 |
| Aqueduct - District of Columbia WASA | 126.4 | 130.9 | 138.1 | 141.0 | 143.8 |
| Aqueduct - Fort Meyer | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Aqueduct - Soldiers Home & Howard Univ. | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| **TOTAL Washington Aqueduct** | **168.4** | **175.7** | **184.9** | **189.8** | **194.0** |
| | | | | | |
| **WSSC** | **169.5** | **180.2** | **189.8** | **199.1** | **214.3** |
| | | | | | |
| City of Rockville DPW | 4.8 | 5.6 | 5.7 | 5.8 | 5.9 |
| | | | | | |
| **TOTAL CO-OP REGION** | **488.5** | **523.2** | **552.1** | **575.2** | **603.5** |

# Appendix H: Alternative Forecast

## Fairfax Water - Dulles

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 23 | 26 | 16 | 0 | 0 | 0 |
| Dwelling unit ratio | 2.63 | 2.89 | 2.86 | 2.94 | 2.96 | 2.96 |
| Single family | 17 | 19 | 12 | 0 | 0 | 0 |
| Multi-family | 6 | 7 | 4 | 0 | 0 | 0 |
| | | | | | | |
| **Employment** | 12,004 | 15,229 | 19,099 | 23,343 | 27,348 | 32,144 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 |
| Multi-family | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 |
| Employee | 61.0 | 61.0 | 61.0 | 61.0 | 61.0 | 61.0 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 0.004 | 0.004 | 0.002 | 0.000 | 0.000 | 0.000 |
| Multi-family | 0.001 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 |
| Employee | 0.732 | 0.929 | 1.165 | 1.424 | 1.668 | 1.960 |
| Unaccounted | 0.074 | 0.093 | 0.117 | 0.142 | 0.167 | 0.196 |
| | | | | | | |
| Total water use | 0.81 | 1.03 | 1.28 | 1.57 | 1.83 | 2.16 |

# Appendix H: Household and employee water use for each supplier

## Fairfax Water - Fort Belvoir

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 484 | 489 | 1,531 | 2,674 | 3,652 | 3,659 |
| Dwelling unit ratio | 2.63 | 2.89 | 2.86 | 2.94 | 2.96 | 2.96 |
| Single family | 351 | 363 | 1,134 | 1,995 | 2,729 | 2,735 |
| Multi-family | 133 | 126 | 397 | 679 | 923 | 924 |
| | | | | | | |
| **Employment** | 24,744 | 26,567 | 30,522 | 34,113 | 38,184 | 40,943 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 |
| Multi-family | 162.8 | 162.8 | 162.8 | 162.8 | 162.8 | 162.8 |
| Employee | 54.3 | 54.3 | 54.3 | 54.3 | 54.3 | 54.3 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 0.1 | 0.1 | 0.2 | 0.4 | 0.6 | 0.6 |
| Multi-family | 0.0 | 0.0 | 0.1 | 0.1 | 0.2 | 0.2 |
| Employee | 1.3 | 1.4 | 1.7 | 1.9 | 2.1 | 2.2 |
| Unaccounted | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 |
| | | | | | | |
| Total water use | 1.6 | 1.7 | 2.2 | 2.6 | 3.1 | 3.2 |

## Fairfax Water - Herndon

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 6,891 | 7,309 | 8,291 | 8,671 | 8,874 | 8,987 |
| Dwelling unit ratio | 2.63 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Single family | 4,992 | 5,482 | 6,218 | 6,503 | 6,656 | 6,740 |
| Multi-family | 1,899 | 1,827 | 2,073 | 2,168 | 2,219 | 2,247 |
| | | | | | | |
| **Employment** | 21,870 | 24,093 | 25,772 | 26,393 | 26,882 | 27,188 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 |
| Multi-family | 162.8 | 162.8 | 162.8 | 162.8 | 162.8 | 162.8 |
| Employee | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 | 38.5 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 1.1 | 1.2 | 1.3 | 1.4 | 1.4 | 1.4 |
| Multi-family | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |
| Employee | 0.8 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 |
| Unaccounted | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.3 |
| | | | | | | |
| Total water use | 2.4 | 2.6 | 2.9 | 3.0 | 3.1 | 3.1 |

# Appendix H: Alternative Forecast

## Loudoun County Sanitation Authority

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 37,455 | 54,932 | 69,129 | 81,862 | 91,132 | 99,766 |
| Dwelling unit ratio | 3.62 | 3.29 | 3.29 | 3.31 | 3.32 | 3.32 |
| Single family | 29,347 | 42,140 | 52,998 | 62,863 | 70,047 | 76,670 |
| Multi-family | 8,109 | 12,792 | 16,131 | 18,998 | 21,085 | 23,096 |
| | | | | | | |
| **Employment** | 55,003 | 72,425 | 88,928 | 105,889 | 123,529 | 143,227 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 210.3 | 210.3 | 210.3 | 210.3 | 210.3 | 210.3 |
| Multi-family | 101.8 | 101.8 | 101.8 | 101.8 | 101.8 | 101.8 |
| Employee | 38.7 | 38.7 | 38.7 | 38.7 | 38.7 | 38.7 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 6.2 | 8.9 | 11.1 | 13.2 | 14.7 | 16.1 |
| Multi-family | 0.8 | 1.3 | 1.6 | 1.9 | 2.1 | 2.4 |
| Employee | 2.1 | 2.8 | 3.4 | 4.1 | 4.8 | 5.5 |
| Unaccounted | 0.9 | 1.3 | 1.6 | 1.9 | 2.2 | 2.4 |
| | | | | | | |
| Total water use | 10.0 | 14.3 | 17.9 | 21.2 | 23.8 | 26.4 |

## Prince William County Service Authority

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 64,868 | 83,468 | 97,091 | 107,517 | 114,449 | 125,782 |
| Dwelling unit ratio | 3.67 | 3.69 | 3.65 | 3.17 | 2.84 | 2.70 |
| Single family | 50,985 | 65,653 | 76,194 | 81,740 | 84,632 | 91,761 |
| Multi-family | 13,883 | 17,815 | 20,897 | 25,777 | 29,817 | 34,021 |
| | | | | | | |
| **Employment** | 66,958 | 80,032 | 94,202 | 107,880 | 122,027 | 138,141 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 213.0 | 213.0 | 213.0 | 213.0 | 213.0 | 213.0 |
| Multi-family | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 |
| Employee | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 10.9 | 14.0 | 16.2 | 17.4 | 18.0 | 19.5 |
| Multi-family | 2.3 | 2.9 | 3.4 | 4.2 | 4.9 | 5.5 |
| Employee | 3.1 | 3.7 | 4.3 | 5.0 | 5.6 | 6.4 |
| Unaccounted | 1.6 | 2.1 | 2.4 | 2.7 | 2.9 | 3.1 |
| | | | | | | |
| Total water use | 17.8 | 22.6 | 26.4 | 29.2 | 31.4 | 34.6 |

# Appendix H: Alternative Forecast

## Fairfax Water - retail

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 268,742 | 297,462 | 317,190 | 324,615 | 332,775 | 336,173 |
| Dwelling unit ratio | 2.63 | 2.89 | 2.86 | 2.94 | 2.96 | 2.96 |
| Single family | 194,672 | 221,006 | 234,948 | 242,190 | 248,667 | 251,301 |
| Multi-family | 74,070 | 76,456 | 82,242 | 82,424 | 84,109 | 84,872 |
| | | | | | | |
| **Employment** | 338,782 | 381,953 | 428,065 | 444,300 | 466,728 | 487,665 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 | 211.6 |
| Multi-family | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 |
| Employee | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 41.2 | 46.8 | 49.7 | 51.2 | 52.6 | 53.2 |
| Multi-family | 12.1 | 12.5 | 13.4 | 13.4 | 13.7 | 13.8 |
| Employee | 15.6 | 17.6 | 19.7 | 20.5 | 21.5 | 22.5 |
| Unaccounted | 6.9 | 7.7 | 8.3 | 8.5 | 8.8 | 8.9 |
| | | | | | | |
| Total water use | 75.8 | 84.5 | 91.1 | 93.7 | 96.6 | 98.4 |

## Faifax Water - Virginia American (City of Alexandria)

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 61,889 | 66,194 | 70,027 | 71,804 | 72,957 | 74,296 |
| Dwelling unit ratio | 0.56 | 0.53 | 0.53 | 0.52 | 0.50 | 0.49 |
| Single family | 22,333 | 23,015 | 24,342 | 24,563 | 24,165 | 24,298 |
| Multi-family | 39,556 | 43,179 | 45,685 | 47,241 | 48,792 | 49,998 |
| | | | | | | |
| **Employment** | 91,277 | 105,612 | 114,881 | 122,138 | 129,803 | 134,774 |
| | | | | | | |
| **% Unmetered (% of billed)** | 10.2% | 10.2% | 10.2% | 10.2% | 10.2% | 10.2% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 153.6 | 153.6 | 153.6 | 153.6 | 153.6 | 153.6 |
| Multi-family | 154.0 | 154.0 | 154.0 | 154.0 | 154.0 | 154.0 |
| Employee | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 | 46.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 3.4 | 3.5 | 3.7 | 3.8 | 3.7 | 3.7 |
| Multi-family | 6.1 | 6.6 | 7.0 | 7.3 | 7.5 | 7.7 |
| Employee | 4.2 | 4.9 | 5.3 | 5.6 | 6.0 | 6.2 |
| Unaccounted | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.8 |
| | | | | | | |
| Total water use | 15.1 | 16.6 | 17.7 | 18.4 | 19.0 | 19.5 |

# Appendix H: Alternative Forecast

## Faifax Water - Virginia American (Dale City)

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 17,653 | 19,574 | 21,179 | 21,479 | 21,479 | 22,065 |
| Dwelling unit ratio | 13.95 | 12.71 | 9.73 | 8.66 | 8.66 | 8.92 |
| Single family | 16,472 | 18,147 | 19,206 | 19,256 | 19,256 | 19,841 |
| Multi-family | 1,180 | 1,427 | 1,973 | 2,223 | 2,223 | 2,223 |
| | | | | | | |
| **Employment** | 8,403 | 9,132 | 10,493 | 11,433 | 12,292 | 13,215 |
| | | | | | | |
| **% Unmetered (of billed)** | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% | 10.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 224.0 | 224.0 | 224.0 | 224.0 | 224.0 | 224.0 |
| Multi-family | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 | 162.9 |
| Employee | 199.6 | 199.6 | 199.6 | 199.6 | 199.6 | 199.6 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 3.7 | 4.1 | 4.3 | 4.3 | 4.3 | 4.4 |
| Multi-family | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 | 0.4 |
| Employee | 1.7 | 1.8 | 2.1 | 2.3 | 2.5 | 2.6 |
| Unaccounted | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 |
| | | | | | | |
| Total water use | 6.1 | 6.7 | 7.4 | 7.7 | 7.8 | 8.2 |

## Washington Aqueduct - Arlington Co. DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 86,596 | 92,643 | 98,534 | 104,506 | 109,974 | 113,138 |
| Dwelling unit ratio | 0.73 | 0.66 | 0.62 | 0.59 | 0.56 | 0.54 |
| Single family | 36,671 | 36,834 | 37,711 | 38,779 | 39,478 | 39,672 |
| Multi-family | 49,925 | 55,809 | 60,823 | 65,727 | 70,496 | 73,466 |
| | | | | | | |
| **Employment** | 157,623 | 165,329 | 185,218 | 197,668 | 213,656 | 222,819 |
| | | | | | | |
| **% Unmetered (% of billed)** | 28.7% | 28.7% | 28.7% | 28.7% | 28.7% | 28.7% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 149.9 | 149.9 | 149.9 | 149.9 | 149.9 | 149.9 |
| Multi-family | 126.0 | 126.0 | 126.0 | 126.0 | 126.0 | 126.0 |
| Employee | 44.2 | 44.2 | 44.2 | 44.2 | 44.2 | 44.2 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 5.5 | 5.5 | 5.7 | 5.8 | 5.9 | 5.9 |
| Multi-family | 6.3 | 7.0 | 7.7 | 8.3 | 8.9 | 9.3 |
| Employee | 7.0 | 7.3 | 8.2 | 8.7 | 9.4 | 9.8 |
| Unaccounted | 5.5 | 5.7 | 6.2 | 6.6 | 7.0 | 7.2 |
| | | | | | | |
| Total water use | 24.3 | 25.6 | 27.7 | 29.4 | 31.2 | 32.3 |

# Appendix H: Alternative Forecast

## Washington Aqueduct - Falls Church DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 47,248 | 48,962 | 52,092 | 53,166 | 53,930 | 54,515 |
| Dwelling unit ratio | 1.82 | 1.74 | 1.10 | 0.83 | 0.72 | 0.69 |
| Single family | 30,477 | 31,087 | 27,328 | 24,058 | 22,529 | 22,184 |
| Multi-family | 16,771 | 17,876 | 24,763 | 29,108 | 31,401 | 32,331 |
| | | | | | | |
| **Employment** | 113,054 | 122,939 | 131,313 | 134,136 | 137,857 | 141,686 |
| | | | | | | |
| **% Unmetered (% of billed)** | 16.7% | 16.7% | 16.7% | 16.7% | 16.7% | 16.7% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 149.9 | 149.9 | 149.9 | 149.9 | 149.9 | 149.9 |
| Multi-family | 126.0 | 126.0 | 126.0 | 126.0 | 126.0 | 126.0 |
| Employee | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 4.6 | 4.7 | 4.1 | 3.6 | 3.4 | 3.3 |
| Multi-family | 2.1 | 2.3 | 3.1 | 3.7 | 4.0 | 4.1 |
| Employee | 3.3 | 3.6 | 3.8 | 3.9 | 4.0 | 4.1 |
| Unaccounted | 1.7 | 1.8 | 1.8 | 1.9 | 1.9 | 1.9 |
| | | | | | | |
| Total water use | 11.7 | 12.2 | 12.9 | 13.0 | 13.2 | 13.4 |

## Washington Aqueduct - Vienna DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 8,350 | 8,463 | 8,671 | 8,829 | 8,985 | 9,101 |
| Dwelling unit ratio | 6.74 | 6.38 | 6.31 | 6.49 | 6.53 | 6.54 |
| Single family | 7,271 | 7,317 | 7,485 | 7,650 | 7,792 | 7,894 |
| Multi-family | 1,079 | 1,146 | 1,186 | 1,179 | 1,193 | 1,207 |
| | | | | | | |
| **Employment** | 13,404 | 13,827 | 14,382 | 14,578 | 14,781 | 14,870 |
| | | | | | | |
| **% Unmetered (of billed)** | 17.4% | 17.4% | 17.4% | 17.4% | 17.4% | 17.4% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 149.9 | 149.9 | 149.9 | 149.9 | 149.9 | 149.9 |
| Multi-family | 126.0 | 126.0 | 126.0 | 126.0 | 126.0 | 126.0 |
| Employee | 77.1 | 77.1 | 77.1 | 77.1 | 77.1 | 77.1 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 |
| Multi-family | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 |
| Employee | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Unaccounted | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | | | | | | |
| Total water use | 2.7 | 2.7 | 2.8 | 2.8 | 2.9 | 2.9 |

# Appendix H: Alternative Forecast

## Washington Aqueduct - DC WASA

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 246,710 | 262,309 | 271,347 | 292,128 | 297,705 | 303,137 |
| Dwelling unit ratio | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Single family | 105,732 | 112,417 | 116,291 | 125,197 | 127,587 | 129,915 |
| Multi-family | 140,978 | 149,892 | 155,056 | 166,931 | 170,118 | 173,222 |
| | | | | | | |
| **Employment** | 699,513 | 741,026 | 775,318 | 813,730 | 836,953 | 860,242 |
| | | | | | | |
| **% Unmetered (% of billed)** | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 169.8 | 169.8 | 169.8 | 169.8 | 169.8 | 169.8 |
| Multi-family | 159.7 | 159.7 | 159.7 | 159.7 | 159.7 | 159.7 |
| Employee | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 18.0 | 19.1 | 19.7 | 21.3 | 21.7 | 22.1 |
| Multi-family | 22.5 | 23.9 | 24.8 | 26.7 | 27.2 | 27.7 |
| Employee | 39.8 | 42.2 | 44.1 | 46.3 | 47.6 | 48.9 |
| Flushing | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 | 12.9 |
| Unaccounted | 27.0 | 28.4 | 29.4 | 31.0 | 31.7 | 32.3 |
| | | | | | | |
| Total water use | 120.1 | 126.4 | 130.9 | 138.1 | 141.0 | 143.8 |

## Washington Aqueduct - Fort Meyer

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 305 | 305 | 305 | 305 | 305 | 305 |
| Dwelling unit ratio | 0.73 | 0.66 | 0.62 | 0.59 | 0.56 | 0.54 |
| Single family | 129 | 121 | 117 | 113 | 109 | 107 |
| Multi-family | 176 | 184 | 188 | 192 | 196 | 198 |
| | | | | | | |
| **Employment** | 6,032 | 6,032 | 6,032 | 6,032 | 6,032 | 6,032 |
| | | | | | | |
| **% Unmetered (% of billed)** | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 146.5 | 146.5 | 146.5 | 146.5 | 146.5 | 146.5 |
| Multi-family | 123.6 | 123.6 | 123.6 | 123.6 | 123.6 | 123.6 |
| Employee | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 | 61.3 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Multi-family | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Employee | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Unaccounted | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | | | | | | |
| Total water use | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

# Appendix H: Alternative Forecast

## Washington Aqueduct - Soldiers Home & Howard University

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 1,628 | 1,628 | 1,628 | 1,681 | 1,715 | 1,750 |
| Dwelling unit ratio | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Single family | N/A | N/A | N/A | N/A | N/A | N/A |
| Multi-family | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | | | | |
| **Employment** | 3,225 | 3,225 | 3,282 | 3,282 | 3,282 | 3,282 |
| | | | | | | |
| **% Unmetered (% of billed)** | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% | 29.0% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 342.3 | 342.3 | 342.3 | 342.3 | 342.3 | 342.3 |
| Multi-family | | | | | | |
| Employee | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 | 56.9 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Multi-family | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Employee | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Unaccounted | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | | | | | | |
| Total water use | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

## Washington Suburban Sanitary Commission

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 563,765 | 595,778 | 626,730 | 656,935 | 681,702 | 726,167 |
| Dwelling unit ratio | 2.02 | 2.01 | 1.97 | 1.94 | 1.92 | 1.88 |
| Single family | 376,921 | 398,035 | 415,809 | 433,443 | 447,946 | 474,447 |
| Multi-family | 186,844 | 197,743 | 210,921 | 223,492 | 233,756 | 251,720 |
| | | | | | | |
| **Employment** | 715,822 | 774,194 | 849,046 | 907,637 | 980,515 | 1,084,568 |
| | | | | | | |
| **% Unmetered (% of billed)** | 19.4% | 19.4% | 19.4% | 19.4% | 19.4% | 19.4% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 178.9 | 178.9 | 178.9 | 178.9 | 178.9 | 178.9 |
| Multi-family | 175.2 | 175.2 | 175.2 | 175.2 | 175.2 | 175.2 |
| Employee | 46.6 | 46.6 | 46.6 | 46.6 | 46.6 | 46.6 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 67.4 | 71.2 | 74.4 | 77.5 | 80.1 | 84.9 |
| Multi-family | 32.7 | 34.6 | 37.0 | 39.2 | 41.0 | 44.1 |
| Employee | 33.4 | 36.1 | 39.6 | 42.3 | 45.7 | 50.5 |
| Unaccounted | 25.9 | 27.5 | 29.3 | 30.8 | 32.4 | 34.8 |
| | | | | | | |
| Total water use | 159.4 | 169.5 | 180.2 | 189.8 | 199.1 | 214.3 |

# Appendix H: Alternative Forecast

## Rockville DPW

| | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| **Households** | 14,696 | 16,186 | 18,886 | 19,027 | 19,183 | 19,248 |
| Dwelling unit ratio | 3.16 | 2.23 | 1.68 | 1.66 | 1.64 | 1.63 |
| Single family | 11,163 | 11,170 | 11,826 | 11,887 | 11,915 | 11,923 |
| Multi-family | 3,533 | 5,016 | 7,060 | 7,140 | 7,268 | 7,325 |
| | | | | | | |
| **Employment** | 61,992 | 69,787 | 80,401 | 86,494 | 89,866 | 91,834 |
| | | | | | | |
| **% Unmetered (% of billed)** | 18.6% | 18.6% | 18.6% | 18.6% | 18.6% | 18.6% |
| | | | | | | |
| **Unit use (gpd)** | | | | | | |
| Single family | 178.9 | 178.9 | 178.9 | 178.9 | 178.9 | 178.9 |
| Multi-family | 175.2 | 175.2 | 175.2 | 175.2 | 175.2 | 175.2 |
| Employee | 16.63 | 16.63 | 16.63 | 16.63 | 16.63 | 16.63 |
| | | | | | | |
| **Water use (mgd)** | | | | | | |
| Single family | 2.00 | 2.00 | 2.12 | 2.13 | 2.13 | 2.13 |
| Multi-family | 0.62 | 0.88 | 1.24 | 1.25 | 1.27 | 1.28 |
| Employee | 1.03 | 1.16 | 1.34 | 1.44 | 1.49 | 1.53 |
| Unaccounted | 0.68 | 0.75 | 0.87 | 0.90 | 0.91 | 0.92 |
| | | | | | | |
| Total water use | 4.33 | 4.79 | 5.56 | 5.71 | 5.81 | 5.86 |